ranean reactor, so that bank filtrate with elevated amounts of iron and manganese could reach the well without passing the so-called oxidation zone.

5 Conclusion

In the special case of *in situ* treatment in the water catchment area near lake Hallwil it was proved that, apart from the physic-ochemical and microbiological treatment processes in the underground the mobilisation of iron and manganese as a consequence of reducing conditions could be stopped by elevating the redox potential in the natural subterranean reactor and by preventing the affluent of bank filtrate to the aquifer.

The treatment results of the case study supplemented by a numerical simulation of ground water flow demonstrate that an active ground water management in the form of a combination of hydraulic and *in situ* treatment components can be an effective tool for the prevention of pollution at source and for the preservation of aquifers for drinking water supply. Similar to the case presented, where the excellent conditions of the aquifer and the ground water before the damage could be restored, this kind of ground water management can be favourable compared with end-of-pipe technologies for the removal of contaminants, that do not protect the aquifer from further contamination.

Besides the removal of iron and manganese from ground water the applied method for subterranean treatment using oxygen as the only reagent also showed good results for nitrification, the removal of arsenic (2) and the degradation of organic substances such as humic acids in other case studies (3).

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How do we decide whether preventive or curative measures are more effective in the quest for compliance with drinking water standards?

M.J. Smit[1] & M.P. Laeven[2]

[1]*Groningen Municipal Water Supply Company, PO Box 1554, 9701 BN Groningen;* [2]*Kiwa N.V. Research and Consultancy, PO Box 1072, 3430 BB Nieuwegein, The Netherlands*

Abstract. The quality of the water supply sources in The Netherlands is deteriorating. If the water supply companies are to comply with the drinking water standards of the future, they must make a choice between preventive measures (i.e. preventing pollution of the sources) and curative ones (i.e. treating the water after abstraction). A four-step procedure is proposed for weighing up the pros and cons of the preventive and curative approaches in individual cases. For the Dutch situation the conclusion is drawn that the preventive approach is cost-saving for the vulnerable ground water well fields with respect to nitrates. If local surface water is used for the water supply, however, the conclusion is that a combination of preventive and curative measures constitutes the optimum solution.

1 Introduction

The water supply companies in The Netherlands use ground water and surface water as sources of industrial and potable water. They are, however, faced with a deterioration in the quality of the sources due to agricultural, industrial and other human activities. High concentrations of nitrates and pesticides are the main problems in ground water; in surface water, on the other hand, it is the high concentrations of pesticides, trace metals and pathogenic micro-organisms that cause the problems.

If future drinking water standards are to be met, then measures must be implemented. As Dutch Government policy has not (yet) formulated a general protection level that meets the demands of the water supply companies, these measures must be implemented by each water supply company individually.

Two approaches can be distinguished: a preventive one and a curative one. In the preventive approach, polluting activities are reduced at source; in this case, a basic treatment of the ground water (e.g. aeration and sand filtration) and/or the surface water (e.g. coagulation and some filtration steps) is sufficient. The curative approach, on the other hand, is an end-of-pipe solution, which means that the water is subjected to additional treatment after abstraction or intake.

This paper describes a range of preventive measures and presents a method that enables the pros and cons of the preventive and curative approaches to be weighed up objectively. This method can be used to ensure a cost-effective selection of the measures required to comply with (future) drinking water standards. In addition the paper presents, in general terms, the results of a study of the pros and cons of preventive and curative measures in the Dutch situation.

2 Preventive measures

In the preventive approach, measures are implemented that use only basic treatment tools to improve and/or sustain the quality of the water supply sources to produce potable water. Preventive measures can be subdivided into three categories:

- *Adaptations of the current land use*, e.g. restrictions on the use of manure and/or pesticides, or a smaller cattle-density. Besides a regulatory policy, an incentives policy can be especially successful in achieving the desired adaptations.
  The costs involved in reducing the nitrate concentration to a level below the drinking water standard (50 mg NO_3/l) are 75–300 ECU/ha/year, depending on the intensity of farming (1, 2).
- *Minor changes in land use*, e.g. conversion from coniferous to deciduous forest (which results in relatively low atmospheric deposition and a high natural ground water recharge, leading to lower ground water concentrations), or conversion from traditional farming to integrated, biodynamic or ecological farming (resulting in less or no input of manure and pesticides).
  Costs can be subdivided into investments and annual costs. The conversion from coniferous to deciduous forest involves an investment of 0–1500 ECU/ha and annual operating costs of 0–100 ECU/ha/year.
  The conversion to integrated, biodynamic or ecological farming has no effect on trading results. A financial incentive does, however, appear to be necessary in most cases (3, 4).
- *Major changes in land use*, e.g. conversion from cultivated land to woodland or nature areas, or conversion from cultivated land to recreational areas.
  The investments required in this category of preventive measures are relatively high:
  - buying cultivated land: prices in The Netherlands are dependent on region: 10 000–30 000 ECU/ha.
  - making the land suitable for the new land use, e.g. removal of nutrient-rich topsoil: approximately 2500 ECU/ha; construction of a recreational area: approximately 25 000 ECU/ha:
  - tree-planting (2000–5000 ECU/ha).

  Apart from the investments involved, allowance should also be made for operational costs, which range from 200–750 ECU/ha/year for woodland and nature areas (excluding profits).

3 Curative measures

The deteriorating quality of the water supply sources has led to investments in additional ground water treatment plants capable of dealing with nitrates and pesticides, e.g. bromacil and bentazon. The costs involved can be subdivided into investments and annual operating costs. Two examples of approximate costs (assuming an abstraction of 5 M m^3/year and a peak factor of 1.5) are:

- nitrate removal (by the ethanol fixed-bed process): investment of 13 million ECU; operating costs of 0.20 ECU/m^3/year;
- active carbon filtration: investment of 2–5 million ECU; operating costs of 0.05–0.08 ECU/m^3/year.

Investments in surface water treatment plants necessitated by the deteriorating quality of the source water are not easy to quantify. This is because disinfection and the removal of organic micropollutants are combined in different process steps.

4 Four steps for weighing up the preventive and curative approaches

Before a water supply company can decide what measures it needs to take in order to comply with (future) drinking water standards, four steps need to be taken (Fig. 1).

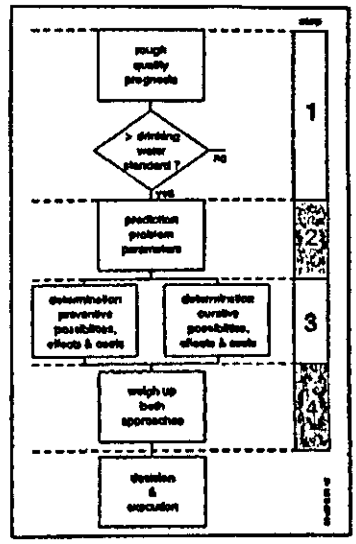

Fig. 1. Flowchart showing the process involved in making a choice between preventive and curative measures.

4.1 Step 1: Rough quality prognosis

Determine whether any problems are anticipated with the quality of the water supply sources. An assessment can be based on two groups of information: actual data from monitoring networks and implicit data such as land use, with related pollution, hydrogeological setting and vulnerability, depth of phreatic level and (hydro)geochemical environment. Both groups of information can be obtained from a monitoring *system* (5).

In The Netherlands the most common problems in water supply quality are the presence of nitrates, sulphates, hardness, trace metals and pesticides in ground water, and the presence of salts, trace metals, organic micropollutants and pathogenic micro-organisms in surface water.

4.2 Step 2: Prediction of problem parameters

Make predictions regarding the concentration of problem parameters in raw water as a function of time: when will a parameter exceed the drinking water standard, and what is the estimated maximum concentration? Which methods of prediction will be of use will depend heavily upon the characteristics of the parameter concerned.

4.3 Step 3: Inventory of preventive and curative options

Make an inventory of possible preventive and curative measures, including their effects and costs. Which preventive measures are likely to prove most effective will depend on several local factors. Important items are the autonomous development of the quality of the raw water and land prices (6).

In general, preventive measures are more effective when applied close to the well field, for two reasons. First, the rapid response, which is due to the short travel time of the water infiltrating near the well-field. Second, the fact that the effect is more substantial, because water infiltrating near the well field is influenced to only a small degree by the sort of soil processes that frequently improve ground water quality (such as denitrification and biotransformation).

In many cases it will be possible to finance part of the preventive measures from external environmental funds. In contrast, curative measures will always have to be financed by the water supply companies themselves.

4.4 Step 4: Weigh up both approaches

By calculating the present values of both approaches, preventive and curative measures can be compared in order to arrive at an optimum solution, in terms of cost-effectiveness, for a sustained water supply.

Not only costs, but other aspects as well, such as nature preservation and the environmental effects of water treatment (evaluated by means of life-cycle assessment (7)), can be used to compare the two approaches, although less quantitatively.

5 Two examples

5.1 The Herikerberg ground water well field

Step 1. The Herikerberg well field of the Overijssel Water Supply Company is located in the east of The Netherlands. Annual abstraction is approximately 4 M m^3 from an unconfined aquifer. The recharge area consists of woodland near the well field surrounded by cultivated land. Based on raw water data, nitrates constitute the parameter of greatest concern (high and increasing concentrations; Fig. 2) (8).

Step 2. A detailed nitrate prediction has been made based on the travel times of the saturated and unsaturated zones as well as on the nitrate load and the local occurrence of denitrification in both the saturated and unsaturated zones. The result is shown in Fig. 2 as the autonomous situation, i.e. only application of governmental rules: the predicted nitrate concentration will then exceed the drinking water standard around the year 2020.

Step 3. The preventive approach: Fig. 2 shows that a conversion to a nature area of 100 ha of cultivated land will significantly reduce the ground water well field's calculated nitrate concentration in raw water. In fact, it will be reduced to below the drinking water standard. The associated present value costs amount to 1.9 M ECU.

It should be mentioned that a conversion of land use should be in accordance with planning plans. Other preventive measures, like incentive measures, are independent of planning plans, and may have the same result at the same or even lower costs.

The curative approach: the nitrate concentration can be reduced to values below the drinking water standard by a treatment plant (ethanol fixed-bed process) on the basis of 25% of the abstracted volume. Present value costs vary from 2.6 M ECU (in the case of a once-only investment in nitrate removal) to 3.7 M ECU (if there is a perpetual investment every 30 years).

Step 4. Comparison reveals that, in this example, the preventive measures are cheaper than the curative measures. In addition, the preventive approach scores higher on additional aspects, such as nature preservation and the prevention of the negative environmental effects of water treatment.

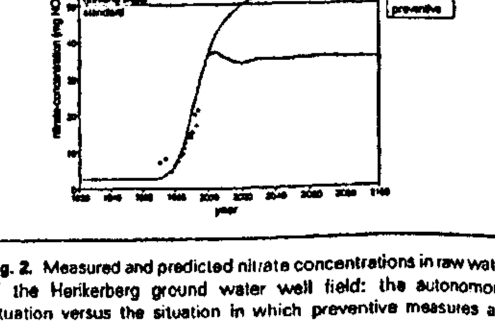

Fig. 2. Measured and predicted nitrate concentrations in raw water of the Herikerberg ground water well field: the autonomous situation versus the situation in which preventive measures are taken.

5.2 Surface water of the Drentsche Aa

Step 1. The Groningen Municipal Water Supply Company (GWG) uses about 5 M m^3/year of surface water from the river Drentsche Aa. The catchment area of the Drentsche Aa consists mainly of grassland and arable land. The quality problems relate to the high concentrations of pesticides and pathogenic micro-organisms.

Step 2. Based on trends in water quality and the anticipated effects of policy plans, it is anticipated that future quality problems will more or less stabilise at the present level: at this level pesticides and pathogenic micro-organisms exceed the drinking water standards for short periods (9).

Step 3. The preventive approach: GWG recently began introducing preventive measures within the catchment area of the Drentsche Aa in an effort to improve surface water quality. Examples of these measures are the diversion of the effluent from waste water treatment plants, the construction of sinks and treatment-reservoirs for waste water, and the introduction of incentives to reduce the use of pesticides and increase environment-friendly farming techniques. In addition, new legislation was introduced in 1995. For example, the use of pesticides in a narrow strip alongside the river is now prohibited, and the filling and cleaning of pesticide tanks is only allowed in reservoirs constructed specifically for this purpose. The present value costs, in as far as these are to be met by GWG, are 1.4 M ECU.

The curative approach: the preventive measures that have been or will be implemented do not make additional treatment superfluous. Nevertheless, preventive measures can result in lower curative costs (e.g. a larger regeneration time for active carbon filtration resulting in 1.3 M ECU in present value savings).

Step 4. In this step the preventive and curative approaches are combined. Preventive measures result in savings of the same magnitude on the curative side. The preventive measures will have positive effects on the diversity of the aqueous and terrestrial ecosystems.

6 General weighing-up of the Dutch situation

Based on the anticipated quality of water supply sources within The Netherlands and on the results of the examples presented in this paper, a general weighing-up of the preventive and curative approach will be undertaken for vulnerable ground water well fields and for local surface waters (6).

Deep, less vulnerable ground water well fields (below confining layers) have been left out of consideration, because no quality problems are anticipated in the near future. The surface water from large water supply systems (Rhine and Meuse) has not been considered either, as it is not regulated by a single water supply company.

6.1 Vulnerable ground water well fields

Twenty-five of the 120 vulnerable ground water well fields in The Netherlands are characterised by large areas of cultivated land in the recharge area, and are expected to reveal increasing concentrations of nitrates in the abstracted ground water. In these cases the preventive approach is preferable, from the point of view of cost-effectiveness, to the curative approach. Even relatively expensive preventive measures, such as the purchase of cultivated land and its conversion into a nature area, are cost-saving when the nitrate concentrations only slightly exceed the drinking water standard — in cases where the cultivated land accounts for less than 50% of the recharge area and/or denitrification occurs, for example. When nitrate concentrations substantially exceed the drinking water standard, relatively cheap preventive measures (e.g. incentive measures to reduce the use of manure) are possible and cost-saving.

The preventive approach to nitrate problems offers some additional benefits:

- it reduces concentrations of sulphate, hardness and trace metals (and pesticides through the conversion of cultivated land);
- it encourages nature preservation; and
- it prevents the negative environmental effects of water treatment.

With respect to hardness, sulphate and trace metals, it is not possible to make general statements about which of the two approaches is the more cost-effective. The prospects for the preventive approach with respect to a reduction in pesticides look promising.

6.2 Local surface water for the water supply

Direct disposals in rivers and pollution at relatively short distances from river-banks are the most important contributors to the deteriorating quality of surface water. Preventive measures should focus on reducing these sources of pollution.

Preventive measures aimed at improving the quality of the surface water will not, generally speaking, result in a less comprehensive treatment, although they may reduce the dimensions of some of the process steps. The latter will lead to cost-savings on the curative side, out of which the preventive measures could be financed.

7 Concluding remarks

The preventive approach is, in many cases, the more cost-effective approach in the quest for compliance with drinking water standards. In individual cases a tailor-made process is necessary if one is to be able to decide between the preventive and curative approaches. It is recommended that an early start be made on weighing-up the relative merits of the preventive and curative approaches in ground water well fields, since the effects of preventive measures on raw water quality take longer to become manifest than do those of curative measures.

Additional advantages of the preventive approach may include nature preservation, the prevention of the negative environmental effects of water treatment and the reduction of a (further) lowering of the ground water table.

Until recently the curative approach was the standard for the Dutch water supply companies. Fortunately, the preventive approach is nowadays often considered to be a more realistic alternative. The number of catchment areas where ecological management has been adopted and the number of incentive projects involving farmers is still increasing.

A macroeconomic study of the situation in The Netherlands reveals that investments made by the Government and farmers in environmental improvements are much higher than the investments made by the water supply companies in additional water treatment. The water supply companies may benefit from the governmental and farming funds if these are invested in their catchment areas.

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