Feasibility of ASR for surface water storage in Haarlemmermeer (Netherlands)

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Abstract

The surface water system in the western part of The Netherlands is not able to deal with the current demands on the system: the risk of flooding due to storm water peak flows is too high, and the water quality in summer is below the Dutch standards due to salinization and low supply of good quality surface water. Enlarging the surface water system to transport extra water to and from the problematic areas is costly. To create extra storage facilities for water the water board of Rijnland has planned large bodies of extra surface water. However, the surface area required for extra surface water is very hard to find. ASR has been studied as an alternative to storage in surface water. The main conclusion is that ASR is technically feasible for storage of storm water peak flows (peak ASR) and for seasonal storage of good quality surface water from winter to summer (seasonal ASR). Seasonal ASR is economically very promising compared to surface water storage, also when the price of the required land is not included in the cost comparison. Peak ASR is economically attractive in urban areas, where the price of land is relatively high.

Keywords

Water management, water storage, ASR, feasibility, seepage.

INTRODUCTION

The surface water system in the western part of The Netherlands is not able to deal with the current demands on the system: the risk of flooding due to storm water peak flows is too high, and the water quality in summer is below the Dutch standards due to salinization and low supply of good quality surface water. Enlarging the surface water system to transport extra water to and from the problematic areas is costly, and the best option is to create extra storage facilities for water: both for storm water peak flows and for summer droughts. Therefore the water board of Rijnland has planned large bodies of extra surface water. However, the western part of The Netherlands is densely populated, and the surface area required for extra surface water is very hard to find. The Water board of Rijnland has calculated that around the Haarlemmermeer polder (the polder that also holds Amsterdam Airport Schiphol) a storage reservoir for 1,000,000 m^3 is needed to be able to handle storm water peak flows (peak storage). Seasonal storage of 2,000,000 m^3 is also needed in that area to meet the need for water in the nature areas surrounding the location of the peak storage facility. A plan was made to solve the need for both peak and seasonal storage by creating 2.5 km^2 of extra surface water in the form of a lake with a varying water level with dikes around the lake. However, the surface area available in this region is limited, and the demand for surface area for urban development is increasing steadily. Also, the growth of Amsterdam Airport Schiphol increases the demand for land in The Haarlemmermeer. This puts a large political pressure on the water board to minimize the demand for surface area for water storage. A possible solution for this problem is ASR. Research was done to find out if ASR is a technically en economically feasible alternative for storage in surface water.

GEOHYDROLOGY

The area of study is located in the polder Haarlemmermeer. The land surface lies below sea level, which implies that the land has to be kept dry by pumping out all net precipitation and water originating from upward seepage. Only the shallow groundwater is fresh and the rest is brackish or salt. The groundwater table is approx. 1 to 2 m below surface level. A system of ditches every few 100 m is in direct hydraulic contact with the ground water. During wet periods fresh water is discharged and during dry periods fresh water must be supplied from elsewhere, which illustrates the benefits of storage. The geohydrology at the site of study is schematically given in Table 1.

Table 1. Geohydrology at the site

Depth (m)	*Type of sediment*	*Layer name*	*Transmissivity (m^2/d) or hydraulic resistance (d)*	*Storage coefficent*
0 – 10	clay and peat	covering layer	1,000 d	0.15
10 – 83	medium fine to coarse sand	first and second aquifer	1,500 m^2/d	0.0016
83 – 90	clay	second aquitard	1,500 d	
90 – 125	medium - coarse sand	third aquifer	1,000 m^2/d	0,0004
125 – 133	clay and peat	third aquitard	1,000 d	
133 – 170	fine - medium sand	fourth aquifer	600 m^2/d	0,0004

General guidelines for ASR (EPA, 2004) mention that ASR should be located in areas with groundwater tables at depths larger then 5 m. Such low groundwater tables are however not found in and around The Haarlemmermeer. ASR in areas with high groundwater tables require extra attention to the impact on seepage/infiltration and changes in groundwater levels.

SEASONAL ASR

Efficiency of seasonal ASR

The efficiency of seasonal ASR depends mainly on the water quality injected, the natural water quality in the aquifer, the geochemical reactions in the aquifer and the demands on the water quality produced.

Density driven flow will occur because the infiltrated fresh water (100 mg/l Cl) has a lower density than the native salt groundwater (approximately 10,000 mg/l Cl). The maximum acceptable chloride content in the extracted groundwater is 200 mg/l. Calculations indicate an efficiency of 50% after a few years (or earlier when a large amount of fresh water is injected in the first year).

The water produced from an ASR system for surface water storage should be suitable for discharge into surface water. To prevent the necessity of water treatment after production, the produced water should be oxic, and only contain negligible amounts of iron and manganese. Depending on the presence and reactivity of components as organic carbon and pyrite, the water injected into an aquifer may become anoxic. Especially during the first years these redox processes could influence the efficiency of the seasonal ASR. In cases of reactive aquifers the impact of water quality changes due to redox processes can influence the feasibility of seasonal ASR as demonstrated in the case of the DIZON pilot described by Stuyfzand et al. (2002). What the efficiency-limiting process will be: redox reactions or buoyancy flow, is unknown. For now the assumption is made that an efficiency of 50% is feasible.

System setup

The source of water for infiltration is surface water. For the design of the ASR system it was assumed that 4,000,000 m^3 will be infiltrated during 4,000 hours (5.5 month with an infiltration rate of 1,000 m^3/h). The amount of wells needed is dependent on the properties of the aquifer, the infiltration rate, the amount of water infiltrated per year and the clogging potential of the infiltrated water.

A parameter that is often used to estimate the clogging potential of water is the Membrane Filtration Index or MFI. Using the MFI, the clogging rate can be estimated using the theory described by Buik and Willemsen (2002). The surface water is estimated to have an MFI of at least 1,000 s/l^2. Water with such a high MFI will rapidly clog infiltration wells. Therefore the infiltration water has to be pretreated before infiltration. In this case the use of a natural channel bed drainage system is assumed for filtering the water. A comparable type of filtering is also satisfactory used by the Amsterdam Water Supply as described by van Duijvenbode and Olsthoorn (1998, 2002). The MFI of the filtered water is assumed to be 20 s/l^2 at most. To minimize the impact on the phreatic groundwater and to maximize the infiltration capacity per well, the wells are situated in the third aquifer. Calculations show that 14 wells are required.

Calculations

Model calculations were performed to quantify the impact of the seasonal ASR on upward seepage and on phreatic groundwater levels. At the top of the model a drainage resistance of 300 d was used. First 4,000,000 m^3 is infiltrated through 14 wells during 5.5 month. After two months without pumping, 2,000,000 m^3 is extracted during 3 months.

Upward seepage

Figure 1 shows the calculated change in upward seepage and the total flow rate of the wells. From the start of infiltration the upward seepage starts to increase. At the end of the infiltration period the flow rate of extra upward

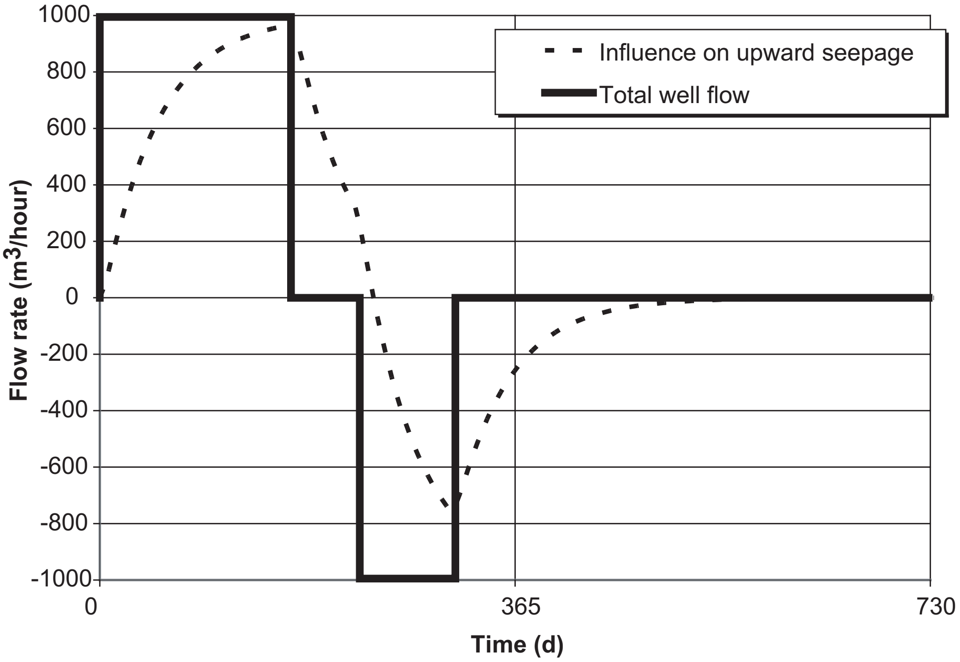

Figure 1. Impact of seasonal ASR on change in flow rate of upward seepage compared to well flow rate

seepage is nearly equal to the flow rate of infiltration. Figure 2 shows the change in cumulative upward seepage as a consequence of the seasonal ASR.

Figure 2 shows that the change in total upward seepage is equal to the net amount of water infiltrated. This means that the amount of water present in the subsoil is in the end equal to the amount that was present before infiltration. The ASR system does not store water quantity. It stores water quality. The ASR system will cause extra seepage of (brackish) groundwater in winter, and a reduced seepage in summer (or even infiltration).

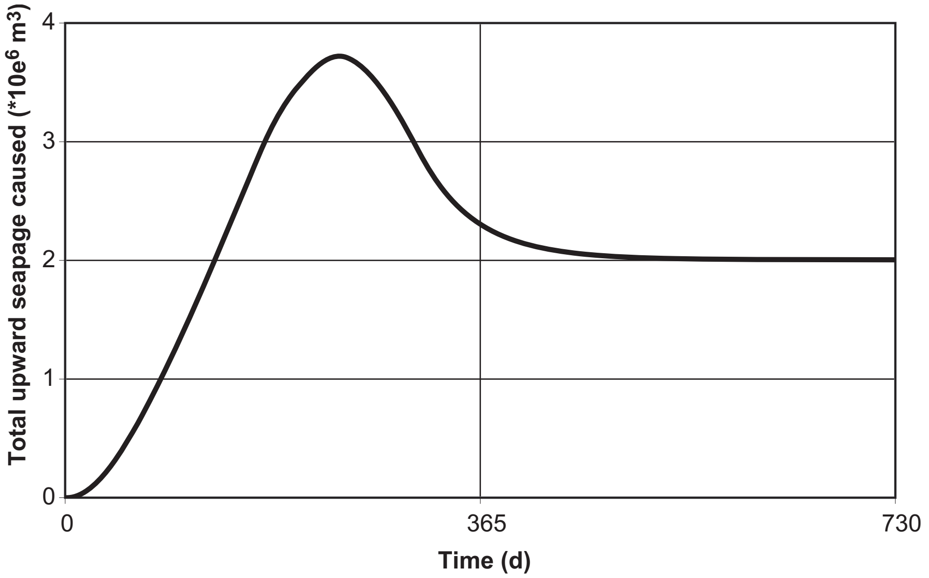

Figure 2. Cumulative change in upward seepage to surface water system caused by seasonal ASR

Groundwater table

The groundwater table in the area is typically situated 1 or 2 m below surface level. A small impact on the groundwater table can have significant consequences. In Figure 3 the calculated influence on the groundwater table is

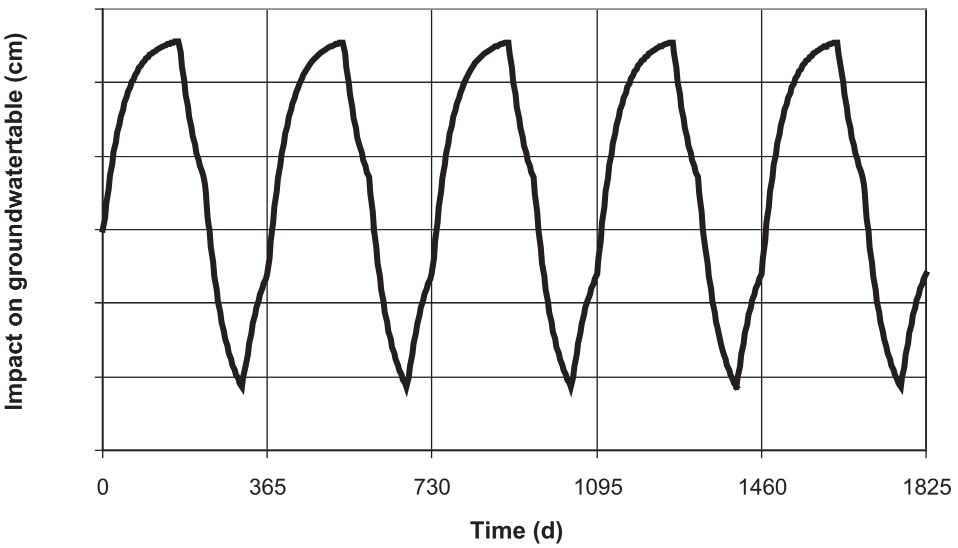

Figure 3. Calculated impact on groundwater level during five years of seasonal ASR

presented. The impact of the seasonal ASR on the groundwater table shows the same pattern every year. Calculations indicate that the maximum influence on the groundwater table is reached at the end of the infiltration period and amounts 0.13 m. This change is not expected to have significant impacts.

PEAK ASR

In case of peak ASR the goal is to temporarily store 1,000,000 m^3 of surface water in a time frame of 18 hours, which corresponds to an average flow rate of 15 m^3/s (56,000 m^3/d). On average, the peak ASR will be necessary once every 10 years.

System setup

Because of the large flow rate, water treatment before infiltration is not realistic. Also, treatment is not needed, because the clogging of the infiltration wells is not the determining factor for the design of the peak ASR: the wells clog only to a limited extent during the very short period of time that they are taking up water. The most critical parameter in the design is the maximum increase in hydraulic head without breaching the confining layer. According to the theory of Olsthoorn (1982) that was extended by Oostveen (2004) the increase in hydraulic head caused by an infiltration well should not exceed the horizontal grain pressure. Using this rule 140 infiltration wells will be needed for the peak ASR in the third aquifer.

Calculations

Upward seepage

The calculations performed for the seasonal ASR indicate that the infiltration of water is eventually fully compensated by upward seepage. Peak ASR is only useful if the amount of water that is infiltrated is larger than the amount of water that seeps upward during the peak flow event. The calculations for the seasonal ASR indicate that the upward seepage needs time to reach the flow rate of the infiltration. This time lapse between infiltrated volume and seepage volume is caused by the fact that for extra flow from the groundwater to the surface water, a rise in ground water table is required. The rise in ground water table takes place with a phreatic storage coefficient of 15%. The drainage resistance determines the head difference for a certain flow between ground water and surface water. A time lapse between infiltration and seepage requires storage, and the only significant storage is found in the phreatic groundwater level, therefore the magnitude of the drainage resistance will determine the success or failure of peak ASR.

The magnitude of the drainage resistance in The Haarlemmermeer is however not very well known. When only the surface water is taken into account, a drainage resistance of 300 d seems realistic. However, when the groundwater level is high, a series of shallow drains might become active, which will lower the effective drainage resistance significantly. In that case a drainage resistance of 10 d might be more realistic than the 300 d used for the seasonal ASR calculations, which means that the seepage of groundwater to the surface water system will respond a lot quicker.

Figure 4 shows the results of calculations performed for the peak ASR with respect to the change in total upward seepage caused by infiltration of 1,000,000 m^3 in 18 hours. The figure clearly shows the significance of the magnitude of the drainage resistance. Other parameters are less sensitive. But even for a low value of the drainage resistance of 10 days, the maximum seepage flow rate is only 11% of the infiltration rate. This illustrates that peak ASR can be a solution for temporarily storing large volumes of water within a short amount of time.

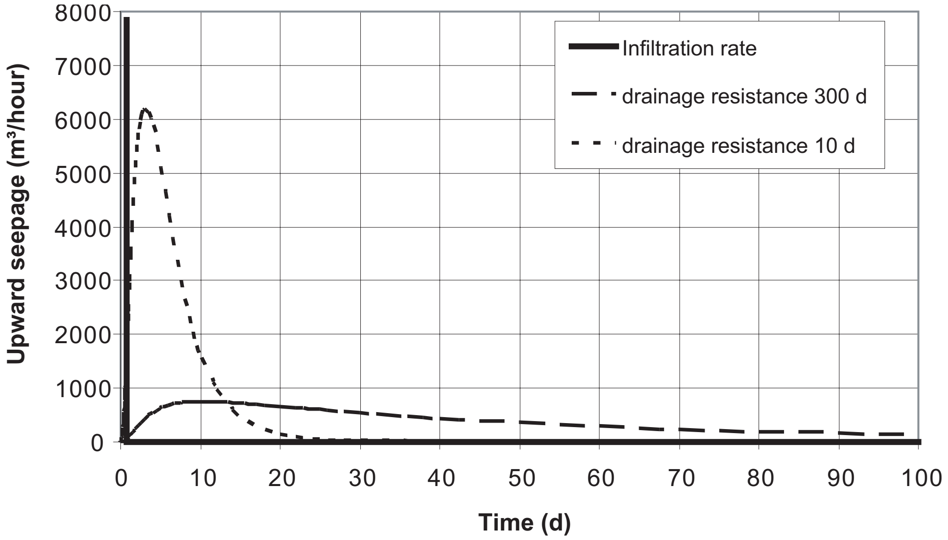

Figure 4. Impact of peak ASR on change in total upward seepage at different drainage resistances

Groundwater table

The calculated impact on the groundwater table in case of a drainage resistance of 300 d is given in Figure 5. The calculated influence is very small. The calculated maximum rise of the hydraulic head in the first aquifer amounts to 1.44 m. This rise of hydraulic head may cause the upward pressure to exceed the vertical grain pressure below ditches. This aspect requires further research. In this feasibility study it was assumed that a short time with high pressures would not harm the integrity of the covering layer.

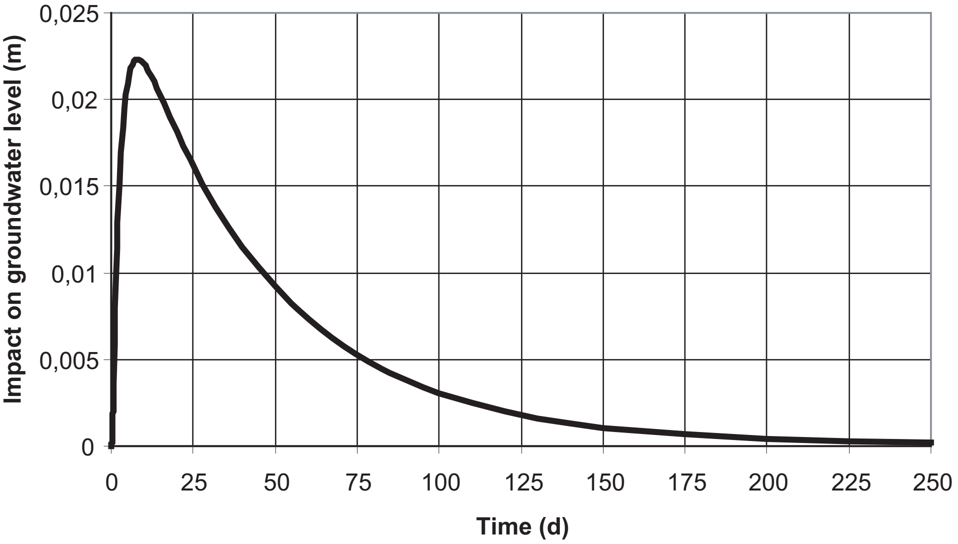

Figure 5. Calculated impact of peak ASR on groundwater level

FEASIBILITY

The major advantage of ASR as compared to storage in surface water is the minimum amount of space needed. Other advantages of ASR are the freedom to choose the locations of the ASR and the fact that an ASR is never full. Disadvantages might be the increase of upward seepage in certain periods and the potential impact of redox processes in the aquifer on the quality of the stored water. An item not discussed yet is the potential presence of pollutants in the surface water.The cost for peak and seasonal storage (combined) in 2.5 km^2 of surface water is estimated to be 35,000,000 (9 million for peak and 26 million for seasonal storage when split up). This price is based on the assumption that the land is obtained free of charge, because the land for the storage reservoir would be bought by the state to increase the area of nature in The Netherlands. The cost of seasonal ASR amounts to 6 million and to 29 million for peak ASR, so also 35 million for a combination. It appears that the cost of seasonal ASR is much lower than the cost for seasonal storage in surface water. Peak ASR is more expensive compared to the peak storage in surface water, as long as the price of the land is low. Peak ASR is becoming economically attractive when the price of land is larger than approx. 30/m^2. Normal prices in urban areas are higher than 100/m^2. Agricultural land in The Haarlemmermeer has a price of approx. 10 /m^2.

EVALUATION

Seasonal ASR is economically very attractive compared to seasonal storage in surface water. Peak ASR is expected to be an attractive option in urban areas. Because of the advantages of ASR compared to storage in surface water it was recommended to proceed with a pilot. The most important aspects that should be subject of study during this pilot are:

- can natural channel bed filtration be an effective method for filtering the water for seasonal ASR?; what will the MFI of the water be after filtering?;
- what MFI values can be expected in surface water?; what is the relation between MFI and the rate of clogging at the high MFI values found in surface water?;
- what is the efficiency of seasonal ASR: what is the influence of buoyancy flow and redox processes?;
- is the impact of ASR acceptable (influence of pollutants in surface water; breaching of the covering layer, settlements, upward seepage, groundwater level, etc.);
- social aspects (acceptation by the population in The Haarlemmermeer);
- legislation and permitting;

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