> Sustainable protection of groundwater

Groundwater is by far the most important source of drinking water in Switzerland. Yet while its quality is generally good, it often contains traces of undesirable contaminants. This is revealed by the latest results of the NAQUA national groundwater survey.

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Main findings of the groundwater survey

> Monitoring facilitates a prompt response to possible hazards

The NAQUA National Groundwater Monitoring provides a central platform for the long-term maintenance and sustainable use of the most important drinking water resource.

Taking a sample at a measuring station in the Emmental region, one of almost 590 NAQUA stations throughout Switzerland.

In Switzerland more than 80% of the drinking and process water supply comes from the predominantly locally used groundwater sources. Compared with many other countries the resource, which is available in sufficient quantities almost everywhere, is generally of excellent quality. For this reason the water utilities can pipe around half of the groundwater used into the drinking water supply without any purification, with the remainder for the most part only requiring simple disinfection.

However, as an extremely vulnerable natural resource, groundwater in intensively used catchments is under threat from the outset from a multitude of human activities. In order to avert the risk of contamination through pathogens, nutrients, pesticides, hydrocarbons and other undesirable substances, the Water Protection Act (WPA) gives priority to preventive measures. To this end there are designated groundwater protection zones in the vicinity of drinking water wells, in which installations and activities hazardous to water are either restricted or completely prohibited. Building and operating regulations, which are graded according to risk, are intended to help prevent contamination of the water with problematic substances.

590 stations throughout the country

The NAQUA National Groundwater Monitoring enables the authorities to respond promptly to newly emerging contami-

nants and hazards on the one hand, and on the other permits ongoing assessment of the effectiveness of water protection measures. In conjunction with the cantonal authorities the Swiss Federal Office for the Environment (FOEN) is striving to ensure the high quality of the most important source of drinking water and to improve the unsatisfactory situation with regard to existing cases of contamination.

To identify anthropogenic and natural impacts accurately, NAQUA has a network of almost 590 monitoring sites. They cover the different regions of the country and the most important aquifers, together with varying geological conditions and land uses, thus providing representative evidence about the key groundwater sources. This monitoring network is composed mainly of measurement stations operated and evaluated in conjunction with the cantonal authorities.

After the first report, which analysed the results collected in 2002 and 2003, an up-to-date evaluation of the data for the period from 2004 to 2006 is now available. FOEN has included pharmaceutical residues in groundwater for the first time, as well as noticeably extending the range of substances investigated in the field of pesticides and their breakdown products.

Traces of contaminants

Water quality is assessed primarily using the limits set out in the Water Protection Ordinance (WPO) and the requirements of the "Wegleitung Grundwasserschutz" (Practical Guide to Groundwater Protection, SAEFL, 2004). These are guided not only by the need to provide pure drinking water, but also aim to keep water both above and below ground as near to its natural state as possible.

According to the latest findings the quality of groundwater is generally so high that in many places it can be used directly as drinking water without costly purification, thus meeting the legally required ideal condition. This applies especially to sources with forest catchments, which are hardly affected by pollutants and where the soil is also undisturbed. However, particularly in conurbations and in areas of intensive agriculture with arable farming, vineyards, orchards and vegetable crops the major use of substances hazardous to water and the soil disturbance leave readily detectable residues in the groundwater, which give some cause for concern. Thus at one of ten measurement sites where samples were taken the pesticide concentrations registered above the limit of 0.1 micrograms per litre (µg/l). In addition one in four of the ground-

Measuring the groundwater level at a drinking water pumping station in Ticino.

As a result of continuing improvements in analysis techniques even the minutest traces of contaminants can be detected in the groundwater.

As part of the NAQUA groundwater quantity monitoring programme spring discharges are also recorded at selected stations.

water monitoring sites exceeded the 25 milligrams per litre (mg/l) nitrate level stipulated by the WPO. 7% of the sites investigated also failed to meet the federal authorities' target requirement of 1 µg/l for volatile halogenated hydrocarbons (VHHs).

No discernible change in groundwater reserves

Like surface water, groundwater bodies can be affected by high and low water levels at certain times, although in their case there is generally a delayed response to meteorological conditions, and low water periods in particular can last for several months or even years, depending on the rainfall deficiency.

After the period of generally above average groundwater levels from 1999 to 2002 there followed a spell of comparatively low rainfall and correspondingly reduced groundwater recharge between 2003 and 2005. Thus, after the extremely hot, dry summer of 2003 a number of sources dropped to record low levels. 2006 was marked by sometimes considerable excess rainfall, especially in Jura and the Central Plateau, leading to the recovery of groundwater levels in these regions. In contrast, the low water situation persisted in Grisons and Ticino on account of the continuing rainfall deficiency. As the data collected nationwide on the amount of groundwater shows, there is as yet no long-term trend towards a quantitative change in subterranean water reserves. However, in view of climate change, future developments will be continuously monitored. The recording of groundwater levels and spring discharges is also a prerequisite for reliable classification and evaluation of measurements relating to water quality.

Contamination with plant protection products

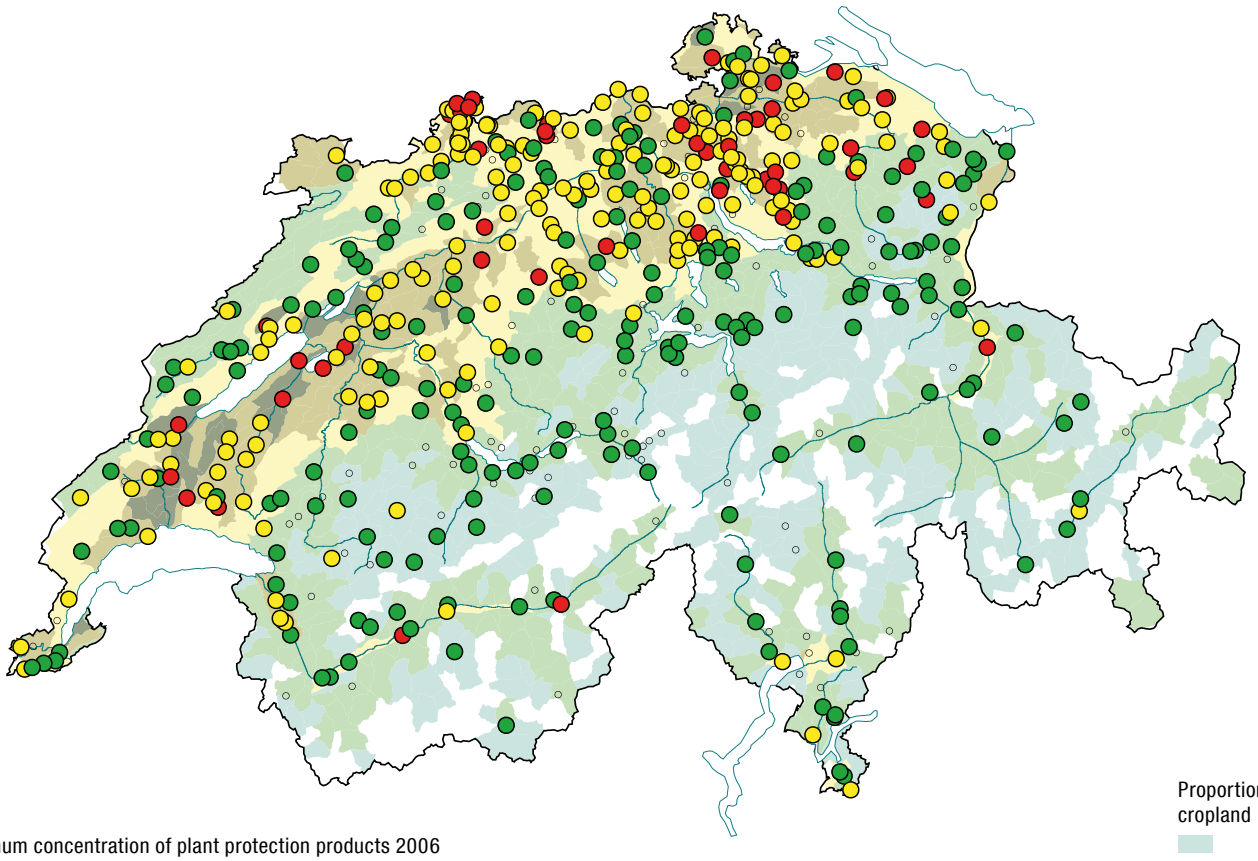
> Undesirable traces of pesticides

In catchments where land use is dominated by intensive agriculture or settlements, FOEN has found pesticide concentrations above the limit specified by the Water Protection Ordinance in one in every six stations.

In Switzerland there are more than 320 approved synthetic organic pesticides, and every year more than 1300 tonnes of these are sold, contained in at least 1000 different products. Fungicides, seed dressings and herbicides make up the most important groups of compounds. These are mainly used in agriculture, although significantly smaller quantities are also applied in tree nurseries, sports facilities, private gardens and industrial areas. The detection of pesticides in groundwater is very complex and places considerable demands on the measuring and analysing procedures. Owing to specific advances in measuring techniques in recent years, it is now possible to detect contaminants even in traces consisting of only a few billionths of a gram per litre. As part of the most recent measurement campaign FOEN detected 69 substances, including 21 pesticides or breakdown products at concentrations above the limit of 0.1 µg/l specified by the Water Protection Ordinance.

The occurrence of these substances in the groundwater shows a clear correlation with the land use in the catchment: contaminated sources are found primarily in intensively farmed areas and urban areas at altitudes of less than 800 metres. The Central Plateau and the principal valleys in Valais, Ticino

Pesticides and their breakdown products washed out by the rain soak away, with some entering the groundwater.



There is a close correlation between the pollution of groundwater with pesticides and the proportion of agricultural land in a catchment. Therefore the highest concentrations are often in areas where arable farming predominates. Groundwater bodies with urban catchments are also often contaminated.

and Jura are particularly affected. In catchments dominated by arable farming and viticulture or settlements, FOEN reported concentrations above the limit specified by the WPO in one in every six stations. Applied to the total of all monitoring sites investigated, "only" one in ten was affected.

Persistent herbicides in groundwater

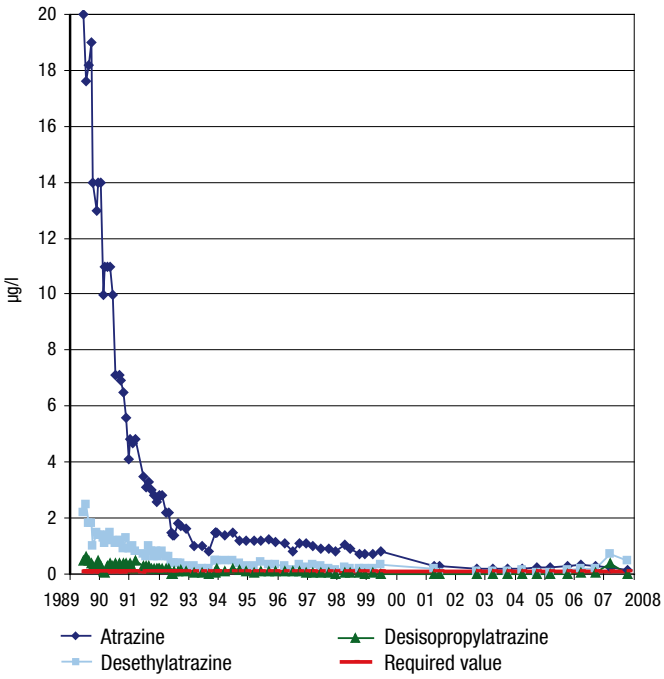
Most cases in which levels above the specified limits are detected involve herbicides and their breakdown products. The latter are mostly found more often and in larger quantities than the original substances. This applies to 2,6-dichlorobenzamide, for example, which derives from the weedkiller dichlobenil, or to metolachlor ESA, an equally mobile and persistent breakdown product of metolachlor, a herbicide used in farming. However, breakdown products of this sort should not be allowed to enter groundwater at all, as the Water Protection Ordinance stipulates that this should contain no persistent synthetic substances. This is a fundamental requirement, even if the concentrations recorded when using these sources for drinking water represent no risk to the health of the people, as far as we know at present.

The problem of long-term groundwater contamination with pesticides which do not readily degrade is illustrated by the case of triazines, in particular the herbicides atrazine and simazine, whose application has been increasingly restricted in the last twenty years on account of the risks they already pose to the environment. Despite a sharp decline in the quantities used, these are still among the pesticides most frequently detected in groundwater, which is why a significant number of samples exceeding the specified limit can be attributed to this group of substances.

Chaltenstein – a prime example

The Chaltenstein groundwater well near Küsnacht, in canton Zurich, provides a prime example of how long it can take before the concentration of a persistent contaminant in a polluted source once again meets the legally acceptable levels. In 1988 the Zurich cantonal laboratory found high atrazine levels of around 20 µg/l there, 200 times in excess of the WPO limit, as well as ten times over the World Health Organization's guideline for drinking water at that time. As a consequence of the severe pollution the local authority had to shut down its pumping station. Extensive scientific investigations identified track maintenance on the Forch railway line as the main cause of the high atrazine concentrations. Because the trackbed that was treated with weedkiller sits directly on molasse rock, the herbicide infiltrated at once – in the absence of adequate filtering through a soil layer – and formed residual deposits in the fine sediment of the aquifer, which were then constantly leached out.

Although no more atrazine has been used in the source's catchment for 20 years, the total concentrations of the herbicide and its breakdown products still amounted to about 0.7 µg/l in March 2008.



Evolution of the concentrations of atrazine and its breakdown products at Chaltenstein pumping station near Küsnacht, Zurich. Although the herbicide has not been used here since the end of the 1980s, the concentrations were still clearly above the 0.1 µg/l value required by the WPO in spring 2008.
(Source: Dr. von Moos AG)

Groundwater bodies in forest catchment areas are hardly contaminated with pesticides.

Even more effective protection is needed against pollutants

Even though the use of atrazine and simazine will be banned in Switzerland from 2011, groundwater contamination caused by these substances may still persist for years to come. Nevertheless, owing to the restrictions in use that have already come into effect, there are signs of a gradual decline in atrazine levels and the number of detected cases. There is a certain risk, however, that banning individual substances may lead to increased amounts of substitutes and their breakdown products entering groundwater. As data on pesticide contamination at the monitoring stations has only been available for the whole country since 2002, it is not yet possible to make any general assessment of longer-term trends. For the moment specific monitoring is also being hindered by the absence of a reliable materials accountancy for the compounds. Exact details of the substances and quantities used, dates and weather conditions in the relevant catchments would be essential to enable efficient monitoring of pesticide contamination of groundwater to take place.

To provide groundwater wells with better protection from contamination the application of pesticides in particu-

larly sensitive locations – in the immediate vicinity of drinking water wells, for example – should be restricted further. In fact, all activities which could be detrimental to groundwater quality in the last stage of its passage prior to extraction are prohibited in these areas. A more selective approval system, generic risk reduction programmes and specific remediation of visible problems can contribute to reducing the contamination of the environment. For example, to comply with the WPO the cantonal authorities restrict the use of pesticides in the catchments of drinking water sources when necessary. However, in addition, the restrictions upon use that are already in force today must in general be more rigorously implemented for the protection of our drinking water supplies.

A further risk of contamination stems from the use of various products for protecting flat roofs and façade rendering from roots, algae and fungal growth. If the resulting contaminated waste water is to be allowed to run off from roofs and paved areas, it should be compulsory for such infiltration installations to include a biologically active, densely planted layer of soil.

In intensively farmed regions the groundwater often fails to comply with quality requirements.

An example of a groundwater source in the middle of a maize field under extreme threat from pollution.

Contamination with the nutrient nitrate

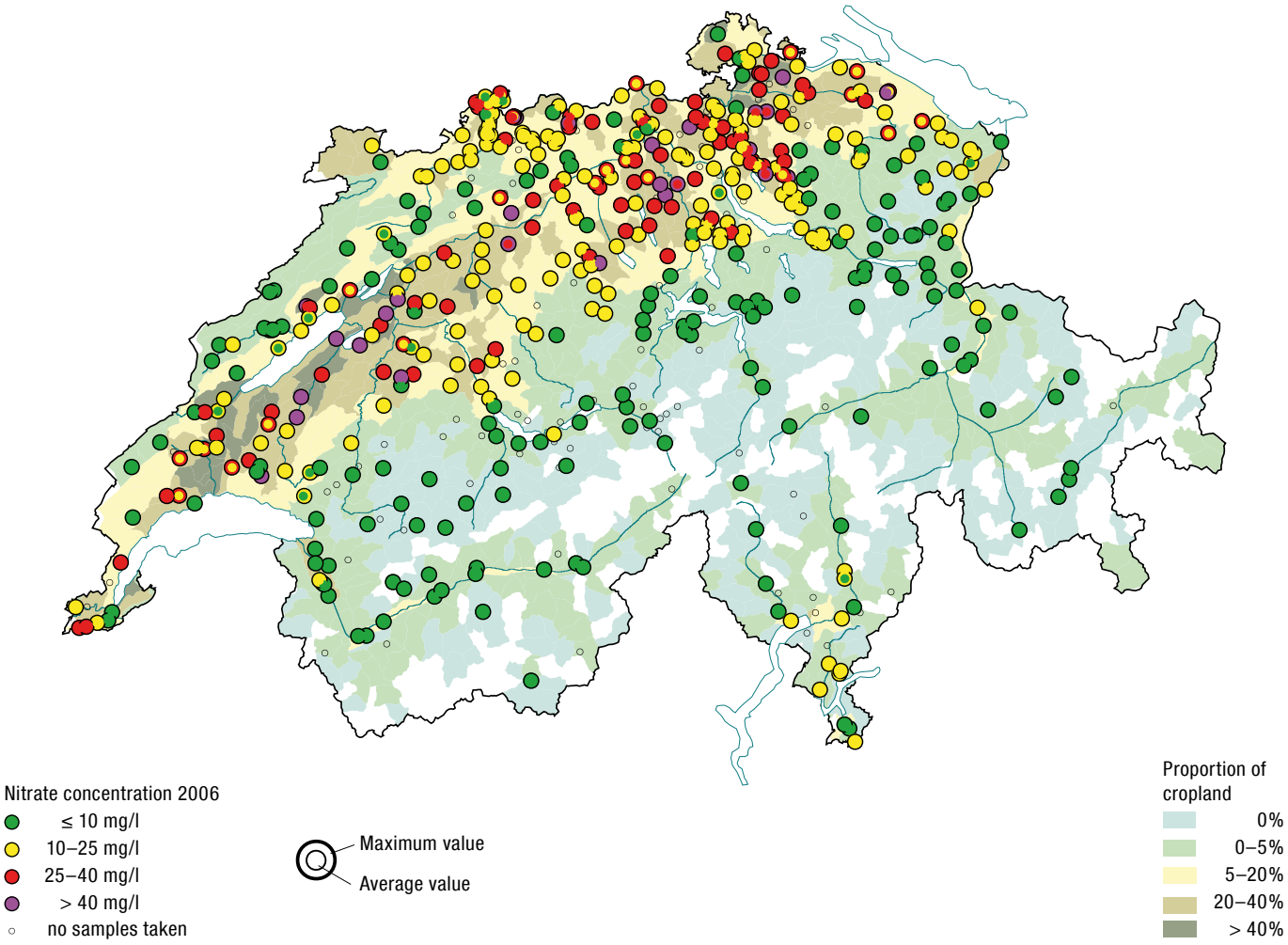
> Renewed rise in nitrate concentrations

After falling for several years, nitrate concentrations again showed a marked rise between 2003 and 2006, especially in catchments of an agricultural nature.

As a rule natural groundwater contains only a few milligrams of nitrate per litre. Higher concentrations are mostly a result of anthropogenic impacts. In particular the intensive farming of the soil for arable and vegetable crops – meaning the high input of nitrogenous fertilizers, mechanical soil cultivation and winter fallow fields – exacerbates the leaching of nitrogen into groundwater. In the majority of cases this occurs in the form of nitrate, while from a national point of view the nitrogen compounds nitrite and ammonium do not pose a problem for the quality of the groundwater. In addition elevated nitrate levels in groundwater are often also an indicator of contamination by other undesirable substances such as pesticides.

The Water Protection Ordinance sets a maximum limit of 25 mg/l of nitrate for groundwater used or intended for use. In 2006 one in four NAQUA monitoring stations tested failed to comply with this requirement. Around 5% of locations also had levels in excess of the tolerance value of 40 mg/l specified for drinking water in the Ordinance on Contaminants and Constituents in Foodstuffs (FIV). The highest levels of contamination are found in agricultural areas, where in 2006 one in six measuring stations exceeded the FIV tolerance value and in all around 60% of sites were above the WPO limit. The most affected areas were the Central Plateau and also some groundwater sources in Jura.

Bare soil encourages the undesirable leaching of nitrate into groundwater.



The highest concentrations of nitrate in groundwater are to be found in the intensively farmed Central Plateau, especially in regions with a large proportion of open cropland.

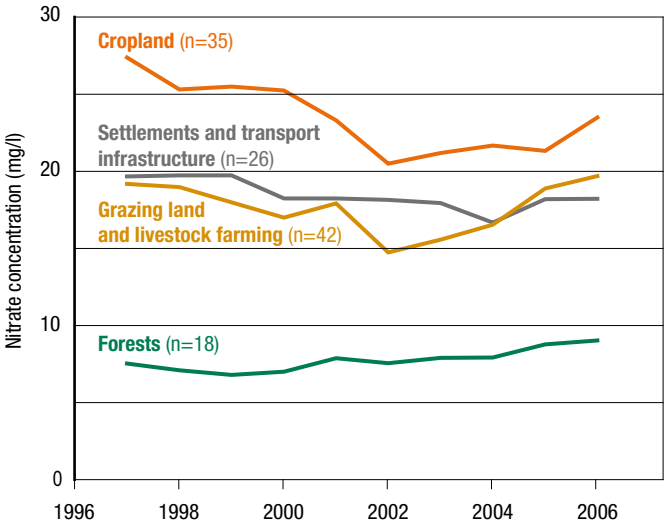
After falling for several years nitrate concentrations again showed a marked rise between 2003 and 2006, especially in catchments of an agricultural nature. This disappointing trend negates more than half of the previous reduction of 10 to 20% achieved since the mid-1990s. The development relates mainly to monitoring stations in catchments where arable farming, livestock rearing and grazing dominate. In these areas the increase in the nitrate concentration averages 2 to 3 mg/l. In contrast no significant increase has been observed at forest-covered sites.

Causes of the increase in nitrate

The causes of the renewed increase in nitrate concentrations are not entirely clear. They could lie either in agricultural practices or in the climatic and hydrological conditions.

After a marked decline in the excess nitrogen levels in agriculture at the beginning of the 1990s, there has been no further downward movement since about 2000, and even a slight increase. In addition, since 2004 the BSI soil protection index has no longer formed part of the ÖLN documentation of ecological services needed to receive public subsidies, a fact that favours an increase in winter fallow land and the consequent leaching of nitrate from exposed fields.

Another reason for the development is undoubtedly a temporary change in the transmission of nitrate from the soil into groundwater on account of the exceptional climatic conditions of recent years. As a result of the severe drought in the summer of 2003 and the rainfall deficiency in the following years, nitrate accumulated in the soil and leached out in larger quantities. However, how far such climatic factors can affect



After a decline between 1997 and 2002, nitrate concentrations in groundwater have since risen again, as is shown by an evaluation of the average nitrate values according to main land use at 121 monitoring stations in 11 cantons.

the nitrate concentrations in groundwater depends on the excess nitrogen remaining in the soil and therefore in the end to a considerable extent on the quantity of fertilizer applied and the type of crop.

Reducing nitrate loss in drainage water

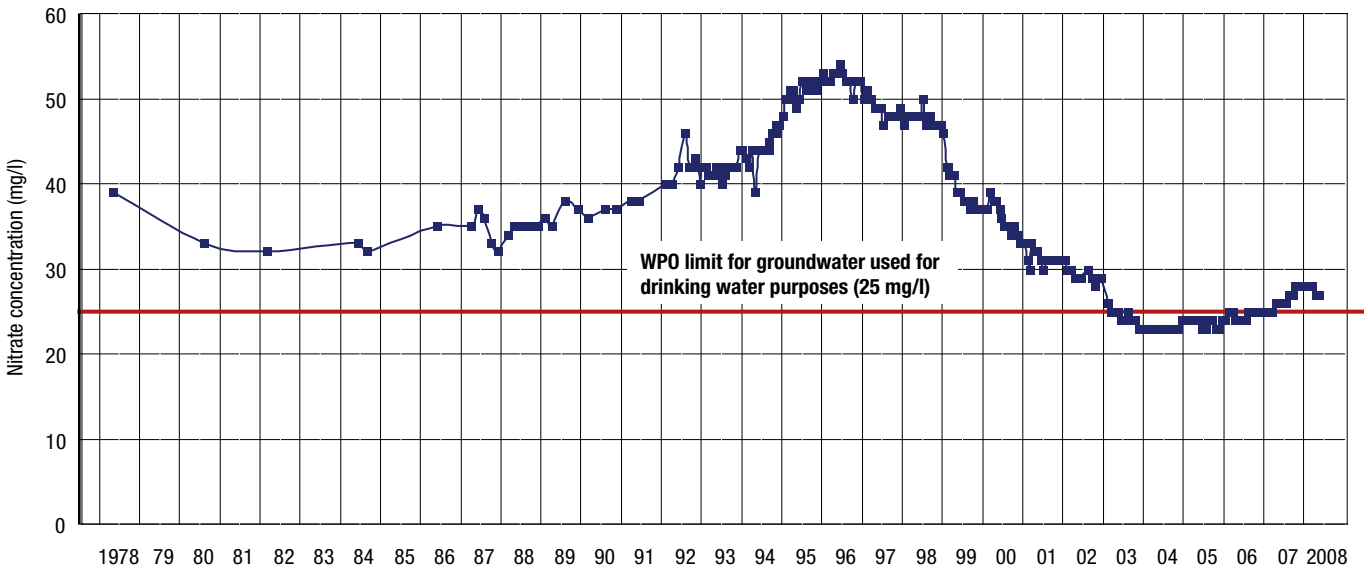
With the aid of the nitrate strategy agreed some years ago, the federal authorities aim to reduce the nitrate concentration to below 25 mg/l in all groundwater and spring water sources used to supply drinking water. After initial successes the latest data now indicates a setback in the progress towards this target. In addition the economic circumstances are threatening to exacerbate the unsatisfactory nitrate situation, as the global loss of productive farmland, the booming demand for agrofuels and growing pressure on prices resulting from the easing of customs restrictions boost the drive for yet more intensive agricultural production in Switzerland.

To remedy the condition of the groundwater bodies which are contaminated with nitrate, regional or local remediation schemes based on Article 62(a) of the Water Protection Act have been carried out in a number of catchments in the cantons of Aargau, Fribourg, Neuchâtel, Schaffhausen, Solothurn, Vaud and Zurich. The federal authorities are supporting these measures to reduce the nitrate in drinking water sources in predominantly agricultural catchments, which are being coordinated at cantonal level. The farmers are also receiving financial compensation to help them invest in restructuring and for the loss of yield arising from the contractually agreed conversion from cropland to permanent meadow.

The success of such schemes is evident from the example of a catchment more than 100 hectares in size at Wohlenschwil in Aargau. The nitrate content of the groundwater here, having reached a peak of 53 mg/l in 1996, then fell by 2003 to below the critical level of 25 mg/l for the first time in decades, owing to a raft of nitrate-reducing measures. In the following years – probably because of the adverse weather conditions – it increased again slightly to almost 28 mg/l, although this does not detract from the overall progress of the remediation. Besides the setting aside of cropland, the package of measures comprises among other things restrictions on the use of fertilizers, ploughing of land and outdoor pig rearing. In view of the encouraging results the federal authorities intend to support more schemes of this type in future, providing long-term safeguards and extending the programme into other regions.

Furthermore, general agricultural policy should also help to reduce nitrate loss further within the framework of ÖLN documentation and the DZV Direct Subsidies Ordinance.

The quantity of fertilizer applied is a decisive factor for nitrate contamination.



Nitrate concentration in milligrams per litre at Frohberg pumping station in Wohlenschwil municipality over the period from 1978 to 2008. The success of the measures introduced after 1996 to reduce nitrate through changes in agriculture is clearly visible. (Source: Wohlenschwil local authority)

Spreading farmyard manure in ideal weather conditions reduces the leaching of nitrogen into water bodies.

Contamination with VOCs

> Traces of hydrocarbons are widespread

Contamination of groundwater with volatile organic compounds (VOCs) is generally a reflection of settlement density. The more urban a region and the heavier the volume of traffic, the more likely it is that traces of VOCs will be found in the subsurface.

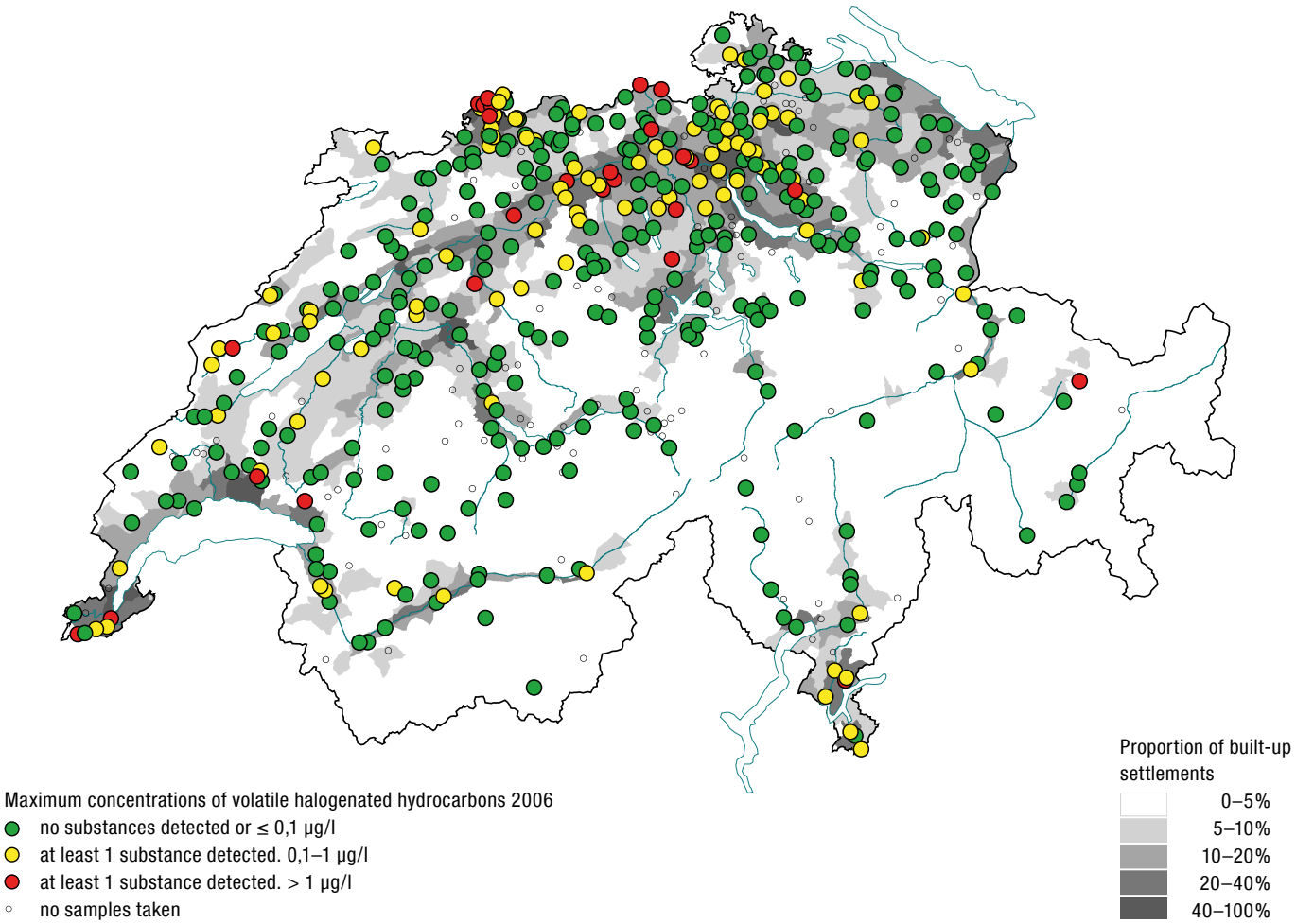
VOC is a collective term for a number of volatile organic compounds from various groups of substances which have a wide range of effects on the environment and human health. Included in this category are for example motor and heating fuels, lubricants, and industrial, commercial and domestic solvents, all of which are used in large quantities. In Switzerland alone around 12 million tonnes of petroleum products are consumed annually. VOCs also serve as reactants and excipients in chemical industry and occur as pollutants or breakdown products – for example, in the form of incineration residues – and owing to the huge quantities of the substances utilized significant amounts are released into the environment in the process.

As a rule the VOC contamination of groundwater reflects the density of population. The more urban a region and the heavier the volume of traffic, the more likely it is that traces of these substances will be found in the subsurface. In water catchments dominated by settlements and transport infrastructure approximately one in five sampling sites – according to the latest NAQUA figures – could not comply with the WPO limit of 1 µg/l at least once a year. On this occasion FOEN discovered traces of VOCs at more than three quarters of the sites. Nationally, an average of around 7% of sites investigated exceeded the WPO limit, and about one in three exhibited traces of VOCs.

The problems of halogenated hydrocarbons

From the perspective of groundwater protection volatile halogenated hydrocarbons (VHHs) present particular problems. They do not readily biodegrade and therefore mostly persist in the environment over a very long period. Because their spe-

Building sites in groundwater and road accidents are just two of the many causes of groundwater contamination with VOCs.



There is a close correlation between settlement density and the maximum concentrations of volatile halogenated hydrocarbons found in the groundwater.

cific gravity is higher than that of water, they can collect on the floor of underground water bodies and continue to contaminate them for decades after their original infiltration. Once VHHs have been absorbed with food, they accumulate in fatty tissue, often with toxic effect, and are also suspected of causing cancer and of damaging the hormone system in higher life forms.

Previously chemicals such as trichloroethylene und tetrachloroethylene, the VOCs by far the most frequently detected in groundwater, were released into the environment by the ton in the form of solvents and cleaning products. Thus older metal and machine industry sites, chemical cleaning businesses and plants processing abattoir waste are often identified as the cause of serious pollution of groundwater sources. It has already been necessary to abandon numerous drinking water wells in Switzerland or to carry out costly remediation on account of contamination levels well above the WPO limit of 1 µg/l for each individual substance.

Because of the reduction measures taken since the late 1980s, the use of VHHs in industry and commerce has shown a marked decrease. However, owing to their persistence and mobility in the environment these problematic substances may still be released into groundwater from contaminated sites for years to come. With regard to areas of settlement and transport infrastructure, levels exceeding the WPO limit are still recorded at one in five NAQUA monitoring stations, necessitating additional purification and remediation measures in some cases.

In general the situation does not give cause for alarm, but is nevertheless unsatisfactory. Cases of groundwater contamination with VHHs, which have in some cases persisted for decades, show that the use of known problematic substances like trichloroethylene and tetrachloroethylene should be abandoned. This applies equally to the use of new persistent and mobile substances, so that further groundwater contamination – requiring costly remediation – cannot occur.

Microcontamination caused by pharmaceuticals

> Drug residues enter groundwater via rivers

Microcontamination by pharmaceuticals occurs mainly in groundwater bodies near rivers and watercourses which infiltrate them. To reduce these pollutants treatment facilities must minimize the release of such substances into surface water.

In Switzerland around 3,000 different active ingredients of drugs are used in human medical treatment, of which 50 account for 95% of the quantity marketed. As the first study of a broader range of pharmaceutical residues at selected NAQUA monitoring stations shows, traces of these substances occur mainly in groundwater bodies which are fed to a substantial extent by infiltrating rivers and watercourses containing treated waste water. Occasionally leaking sewer pipes may also be responsible.

Tests for around 80 pharmaceuticals and breakdown products revealed a total of 10 active substances in the groundwater. These comprised 6 antibiotics, 2 X-ray contrast media, 1 anti-epileptic drug and also the breakdown product of an antihyperlipidemic drug. One in four of the stations measured was affected. At these FOEN recorded typical values of around 0.01 to 0.02 µg/l, whereas concentrations higher than 0.1 µg/l were found only in exceptional cases. The maximum values were considerably below the therapeutic concentrations, so that, based on current knowledge, using this groundwater for drinking purposes does not present a risk to human health. Nonetheless, the occurrence of microcontaminants of this nature in groundwater is undesirable and contravenes the environmental aims of the Water Protection Act.

A challenge for water treatment operators

As a large number of contaminants are inadequately removed or degraded at the riverbank filtration stage, an improvement in groundwater quality can only be achieved through a reduction in concentrations in the surface water bodies. This requires further measures at the treatment plants, such as an additional purification stage to eliminate this type of contaminant in treated waste water. FOEN is currently devising a strategy for effectively restricting the entry of these substances into water bodies.

Treatment works are still unable to eliminate microcontaminants in waste water adequately.

Imprint

Issued by
Federal Office for the Environment (FOEN)
FOEN is an agency of the Federal Department of Environment, Transport, Energy and Communications (DETEC).

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Photographs
AURA photo agency, Lucerne: cover photo, 8 top; FOEN: 2, 3 left, 4, 5, 8 bottom; Markus Zeh, GSA, Berne: 3 right; Beat Jordi, Biel: 7, 9, 12; Margrit Sixt, Kerzers: 11; Alison Pouliot, Biel: 13 left; St. Gallen cantonal police: 13 right; Roland Senn, Altdorf: 15.

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www.environment-switzerland.ch/ud-1003-e

Order number: UD-1003-E; free of charge
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[Management of Groundwater in Switzerland], FOEN, Bern, 2008, 40 pp.
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Wegleitung Grundwasserschutz (german) / Instructions pratiques pour la protection des eaux souterraines (french)
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