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Impact of groundwater on urban development in The Netherlands

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Abstract Although existing urban areas in the Netherlands suffer from groundwater nuisance, the groundwater system seems to be a neglected part of the urban water system. This also is the case in recent plans for new urban areas, which constitute a substantial growth of the total Dutch urban area. Groundwater related problems include hazards to public health, unwanted effects on the environment and economic attenuation. For these problems a number of causes and effect are identified. These include problems with groundwater quantity and quality, besides geological problems and organizational problems. The impact of groundwater on present Dutch urban development planning is too small, as groundwater related problems are not given proper attention.

INTRODUCTION

According to existing plans, over the next five to ten years the number of houses in the Netherlands will increase some 10%, which is estimated to be equal to some 15% of the present urban area. For this same period, water management policy aims at large scale introduction of stormwater infiltration and at the reduction of consumption of high quality drinking water. Stormwater infiltration is introduced mainly in order to reduce (combined) sewer overflows and flow of stormwater to the treatment plant, and not with the purpose of influencing the groundwater system. Consumption of drinking water is reducing partly in favour of lower quality water from local sources, distributed by a second network. The hydrological cycle in urban areas will be very much influenced by these developments, as it is by urbanization in general. As a result of these developments—and partially as a trigger—surface water pollution and urban storm drainage are already subjects of considerable research. Meanwhile, an important element of the urban water system seems to be almost forgotten or neglected: the urban groundwater system. Even though it is well known that about 200 000 houses in the Netherlands suffer from too high groundwater tables, and even with the present trend towards integrated approaches to water management, little attention is paid to the groundwater. The question is why?

The answer is delicate but straightforward: groundwater is an invisible, slowly reacting, complex phenomenon, beyond the reach of the normal man. Moreover, the Dutch are used to living with groundwater problems; most of our urban developments are located in lowlands and polders, where the groundwater table is typically less than one metre below surface level. And most often there is no direct, visible threat from groundwater. Furthermore, the population does not relate problems and nuisances explicitly to groundwater management itself. A dangerous pitfall is its characteristic slow response: a source of pollution can often continue unnoticed for several years, until the negative effects begin to show up. Its long-term effect tends to be underestimated.

Dutch cities suffer from both too high and too low groundwater tables. If the natural conditions prevail, levels will generally be too high. On the other hand we see that, due to excessive drainage and groundwater abstraction, parts of our cities and the surrounding rural areas suffer from too low groundwater levels.

This paper aim to show the relevance of groundwater to urban development in the Netherlands; groundwater-related problems, effects and possible causes will be identified and evaluated. The need for policy development, action and for further research will be identified.

GROUNDWATER RELATED PROBLEMS

Inadequate groundwater management can have a major impact on the health, environment and economy of an urban area. The most important problems in the Netherlands are:

- hazards to public health;
- effects on local hydrology and the (built) environment;
- attenuation of the economy.

These problems are described below.

Hazards to public health

Moisture problems in houses can often be related in some way to high groundwater levels and, while in the Netherlands about 1 000 000 houses have a moisture problem, in about 200 000 houses the moisture problem can directly be related to high groundwater levels (Beenen, 1992). Socio-medical research proves clearly that high moisture contents aggravate the physical health of the inhabitants; this results in a decrease of the working-efficiency of the population and an increase in the medical expenses of a community. The effects have never been quantified financially.

In the case of polluted groundwater, health-endangering pollutants can reach inhabitants by damp and moisture that is penetrating the buildings. The size of this problem and its effects on public health are unknown. Polluting substances in groundwater can infiltrate through the PVC-piping of the drinking water network, thus endangering the consuming population. At polluted places the water mains are replaced by copper piping; again costs and risks are unknown.

Effects on local hydrology and (built) environment

Locally low groundwater tables cause rotting of wooden pile foundations, resulting in damage to old buildings. Moreover the lowering of the groundwater tables cause additional subsidence, leading to breaking of sewer and drinking water pipes. High groundwater tables make roads and paths unstable.

The storage capacity of the unsaturated zone is limited by the shallowness of this layer and its high moisture content. Response to rainfall is quick and peaks are hardly reduced.

In parts of the Netherlands low groundwater tables result in dehydration or desiccation, the withering and dying of ecologically valuable plants and trees; as a result the ecological quality of the city and its vicinity is much less than it could be. Due to high groundwater levels the root zone in gardens and public greens can not develop sufficiently, while due to the shallow root zone trees are easily blown over. Moreover the groundwater abstraction for the drinking water supply to our cities is a significant cause for dehydration in rural and natural areas. As about 60% of Dutch drinking water is produced from groundwater any increase in abstraction can cause significant ecological effects.

Attenuation of the economy

To mitigate the effects of urbanization, numerous expensive and complex projects have to be undertaken, generally by the municipal government. These measures introduce a constraint: the budget, resulting in a growth of the financial burden to the population.

Leaking sewers, recharging the groundwater with polluted wastewater or draining large quantities of groundwater to the treatment plant, have to be repaired, introducing very high rehabilitation costs. In the Netherlands about 1000 million ECU is spent each year on sewer renovation.

Leaking drinking water mains not only lose valuable first quality water, they also create artificial recharge; rates of 100 to 300 mm^{-1} $year^{-1}$ are common according to Lerner (1990). Drinking-water companies report losses of about 5% on average, in some cases making replacement works extremely efficient.

Drinking water companies have to upgrade their purification plants due to increased (risk of) pollution in the water source. This demands more investments and thus higher user-fees.

Municipalities have to sanitize numerous groundwater and soil pollution sites. In the Netherlands 3000 sites have been marked by the government for cleaning up of more than 100 000 sites, representing about 2% of the area of the Netherlands (Schrauwen, 1993).

Extensive groundwater control measures are required for preparation of the building sites in order to prevent damage to buildings and gardens by high groundwater levels and polluted or aggressive groundwater. This results in higher land prices for the buyers. Nonetheless, prevention is much cheaper than restoration afterwards (Dijkmeester, 1988).

This list of problems leads to the conclusion that the negative impact of groundwater on the urban environment is substantial. Hence, one would expect groundwater to have an impact on urban development too. Thorough investigations of the causes of groundwater related problems should be made, in order to realise effective solutions and to prevent such negative effects. However in current practise these investigations are rarely executed. What do we already know about the causes and effects of groundwater problems?

CAUSES AND EFFECTS

The causes of groundwater-related problems in urban areas can be divided into four groups: the first deals with the problems from a quantitative point of view, the second group deals with groundwater quality, the third deals with geo(hydro)logical aspects and the last one deals with the organizational aspects of the problems.

Problems with quantity: their causes and effects

As explained before, high groundwater tables are natural in many of the Dutch urban areas. The hydraulic head in confined aquifers can reach metres above the land level. Several mechanisms can lead to problems with the groundwater level.

Seepage If the hydraulic head in the aquifer exceeds the phreatic groundwater level, a seepage flow will occur. Typically this flow is in the order of 1 to 2 mm day^{-1}, but in some areas (north of Gouda) this can exceed 10 mm day^{-1}! Cities along rivers suffer from increased seepage during periods of high water levels. Seepage requires additional drainage and is expected to increase in the long run, due to sea level rise and salt water intrusion. When impermeable clay layers are perforated by construction works and foundations, the percolation and seepage can be increased if the pressure head difference between the aquifers allows it.

Reduction of local abstractions Due to the migration of industry out of town centres and to pollution of urban aquifers, local groundwater abstractions for industry and drinking water have decreased dramatically. In The Hague, for example, between 1970 and 1980 a reduction of 3 million m^3 year^{-1} in ten years has been observed, resulting in a significant rise of the groundwater table over a large part of the city and a steep rise in drainage-complaints in the old parts of the city (Werkgroep Grondwateroverlast, 1986). Some drinking-water companies reduce their abstraction from deep confined aquifers to solve dehydration problems in the region, resulting in higher groundwater tables.

Groundwater recharge projects Some drinking water companies try to increase production and/or to improve the quality of their product by artificial infiltration of surface water. This bank or dune filtration causes a rise in the hydraulic head in the deep aquifers with its related groundwater problems. A number of cities along the coast, in the vicinity of the dunes, suffer from this problem.

Decrease or increase of subsurface drainage Subsurface drains need regular maintenance to function properly. The drainage water often contains a high amount of iron-hydroxide, which flocculates and blocks the drains. High groundwater levels are the logical result. Drainage-pipes can also be damaged or ruptured by construction works (e.g. sheet-piling). When new watertight sewers are replacing leaky, partially draining ones, the drainage-capacity is reduced and thus high groundwater levels can result from sewer rehabilitation. When sewer and water mains, as well as electricity and telephone cables are being installed or replaced, deep trenches are dug. These trenches are often filled with highly permeable sand- and gravel-material, possibly enhancing the drainage of the urban area considerably and lowering the groundwater table beyond expectations. Leaky sewers can function as subsurface drainage systems. Due to subsidence of the soft subsoil (peat and clay) it is difficult in many places to avoid leaky sewers in the longer run.

Leakage of drinking-water mains As already mentioned, leaking drinking-water mains can create an important recharge flow resulting in a significant rise of the groundwater level.

Increased or reduced infiltration capacity Stormwater infiltration is becoming more popular as a way to reduce peak flows, combined sewer overflows and flows to the treatment plants, raising the groundwater levels. By increasing the impermeable surface and creating more storage-reservoirs, less natural recharge occurs and groundwater levels fall. Moreover, percolation is in some cases increased by vertical drainage, installed to accelerate the land subsidence.

Decrease of evapotranspiration When the vegetation of a future building site has been removed, the interception and evapotranspiration is less. Only after a few years, when the original vegetation has been replaced or has grown back, will the natural recharge of groundwater decrease again.

Problems with quality: their causes and effects

When dealing with groundwater quality problems a distinction is made between point source and non-point source pollution. The former deals with clearly identifiable activities, causing soil and groundwater pollution, such as large chemical plants and petrol stations. At present, industrial point sources hardly exist in the Netherlands as a result of strict regulation, maintenance of these regulations and the changed attitude of the industries—partially due to the fact that they are liable for the cleaning costs. The latter, non-point sources, represent poorly characterized, diffuse sources such as stormwater-runoff pollution and sewage leakage. Due to their non-point character they pose great problems in identification, evaluation and control. The focus must be on this last pollution-type, trying to identify causes and effects as follows.

Rise of groundwater table A rising groundwater level can induce a re-mobilization of old pollutants in upper layers, precipitated in the past, increasing the pollutant concentration of the groundwater.

Drought Sometimes, extreme drought will reduce groundwater volumes. As long as the same amount of pollutants is produced in an urban zone this will be added to a smaller water-volume or flux, thus increasing the pollutant concentration.

Sewer-system leakage Leaking sewer-systems can have a large influence on the quality of urban groundwater. However, as most of the sewers are below the groundwater level, this is not a big problem in the Netherlands, with the exception of some cities. According to the literature, chloride and especially nitrate are problematic (Foster, 1990), while pathogenic bacteria and viruses can contaminate the aquifer, causing severe health risks.

Road runoff Numerous studies have been done on the characteristics of urban stormwater runoff, their pollutant-concentration and migration through the urban water system. The general conclusion is that the concentrations of pollutants such as oil, heavy metals, toxins and organic substances (like polyaromatic hydrocarbons) are very high in runoff from busy roads. It is recommended that runoff from these roads should be directed to the sewer system, instead of infiltration to verges and ditches alongside the road. On the other hand the effect of this polluted water on the groundwater is found to be relatively small or not detectable, due to the fact that these pollutants are well bound to the soil material (Grotehusman, 1995).

Chloride pollution Some coastal provinces notice an increase of the salt concentration in the groundwater under their cities. Different causes can be identified:

- salt water intrusion can push saline groundwater further inwards; sea-level rise, very low surface water levels or freshwater abstractions can also be a cause;
- seawater-spray supplies salt to the atmosphere and hence to precipitation, increasing the chloride concentration in the recharge and groundwater;
- salt additions for road de-icing pollutes the road runoff.

Unlike the above mentioned pollutants chloride is easily transported with the groundwater flow.

Pollution related acidification Acidification of urban aquifers has been reported by Ford *et al.* (1992) who made a comparison of groundwater quality data ten years apart. Six potential causes were considered: (a) rise of water level into the carbonate-poor upper levels of sandstone aquifers; (b) oxidation of Quaternary deposits lying over aquifers; (c) inorganic acid spills; (d) other acidic recharge; (e) oxidation of inorganic pollutants; (f) decomposition of organic pollutants. Causes (b)–(f) can be relevant in the Netherlands.

In 1983 an estimated 185 000 underground oil tanks were still buried in the Netherlands. Many of these tanks have been since removed, but their number is still so large that there remains a risk of diffuse contamination of the groundwater. Oil pollution due to spillage, tank bursts and corrosion has been reported frequently and groundwater with higher acidity is more aggressive to concrete. Maps indicating the aggressiveness of groundwater in the Netherlands have been recently produced (NITG-TNO, 1998).

Intrusion of polluted water and atmospheric deposition Polluted bed sediments in lakes and canals can contribute to the pollution of the aquifer whenever infiltration occurs. Atmospheric deposition is in some places a large contributor to groundwater pollution. Dust emissions from industries and spraying of pesticides—for weed control in the city, and as agricultural practice in the rural area surrounding the city—have an observed influence on the quality of the urban groundwater. Acid rain and chloride contamination by sea-spray have already been mentioned as a source. The increasing trend to infiltrate stormwater poses a potential risk to the quality of the aquifer. Monitoring of the development of soil quality is recommended to avoid unpleasant surprises.

Geo(hydro)logical problems

Local geo(hydro)logy has a major influence on the groundwater-system; if the structure of the underlying soil is poor, as in towns having a peaty subsoil, there is no easy and cheap way to improve the water-management, despite the vast amount of technology available. Some of these problematic soils are as follows.

Peaty subsoil Peaty subsoil is hard to drain without causing subsidence and oxidation, making maintenance of a given soil surface level difficult.

Sandy subsoil Perched water tables occur in sandy areas, due to intercalated fine clay and loam layers. These are sometimes hard to detect in the design stage, but they can pose serious drainage problems later. Permeable sand layers that are directly connected to polluted or saline surface water or groundwater aquifers can also allow undesired substances to infiltrate.

Clay top layers Clay top layers are hard to drain, and in many cases a layer of 0.6 to 1.2 m of sand is applied before building activities start.

Organizational problems

The identification, evaluation and control processes, belonging to the organizational aspect of the management of urban groundwater, are causing many problems too.

Citizens lack knowledge of the process Due to a lack of knowledge, people do not relate some of their problems and nuisances to groundwater. Consequently politicians do not act or react either, leaving the cause of the problems and nuisances unnoticed.

Absence of proper legislation Law or regulations stating who is to control the urban groundwater is absent in the Netherlands. Municipalities do not have a duty of management of the groundwater level as such. As a consequence, the municipality cannot be approached for negligence with respect to damage as a result of either high or low groundwater levels; neither can the water board or the province be approached. Habitants suffering from drainage and groundwater quantity problems have to resolve them themselves. Only in the case of groundwater pollution where a person can identify the source can they go to court to claim liability of the polluter; here the "polluter pays" principle can be applied.

No organizational and financial responsibilities Even when a technological solution to a groundwater problem seems obvious, it is not clear who should provide this solution. Although parties have drafted official recommendations nobody seems to implement these agreements. In general, people cannot even obtain adequate information about solutions from official organisations although exceptionally some cities have installed help-desks over the past few years.

No clear standards There are no clear standards for the minimum or maximum groundwater-depths, making evaluation of a drainage situation difficult and although for many chemical substances, quality standards are present, the picture is not complete.

No systematic priority list available Not all the problems can be solved overnight and there is simply not enough money to put all the plans into practice. Presently, the choice of municipalities and other authorities in terms of which projects to spend their money on seems to be arbitrary, without a thorough investigation of the underlying problems. A clear priority statement, based on risk-analysis, would help municipalities to set priorities.

No cooperation between governmental authorities Presently, municipalities can choose their own approach to groundwater and declare their own standards, without external approval of agencies such as the water boards. Inhabitants are therefore confronted with different policies by various organisations.

No integral approach Groundwater, stormwater, surface water, sewers and drinking water supply, all represent different aspects of the same water system within an urban area. Nonetheless these activities have been studied and planned for separately in the past. This segregated approach is not adequate anymore. Only over the last 2–3 years have municipalities started to consider a more integrated urban water plan in collaboration with the water boards. Such plans do not have any official status, and some of these plans lack any statements on groundwater. As a number of the effects listed above find their cause in design and maintenance of urban areas, one would expect groundwater aspects to have a larger impact on future design and maintenance of Dutch urban areas than they do today.

CONCLUSION

In current practise the impact of groundwater on urban development in the Netherlands is almost negligible. Urban developers assume that civil engineers prevent or solve any problems related to groundwater. However, many problems do occur and the solution is not achievable by technical means alone. For some problems a solution is blocked by the fact that nobody takes responsibility. Most of the problems are solved *ad hoc*, partly because of the absence of laws and regulation on groundwater management, and without sufficient theoretical knowledge of the problem at hand. On the other hand the lack of regulations allows for unexpected opportunities and stimulates creative solutions.

Groundwater should have more influence on urban development. In order to achieve this goal the following actions are considered necessary:

- communicate the role of urban groundwater to the general public;
- install adequate systems for monitoring levels and quality of groundwater in urban areas;
- improve economic evaluation and decision support methods: current methods give rise to questions of equity and efficiency;
- develop better models and tools for analysis of groundwater flow in urban areas, e.g. to elucidate groundwater flows, levels and pollutant transport;
- create legislation, clearly defining responsibilities for groundwater management;
- develop quality and quantity standards, as well as a classification method, to facilitate system evaluation procedures;
- enhance co-ordination and cooperation between the different authorities, stimulating a more integral approach.

urban water plans are becoming more and more popular in the Netherlands and can be effective tools for defining a common strategy to overcome existing groundwater problems and to ensure the impact of groundwater on future urban development.

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