Hydrogeological situation and groundwater monitoring in the area of the 'Dollart Port Project' in Lower Saxony, Federal Republic of Germany

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ABSTRACT

Groundwater drawdown will be necessary during the construction of the projected harbour expansion near Emden ("Dollarthafen"). This will have consequences for the groundwater table and the hydrogeological situation in the surrounding area.

A large amount of groundwater data has been made available for working out a plan for monitoring during and after construction of the harbour and to provide documentation about the natural, uninfluenced groundwater table without drawdown. The study area is north of the river Ems and consists of coastal marshes and polders.

The aquifer consists of Quaternary and Pliocene sand and gravel, covered by low-permeability Holocene sediments. The inland groundwater is influenced by salt-water intrusion from the sea.

The groundwater table and groundwater movement in the confined aquifer are influenced by the tidal range of the Ems, by the inland groundwater situation outside the tidal influence, the climatic conditions, atmospheric pressure, etc.

Manually and automatically monitored groundwater observation wells, weather stations, and chemical groundwater analysis yield information on hydraulic and hydrochemical correlation and tidal effects.

The groundwater-monitoring plan, taking into account all of the most important factors, is to provide information about how large the drawdown is in the hinterland and how large an area is influenced by it.

1. DESCRIPTION OF THE DOLLART PORT PROJECT

The Dollart is a shallow bay on the North-Sea coast near Emden and has existed since the late middle age. A port expansion, including the construction of a large sea lock as an important component, has been planned in Emden for more than twenty years. This lock is planned to be built near Knock in the Ems channel, which is the present approach to the port of Emden. The natural barrier south of the present channel, called "Geisesteert" and stabilised at the end of the last century to prevent the Ems channel from shifting into the Dollart, will be converted into a dike with a smaller lock at the eastern end at the Borssum flood gate (fig. 1).
The area enclosed by the new dike, the two locks at the eastern and the western ends and the dike on the north side of the river Ems, will form the enlarged port of Emden. The river Ems will be diverted south of the Geisesteert (CARSJENS & CLASMEIER, 1985).

The construction of a new sea lock is planned for the following reasons. At present, mud and sand, transported by the river Ems and by tides, have to be dredged continually from the Ems channel and the harbour to maintain sufficient depth. This is very expensive and the new lock will reduce the amount of necessary dredging. Owing to its age and size, it is also necessary to renovate the present lock, which no longer meets the needs of present-day merchant shipping. This enlargement of the port would provide larger capacities for merchant shipping and inducement for industry to settle there.
Tasks

The Hydrogeology Subdivision of the Geological Survey of Lower Saxony (NLfB) was commissioned by the Emden Port Authority of Lower Saxony to monitor the hydraulic and hydrochemical changes in the groundwater resulting from the planned construction.

Groundwater monitoring is necessary because the groundwater table has to be lowered to -7.5 m for about 5 years during construction of the new sea lock.

An area north of the Dollart, a strip about 3.5 km wide and 12.5 km long from Emden westward along the Ems to the flood gate at Knock, is the main area of investigation (fig. 2). The geological conditions in the southwest part of the construction area provide a direct hydraulic connection of surface water with the aquifer in the study area. Therefore, the drawdown cone will not extend in this direction and it is only necessary to monitor the hydrogeological situation of the area north of the sea lock.

2. GEOLOGY

A simplified depiction of the geological situation can be seen in a N-S cross section (fig. 3) from the planned sea lock in the Ems channel to the 190 m deep borehole R79 Neelenhof. The Holocene cover of fine-grained marsh sediments, about 10 m thick, overlies a Pleistocene sequence of sand and fine gravel, 20 to 30 m thick. In the area of the lock the sandy Pleistocene beds are thinner and overlie Lauenburgian beds up to 70 m thick. The Lauenburgian beds, which accord with the so-called "pot-klei" in the Netherlands, fill an erosion channel formed during the Elster glacial stage and are found nowhere else in the study area. The next underlying deposits are Pliocene sediments of gravel, sand, silt, and clay. See also: BARCKHAUSEN & STREIF (1978), BARCKHAUSEN (1984).

3. HYDROGEOLOGY

The base of the aquifer is at a depth of about 130 m. The underlying strata consist of 60 m of Pliocene silt and fine sand. Generally, there is only one aquifer present, which is largely heterogeneous. There are a lot of thinner layers of low permeability. They have a very local extension and function as aquicludes. In the area of the sea lock and somewhat north of it, this aquifer is divided into two parts by the Lauenburgian beds. The groundwater is confined below the Holocene marsh deposits of low permeability.

The groundwater is monitored in more than 45 observation wells, in some of them since 1978. The screens in most of these wells are at depths of 20 m within the Pleistocene sediments or at 40 m within the Pliocene sediments. In some cases, the groundwater table is recorded automatically by a chart recorder; in the other wells, the groundwater table is measured manually once a week. One value per week is taken from the recorder sheets, it is the mean level between the high and low tide influenced levels on Monday; the tidal influence is eliminated. These values are stored in the computer with the other values.
We found, that once a week is sufficient for a long-term mean of acceptable precision; more data do not significantly improve the accuracy of the mean but would require considerably more work.

4. HYDROCHEMISTRY

Water samples are taken at regular yearly intervals and analysed for sodium, potassium, magnesium, calcium, iron(II), manganese, bicarbonate, chloride, and sulfate. The groundwater is saline; a freshwater component from the Geest is observed at only a few of the observation wells.

An isoline map of the chloride content in the groundwater is shown in fig. 4; the saline/fresh-water interface lies a few kilometres west of the study area, it courses in a northerly direction. The presence of seawater in the aquifer is clearly shown by this data: the amount of chloride content in the groundwater increases nearer the coast. The source of this seawater could be infiltration either from the river Ems or through the floor of the Dollart directly into the aquifer or both, or inclusion during sedimentation of the Holocene marsh, or, to a smaller part by drainwater from the mud dredged from the harbour and the Ems channel, which was used as landfill behind the dikes. Generally, the groundwater at a depth of 40 m is somewhat more saline than at a depth of 20 m. Only at a few observation wells near the dike a higher salinity is present in the upper part of the aquifer. The Ems water at Knock has a salinity of 60-70% of that of seawater. The groundwater near the dike on the north side of the Ems has a salinity of about half that of seawater, and 3700 m inland, in the area of borehole R79, the salinity is only about 20-30% of that of seawater, depending on the depth.
5. RESULTS OBTAINED TILL NOW

5.1. Groundwater flow

To document the changes in the hydraulic situation resulting from the construction of the Dollart Port, it is necessary to monitor the present groundwater conditions for several years. Measurements on individual days, as well as the mean of measurements over many years, show that the river Ems in this area does not function as a gaining stream; instead, water from the river infiltrates into the aquifer with groundwater flow to the north.

The groundwater level is influenced by the surface water level behind the flood gate at Knock, which is kept at about 1.3 m below mean sea level by opening the flood gate at low tide and pumping. The effect on the groundwater resulting from drainage ditches ending at Knock can be seen in the groundwater equipotential lines and hydrographs (fig. 5). South of the main drainage ditch leading to the flood gate, the Knockster Siel, the generally northward groundwater flow at a depth of 20 m bends towards the drainage ditch. Unfortunately, there are no observation wells north of it to see the influence of the drainage at this side of the main ditch.

If the hydrograph for the drainage ditch just behind the flood gate is compared with the hydrograph for the observation well near the flood gate (DH 15), it can be seen that the lowering of the water level behind the flood gate is reflected in a lowering of the water table in its vicinity.

When the equipotential lines were determined, the differing groundwater densities resulting from differing degrees of salinization were normalized to the mean density of the river Ems at Knock (1.0155 kg/l at 10 °C). Fig. 6 shows the equipotential lines for a depth of about 20 m. The largest difference (about 50 cm) between the hydrostatic head measured in the observation wells and the hydrostatic head obtained by normalizing to a uniform density was at the well

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Fig. 5. Three different hydrographs:
- DH 16 - distance to the Ems: 970 m,
- DH 17 - distance to the Ems: 2160 m,
- DH 15 - distance to the Ems: 2250 m, distance to the main drainage ditch: 50 m.
The mean apparent flow velocity of the aquifer ranges about 3,10 m/year at a depth of 20 m and about 3,80 m/year at a depth of 40 m.

5.2. Pumping test and hydrogeologic properties

A pumping test was carried out at an early stage of investigation, which, however, involved only a small area near the sea lock (GERHARDY & GIESSEL, 1980). The transmissivity values determined for two wells at this site were 39 m²/h and 55 m²/h. These two values do not seem to be applicable to the rest of the study area because these wells lie at the limit of the Lauenburg Clay, which does not occur further to the north.

Therefore, other methods were applied to obtain a picture of the hydrogeologic conditions of the study area as a whole. The hydraulic parameters can be calculated on the basis of the hydraulic relationships between the river Ems and the groundwater in the study area, recognizable by the reflection of the tidal fluctuations in the groundwater table (LANGGUTH & VOIGT, 1980).

The transmissivity of the aquifer was calculated by two different methods, both of which take into consideration the influence of the tide on the groundwater.

The first method, Ferris' first straight-line method, is based on the decrease in the tidal range as a function of distance from the river Ems (fig. 7). Using this method, we have calculated a mean value of about 317 m²/h. The second method, Ferris' second straight-line method, is based on the time lag between the high-
Fig. 7. Time lag of tides versus distance to the coast.

lated a mean value of about 317 m²/h. The second method, Ferris' second straight-line method, is based on the time lag between the high-water and low-water levels in the river Ems and their appearance in the groundwater table. It was used to calculate a mean coefficient of transmissivity for the whole area. The resulting value was about 234 m²/h. These two values seem to be too high but they show, that the transmissivity of the whole area is higher than at the site, where the pumping test was carried out.

The results of such calculations depend on certain parameters, the exact determination of which is very difficult. One of these parameters, the storage coefficient, must be determined before transmissivity can be calculated, because it significantly influences the value obtained. One possibility for calculating the storage coefficient is via the relationship between changes in atmospheric pressure and changes in the groundwater level, as expressed by a parameter called the barometric coefficient or barometric efficiency (BE).

The barometric efficiency is a measure of the ability of the confining beds overlying the aquifer to resist changes in atmospheric pressure. An accurate value for the barometric efficiency can be obtained only if changes in the groundwater table are caused only by changes in atmospheric pressure. Even the groundwater table for which the tidal range has been eliminated seems to be dependent on other factors besides atmospheric pressure and the tide. Therefore, the method of CLARK (1967), where these other factors were eliminated, was used to calculate the BE. The mean value for the barometric efficiency lies about 16%.

Using an assumed porosity of 20 % and an aquifer thickness of about 120 m, a storage coefficient of $8,8 \times 10^{-4}$ is obtained. This value gives a real good approximation to the experience of similar investigations in other areas. These calculations cannot and are not planned to replace pumping tests. They only serve as a preliminary evaluation of the hydrogeological conditions. If the Dollart port is built, a short-term drawdown test will then be conducted prior to its construction.

If it can be done using simple methods, it is hoped to investigate the extent to which the groundwater table is influenced by other factors, e.g. precipitation, air temperature, and the drainage system. These are, however, probably secondary factors. Much more important is the influence of the wind. When the wind is from the north or northwest, water from the North Sea is blown into the Dollart, resulting in higher water levels there, which directly influence the groundwater levels. When the wind is from the south or southeast, the opposite occurs.

6. PREDICTION OF THE SIZE OF THE DRAWDOWN CONE

An important part of the hydrogeological investigations is the calculation of the extent of the drawdown cone when the groundwater table is lowered to -7,5 m. The excavation will be more than 20 m deep but a lowering by 7,5 m will be sufficient because the pit will be to a large extent protected from the groundwater by sheet steel piling.

Hantush's method was used by KOSCHEL (1985) to calculate the radius of influence (fig. 8) because the aquifer is either a so-called leaky or a semi-confined aquifer. For foundation engineering, drawdown greater than 1 m is of importance. The model shows that this will occur up to about 1200 m from the pit.
7. GROUNDWATER MONITORING DURING THE DRAWDOWN

To determine the extent of drawdown during pumping, it is necessary to know what the groundwater level would have been in the absence of pumping. Trend analyses or comparison wells are not appropriate for assessing the complex groundwater relationships in the study area. Mean values for previous years can also not be used because they are too imprecise. The fact that the groundwater table in the study area is influenced by several factors led to the method that will be used for determining the amount of drawdown.

The water level in the river Ems is influenced by the tide and the amount of water borne by the river from the hinterland and will not be significantly affected by the construction of the port (measured at the Ems gauge at Knock, (fig. 9)).

A groundwater observation well was chosen that is far enough inland to be uninfluenced by the tide or the groundwater lowering but which is still within the marshland (well R80 at Pewsum, distance to the Ems 11000 m). At this site the groundwater hydrograph is affected only by the usual factors, such as precipitation, groundwater recharge, and groundwater flow.

A formula correlating the values measured at these two sites and the values measured at each of the other groundwater observation wells will be used to calculate the relationships between these three water levels. For an observation well relatively far from the Ems, this formula will give more weight to the value from well R80; and for an observation well directly on the river Ems near the dike, more weight will be given to the value measured by the Ems gauge at Knock (fig. 10).

For each groundwater observation well, a formula will be derived for the regression line, which can
then be used to calculate the amount of drawdown at that site during the five years of drawdown.

REFERENCES


