SUMMARY, CONCLUSIONS AND RECOMMENDATION

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MR. PRESIDENT, LADIES AND GENTLEMEN,

During the four days of this symposium, a comprehensive transfer of knowledge on groundwater quality has taken place. With the help of 120 papers and more than 40 poster sessions, that is one event for every two participants, we learned the facts and figures of groundwater pollution and gained insight in new ideas and theories. It will take all of us many months to absorb fully what we have seen and heard, implying at the same time that my task to give conclusions and recommendations cannot be complete, but I will do my best.

INTRODUCTION

For a public water supply, groundwater has many attractions. It does not contain the pathogenic bacteria and viruses responsible for the spread of water-borne diseases, it has a constant quality, in many cases it can be distributed without any treatment and when treatment is required to remove impurities such as iron, manganese or ammonia, this treatment is simple, cheap and fool-proof. Groundwater moreover can be withdrawn at many places, so that with rural supplies long pipelines for the transport of water are no longer required. Surface water from rivers and lakes on the other hand always needs treatment, if only to remove pathogenic organisms and turbidity. When the suspended matter content is high, this treatment is expensive and complicated, asking for expert supervision. In case the river is polluted by municipal and industrial waste discharges, still more elaborate purification systems are required, increasing again the cost of construction and operation.

Notwithstanding the appeal of groundwater for public supplies, surface water is used in many cases, because fresh groundwater is not available in the amounts required or its withdrawal would lower the groundwater table too much, in this way damaging neighbouring interests. To facilitate the purification of polluted river water, many options are open, but the major ingredient today is the use of storage, not so much for quantity considerations but to improve water quality.

In storage reservoirs, the suspended matter content goes down by sedimentation, contents of conservative substances level out by mixing, while self-purification lowers bacterial counts and the contents of ammonia, organic matter and micro-pollutants. In particular when a selective intake is possible, spectacular results can be obtained in this way, producing a first class water that could be treated by simple means, for instance by rapid and slow sand filtration. Mostly, however, a much more elaborate treatment is available to maintain the quality of the water going into the supply when the raw water in river or reservoirs is polluted by accidents such as mistaken industrial discharges, colliding ships, crashed lorries or aeroplanes. For unpolluted groundwater from protected catchment areas, such a safety treatment is not required, but does such water still exist?

GROUNDWATER POLLUTION

Groundwater is born as rainwater or as water in rivers and lakes with a water level above the groundwater table in the aquifer below. This origin, however, has only limited influence on groundwater composition. Indeed, during the fall through the air, rainwater will pick up atmospheric pollution. Due to the use of fossil fuels and the increase in CO_2 content of atmospheric air, the pH shows a drop to a value of 5.6 at the moment, while the discharge of sulfur and nitrogen oxides by industry and traffic has caused the pH locally to fall to values as low as 4 in Europe. Fortunately the carbonate content of aquifers is mostly adequate to neutralise this acidity. Still more locally, other stack discharges may even be more important, such as fluorine, arsenic and other heavy metals from smelters. In polluted rivers on the other hand, the oxygen content may be low so that the water entering the aquifer soon becomes anaerobic, resulting in nitrate reduction and the pick-up of iron and manganese, but again here only local effects will occur.

For the major part, the adverse effects on groundwater quality are the result of man's activity at ground surface, unintentionally by agriculture and industry, unexpectedly by sub-surface disposal of sewage and industrial waste water and by solid waste dumps, illegally by small workshops and unfortunately also by the abstraction of groundwater itself.

After the second world war, the agricultural use of artificial fertilizers, nitrates and phosphates increased enormously. Nitrates are only partly used by the crops, sometimes for only 50%, the remaining amounts to be flushed down by rain, increasing the nitrate content of groundwater over large areas to values up to 50 mg/l, that is above the safety level in drinking water. Until now the unused phosphates are strongly bound to the soil particles and only the accompanying heavy metals pose a danger, but this may change in future. In the

same period, the agricultural use of pesticides also grew strongly. Their break-down rate is usually small from which another groundwater pollution originates. Nitrate and chloride levels are furthermore increased by irrigation with secondary sewage effluents, while irrigation without adequate drainage strongly increases the salt content of the groundwater concerned. Intensive livestock farming finally produces enormous amounts of manure, which locally cannot be used to advantage. It is more or less dumped on agricultural grounds, again polluting the underlying aquifers. Industrial pollution of groundwater is on the one hand due to nearly unavoidable leakages in the premises and on the other hand to accidents such as crashed road or railroad tankers, bursting pipelines carrying oil, etc.

In many areas the groundwater table is at a large distance below ground surface, rivers are far away and, for the liquid wastes of the various communities sub-surface disposal is the only possibility. This increases the salt content of the groundwater, in particular with nitrates and chlorides, reduces the oxygen content and so mobilizes iron, manganese and heavy metals when present, while the introduction of pathogenic bacteria and viruses has caused many outbreaks of waterborne diseases in the past. For a large part, these deleterious effects can be prevented by treatment of the wastes prior to disposal, removing oxygen consuming organics, nitrates and pathogenic organisms or by deep well injection in saline aquifers, overlain by impervious deposits so that migration to the fresh groundwater above is next to impossible.

Before the second world war, the solid wastes of a community were rather innocuous and disposal by sanitary landfill an acceptable solution. Today the amount and particularly the variety of chemicals used in our society has increased tremendously, not only in industry but also in everyday life. Industrial and municipal wastes will nowadays contain many substances harmful to human health, with heavy metals, chlorinated hydrocarbons and organic solvents being most notorious. The dumps formed by land disposal of these wastes are percolated by rainfall, dissolving many chemicals which subsequently pollute the underlying and downstream part of the aquifers. The same holds true for illegal discharges by small workshops, where the damage done by discarding, for instance, spent organic solvents in this way is not realized. After possibly tens of years, the chemicals will reach the groundwater collectors of a public water supply, making the water unfit for direct use, while an additional treatment facility takes years to build.

Abstraction of groundwater lowers piezometric levels and changes flow patterns, in severe cases even resulting in flow reversals by which lower quality water from neighbouring areas may be attracted. Sea water intrusion in coastal aquifers and upward migration of salt water from underlying formations are well

known problems all over the world. The same holds true for waters which in their natural state have too high contents of, for instance, sulfate, heavy metals or fluoride, to which today must be added the influence of groundwater pollution described above. Quality deterioration of the water abstracted can be reduced by lowering the rate of withdrawal and prevented by increasing the natural recharge by an artificial one. When only lower quality water is available for this purpose, secondary sewage effluent for instance, the cure may be worse than the ailment and the overall effect on water quality should be evaluated carefully.

Groundwater pollution is always disadvantageous but some cases are more critical than others, for instance when occurring in the neighbourhood of groundwater recovery schemes for public supplies. It is now essential to know how much time will elapse before pollution reaches the collectors and in which concentration it will appear, taking into account the original values and the decrease by dilution, mixing, dispersion, ad- and desorption, chemical and bacteriological break-down. The largest number of papers at our congress were devoted to this subject and it is pleasing to note how many advances have been made in the mathematical description of the simultaneous flow of groundwater together with the transport of chemicals. Many mathematical techniques are available nowadays, but all suffer from the lack of geo-hydrological data which are almost impossible to gather in the amount required.

POLLUTION PREVENTION AND CONTROL

When listening to the papers of this congress, I almost got the impression that unpolluted groundwater is no longer available. Fortunately it also became clear to me that the major part of this pollution is due to ignorance, although in some cases this may better be called stupidity or even criminal negligence. The first thing to do therefore is educate the public, so that not only government and industry, but also the owner of a small shop and the man in the street knows what is at stake. Using the impact of today mass media this will not be difficult nor expensive to achieve.

Mopping up existing cases of groundwater pollution and stopping others from arising is a necessity, but it will prove to be an enormous task, taking for the Netherlands alone billions of dollars and tens of years to achieve. According to Roman philosophy, the virtue of Caesar's wife should be above all suspicion and the same holds true for the quality of drinking water. In the present situation this can only be assured by establishing protection zones around groundwater catchment areas and eliminating all pollution within these zones. Accidental pollution, for instance caused by leaking sewers or by corroding oil tanks used for domestic heating, is impossible to prevent entirely and the

protection zones must therefore be equipped with an extensive network of test-holes to monitor groundwater quality at short intervals, say once a month. The moment pollution is noted, the possible effects on the quality of groundwater recovered some distance away can be predicted using one of the many mathematical models presented at this symposium. When not acceptable, the pollution should be removed using scavenger wells or given another direction with the help of injection wells.

The present pollution of groundwater is certainly not a reason to abandon groundwater abstraction for public supplies, but the ubiquitous nature of groundwater contamination makes me look back to what I said in the beginning about surface water supplies having a very elaborate treatment system as safety precaution for the remote possibility that a serious pollution takes place. After attending this symposium, I am inclined to say that a similar emergency purification is also required for groundwater pumping stations in the western world. Again the quality of the raw water should be carefully measured, taking weekly and preferably daily samples.

When I started my career in the water industry, microbiologists told me that everything was everywhere and that only a clever man was needed to find the particular bacterium at the chosen spot. At that time, long ago, chemists were not so clever and with water analysis the part per million gave them trouble. Today the part per billion is commonplace and many of you will live to see the day that the part per trillion enters the field of groundwater pollution. When this occurs, everything is everywhere in chemistry also, but there is no need to bother. I often wonder whether this is not already the case today, which brings me to my fourth recommendation, that toxicologic work is to be pursued with force, to provide answers for the poor engineer in the field, who today has to take decisions based on inadequate knowledge, in some cases wasting millions of dollars to stay on the safe side.

Our society whether we like it or not, is a wasteful society and our first duty therefore is a reduction in the amounts produced, by re-circulation and re-use, by a change in our bad habits. As already noticed tens of years ago, but according to this symposium still not understood, dilution is no solution for pollution and all waste waters should therefore be purified before discharge into our own environment, while solid waste dumps should be provided with a water tight bottom and a drainage system to carry away downward percolating rainwater. Unfortunately some wastes are impossible or very dangerous to treat and for them a safe storage must be found, in abandoned mines and salt domes, by deep-well injection, etc. To study these possibilities many years are required and it is therefore essential that the governments concerned initiate such studies at short notice.

My sixth and last recommendation goes back to what I said at the very beginning about the comprehensive transfer of knowledge in this relatively unexplored field. I would therefore suggest that other governments, international agencies, learned societies and the like keep the flame burning and organize another congress about this subject, or perhaps better: meetings of specialists on part of the subject matter, in the near future. Problems are pressing, and much work is done all over the world, making me certain that further information can be made available in this way.

ACKNOWLEDGEMENTS

I am sure to speak on behalf of all the participants when I note that we enjoyed this symposium tremendously. We learned a lot, we met old acquaintances and made new ones in very pleasant surroundings. For all this we have to thank the organisers of this congress, everyone who did her or his part to make this symposium a success. It is impossible to thank everybody in person, but an exception should be made for Mr. van Duijvenbooden and Mr. van Lelyveld. I beg the audience to join me in applause as an expression of our gratitude.