J.M.K. Pennink director/hydrologist of Amsterdam Water Supply 1900-1917

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1 Introduction

Johan Pennink (1851-1936) was director joined the Amsterdam Water Supply in 1890 and served as its director between 1900 and 1917. He, therefore, already had a long career with the company when he was appointed. His major concerns were the threatened future of the dune area along the North Sea Coast, now known as the Amsterdam Water Supply Dunes, as a resource for the drinking water of the capital of the Netherlands.

On the photo we see him at work, with at the wall to his right we see a map of the dune area and behind him the cross section through the dunes perpendicular to the coast he assebled based on the drillings made during the last 20 years of the 19th century. This cross section shows the geology, but most importantly the the up to 120 m thick freshwater lens floating on saltwater. Discussions on what actions to take given the shortage of drinking water production capacity form the dunes that has intensified since around 1880, when vertually all natural recharge was recovered yearly with the extended set of canals that had been constructed and meantime deepened since the start of the drinking water supply in 1853.

After discussions that went on for twenty years, the municipality decided that tube wells would be installed to extract the fresh water present in the second aquifer below -25 m, as it was the cheapest of the available solutions. However, Pennink was aware of the limited resource the yearly downward leakage into this aquifer presented; he had in mind the then recent discovery of Badon Ghijben (Drabbe & Badon Ghyben, 1888) and Herzberg (1901) concerning the equilbrium between fresh and salt water. He was against this large-scale extraction of deep fresh water, because he feared salinzation of the aquifer, which might cause the permanent loss of the area as a resource for fresh drinking water. Neverthless, the first series wells were sunk in 1903 and two decades later the area showed a total of around 500 wells, which were all screened around 25-35 m below mean sea level, and stood around 50 m apart, and each well had a capacity of about 7 m3/h.

Given this situation and concerned, Pennink launched a modeling project to study the behavior of fresh and saline groundwater flow. Between 1904 and 1905 he carried out a fair number of tests with a sand-box model, which he already

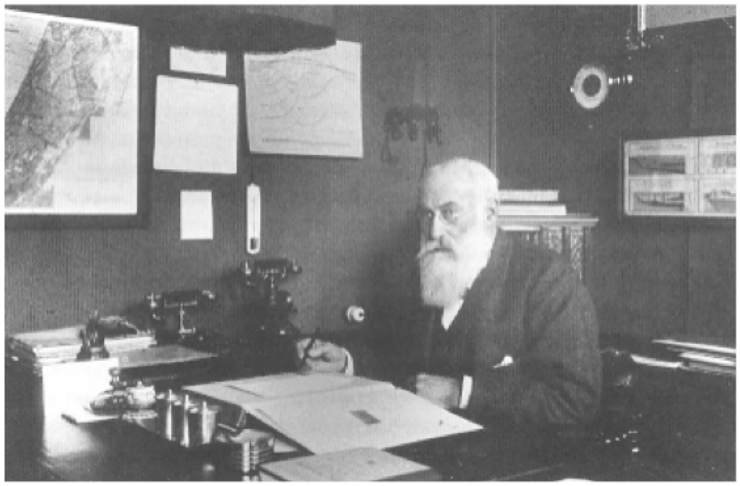

Figure 1: ir. JMK Pennink, director of the Amsterdam Water Supply 1900-1917 doing hydrology at this desk.

announced in Pennink (1903 and 1904) and published in Pennink (1905) and, againlater, in 1915, in a large, 150 page book called “Grondwaterstroombanen” (Eng.: Groundwater Flow Paths). In this book of size 40x30x2 cm, he describes his tests in four languages (Dutch, German, French and English) with a photo on about every second page showing one of the modelling results. The book has recently been scanned and put on the web. It is available at

http://www.citg.tudelft.nl/live/pagina.jsp?id=68e12562-a4d2-489a-b82e-deca5dd32c42&lang=en

Pennink also compared his sand-box model, which he called “little reality”, with field tests, specially designed to show upward flow below canals in the dunes. The latter was important to him, as according to a then widely used German hydrology book (Lueger, 1890), groundwater flow towards canals was only possible above the canal bottom. From the water balances he had made of canals in the Amsterdam Water Supply Dunes, when combined the measured head gradient and measured conductivities, this theory predicted a capacity a factor or 2 to 3 below what actually was encountered in the field. So Pennink reasoned that water towards canals must just as well below their bottom and must be upward below them. Which he went on the actually measure in the field with a set of piezometers at different depths below a canal bottom, showing that indeed head declined from deep to shallow below discharging canal bottoms, proving that flow was upward. He then went on with his modeling project to verify what had to be true. Therefore, his first tests concerned the flow of fresh water towards a canal, showing the flow lines and groundwater speed by Indian ink-as a tracer.

These tests were conclusive as they showed what Pennink had realized had to be true, flow below canal bottoms and upward below them. Given the actual depth of the shallow aquifer in the dune area, the measured and computed

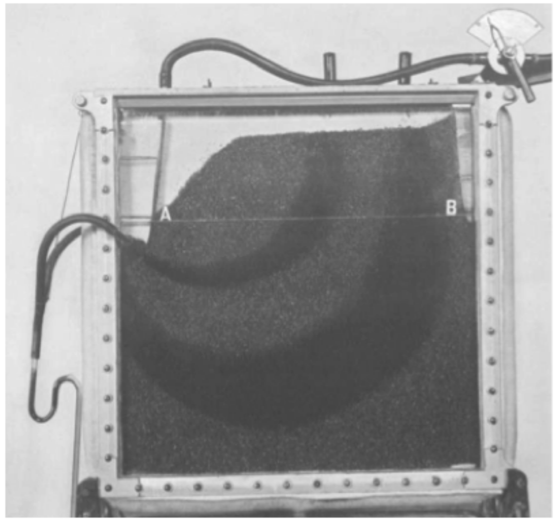

Figure 2: Pennink's fist tests March 1904, showing sand-box model simulating flow from rain to recovery canal and flow paths indicated by indian ink

canal discharge now matched once the thickness was measured from the aquifer bottom to the water table.

He then continued his modeling with salt water, as salinzation concerned him most. To do this, he used milk as a surrogate for saltwater, as milk has about the same density, 1.03, and is clearly visible. I later realize that milk had other purposes as well; it is a little fatty and thus prevents mixing with water, causing the interface to remain sharp during his tests. The sharpness of the interface is visible on most of the photos showing result of the fresh-saltwater models.

The first model that included saltwater concerned the siutation of an area with rain recharge descharing towards a canal at the left side of the sand-box model.

To obtain a better insight in upconing he had a large model made, 96x97 cm this time, in which he could model the flow from the sides of the model toward a canal or well in the center. The interesting part is, that Pennink not only simulated regular upconing from below, but also investigated the shape of the cone in the case of substantional lateral groundwater flow. He so demonstrated that the saltwater may in such cases enter a well from the side instead of the bottom. Between 1951 adn 1953, almost 50 years later, long after Pennink resigned in 1917 and 15 years after his death in 1937, when severe upconing had affected many of the wells, just as he feard half a century erlier, the salinty profile was actually measured in many of the wells. These measurements of the EC over the length of the screen in wells in which salinization occured showed that in many of them the salt entered somewhere above the bottom of the screens. I'm not aware that such measurements have been done elsewhere. All in all they

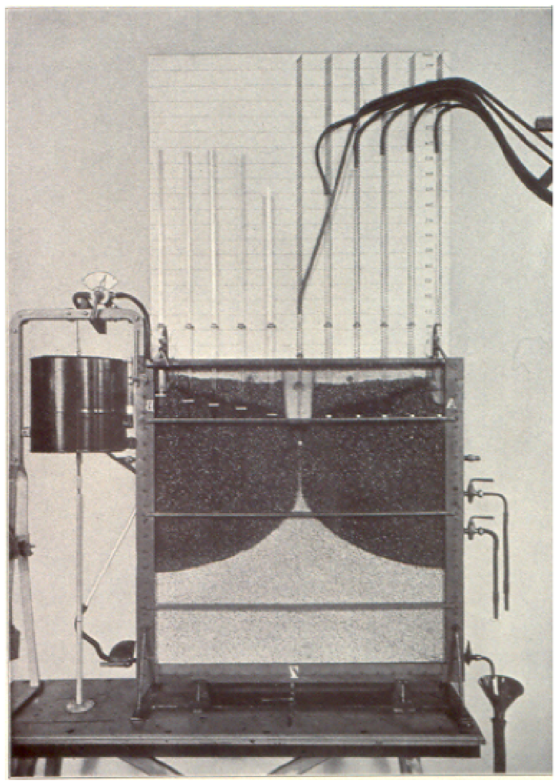

Figure 3: Pennink's second model, with upconing milk. The water table is visible in the top, it was colored with indian ink

seem to fit in with the sand box modeling done by Pennink half a century before and which might have been forgotton since. These extended measurements are unique as salinzation has effectively been halted in the dunes after the artificial recharge with treated river water was put in place in 1957. This extra supply of water reestablished the balance of the area between recharge and extraction. It allowed to reduce the well extraction from the second aquifer, so that since then the interface between fresh and salt water recuperates. Nowadays the wells are only stand by for use in emergency, i.e. when supply of treated river water is interrupted for whatever reason.

It has been long-desired challenge to model Pennink's sand-box experiments. Now with *mfLab* and SEAWAT available it is possible. Therefore, I added test Pennink's series 1 to 6 to the example repository of mfLab under mfLab/examples/swt_v4/Pennink. The examples are called Series1 .. Series6. Each test series is also described in the mf_adapt.m file belonging to the test. Each such directory has a subdirectory with the photos scanned from Penninks 1915 book pertaining to the particular sand-box modeling experiment. All photos are in the directory Photos at the level of the series. Every photo directory has a file photostruct.mat which hold a struct "d" which contains the name of all photos, the pixel coordinates of the model on the photo and the actual size of the model. This struct is used to plot results directly on the model on the photo. The struct was made using the file MakePhotoStruct.m on the directory mflab/examples/swt_v4/Pennink/Photos.

2 Pennink's two models

Pennink used two models, see previouw figures. The first was used in tests 1 to 3 measured 65 by 65 by 2 cm from which the water was discharge through a "canal" at one side and a larger 97 by 96 by 1.8 cm one, in which the water could be extracted in the center. As the photos show, the sand box did not reach to the very top of the model. For the simulations I measured the contour of the sand box from the photos and also took the top of the saturated zone into consideration. By close inspection of the photos, the full capillary zone is probably about 2 cm . This is consistent with the sand that Pennink used. It is a very coarse sand, of unknown grain size, but whos conductivity I calibrated to be as high as 860 m/d! It implies that Pennink used a fine gravel in his model. This calibration was done given the head gradient specified in the book combined with the supply of water and the velocity of the Indian ink tracer. The latter allowed the porosity to be calibrated to 38%. The high conductivity of the sand is consistent with the coarse grain implression shown by the texture of the sand on the photos. It is also consistent with the thin capillary zone deduced from the photos. It is consistent with the disperson of the Indian ink during the experiments. It is finally consistent with the behavior of the milk he used in his modlel as a surrogate for saltwater. It is unlikely that fatty milk will flow easily in fine-grained sand, given the capillary effects expected at the interface with pure water; in fine gravel these effects are likely negligable. Moreover, fatty milk will have prevented transversal dispersion at the interface between milk and water. This allowed for pictures with a sharp contrast between the milk and the fresh water. Further, a fine gravel permits easy constant sand filling of the model, fast water filling and draining and easy expulsion of air. It also prevents a thick capillary fringe, which, on the scale of the model, would complety disturb the flow. That is the modle would always be completely saturated and gradients would be virtually impossible to manage as the water table would always equal the top of the sand in the model. Finally, the coarse material allowed for fast models with substantial flows under small easily maintained and managed head differences, leaving the water table essentially horizontal in all test situations. For short, Pennink has put a lot of thought and modeling experience in his tests. He prevented lots of problems. It is likely that the model experienced had been preceded by many trials in which such problems were gradually practically overcome until he obtained the models for the tests that he published in his book. From the careful prepration and the beautiful print of his book, with all the photos, it is clear that Pennink considered his experiments of great importance. It is noted that the book was published 10 years after the last experiment was finished. It was a time of intense discussion between those who were convinced that the salinzation predicted and feared be Pennink around 1900 and those who were convinced that this would not happen. As salt measurements in the wells showed no signs of salinization until 1915, the latter gained terrain with as a climax his engineer Hoogesteger, who, in 1915, on his onw initiative, without letting know his director, wrote a report telling that salinzation was no serious issue, which he sent to the municipality. After heavy arguments Pennink had to resign in 1917. However, history proved that he was right. Salinzation started to occur in the twenties and intensified over the decades that followed. This situaiton deteriorated so much that drastic measures becase necessary to save the dunes as a resource in the future. The solution was artificial recharge using treated water from the river Rhine, a solution that Pennink had advocated already in 1901. Hence Pennink was right, he only missed the time scale of the salinzation. But who could blame him for that?

3 The numerical models

All simultations are carried out in minutes and cm. Hence the conductivity of 860 m/d becomes 86000/(24*60) cm/min and all flow rates are converted to cm2/min or cm/min. The density does not change as SEAWAT only needs the relative density $(\rho_s - \rho_f)/\rho_f$ which does not change under any unit conversion. Gravity is of course, dependent on the units, but it is already included in the hydraulic conductivity and, therefore, not a concern. Dispersivities must be changed to cm and stress period lengths to minutes. Diffusion must be changed, but it has not been used in any of the simulations.

The numerical models use a grid with 1 cm cells in vertical (z) and horizontal (x) direction and the thickness of the model in y direction. As each model is parameterized in mfLab, the model has often been run with grid size of 2x2 cm in z and x direction to test and reduce waiting time, to resort to 1x1 cm for te final run and obtain optimal resolution for vizualization.

Fixed-head boundaries have been established using the CHD package, because this allows changing them during a simulation, which is often necessary to mimic what Pennink has done. Only in Series6 we used GHB package to specifiy the heads, because it is impossible to switch fixed-head cells back to computed head cells when CHD is used. GHB does not have such a limitation, but requires to specify some more or less arbitrary conductance to connect the model cell with the outiside source. For models with rain we used the recharge package (RCH).

For transport we have to specify the concentration of cells with sources having a concentration of incoming water different from zero. These are only the locations where Indian ink was supplied and the point in the model with milk, where it was connected with the external milk reservoir. All other sources were assumed to have water of zero concentration and therefore need not be specified in the source sink package SSM of MT3DMS/SEAWAT. The milk entry point has been specified as a well (supplied source) in test Series3, because Pennink mentions that the milk as been supplied on a drop by drop basis. The milk has been specified as a fixed head point, using the CHD package, in the other models with milk, except in Series6, in which the GHB package was used. The only advantage of GHB relative to CHD is, that the GHB specified fixed-head points can be turned back into computed points during a simulation.

Points where Indian ink was supplied as a tracer have been specified has fixed concentration cells. Doing this an undefined amount of tracer is added to the model by virtue of the advection by the flow through this cell. However such points do not add water to the model and, therefore, have no influence on the water balance. The added mass through such points can be computed afterwards from the concentration in the cells of the model, by summing the mass in those cells, if need be.

In all models, the circumference coordinates of the sand-mass was measured from the screen. Model cells outside this circumference were inactive. The approximate elevation of the water table was also measured from the screen. Cells above it were either made inactive or, depending on the situaiton, obtained a horizontal conductivity of 1/10 th of that of the saturated cells (while the vertical conductivity was unaltered to let rain flow through) or were set to inactive in the Series6 model. This elevation remained fixed during the entire simulation. The wetting/rewetting option was not used to save computation time. Of course, this option is the most logical way to simulate the top of the groundwater system. It's straightforward to use it in *mfLab*, but not essential for the purpose of these simulations. Clearly, the cells in the canals above the water table were also set to inactive.

TVD was the only method used to compute the transport with dispersion. It works very well in this context and no visual numerical dispersion occurs.

Longintudal dispersivity was set to 0.25 cm and the two transverse dispersivities were fixed to 20% of that value. Diffusion was zero in all the simulations.

The density of the milk was set to 1.029 kg/L according to Pennink (1915).

The freshwater concentration was set to 0 and the seawater concentration to 1, so that relative concentrations are used. The corresponding density to concentration slope is, therefore, 29 (kg/m3)/(1 conc unit). The NSWTCPL swithc was used in SEAWAT's VDF package to cause updating of the flow field only when the density change in any cell exceeds 1 kg/m3.

Sometimes a different MODFLOW solver had to be used when SEAWAT claimed that the flowmodel did not converge. This sometimes happens when the dispersivity is changed. SIP and SOR may then prove superior over PCG. Problems with the flow model not converging seldom happens and when it does mostly early during the simulation and when large changes of the density occur. A good initial situation should help, but is difficult to come by. It may also help to lessen the flow and head convergence requirements, as the repeated recalculation of the flow field will cause sufficiently accurate computations later on. This has of course to be verified in the LIST file by checking the models mass balance.

One of the nice things with SEAWAT is that one can immediately compute the same model using MT3DMS with the same input files. To do this switch off the package VDF and VSC and switch on LMT and FTL. Alternatively leave off LMT and FTL and switch on VDF with the option -1 instead of 1. mfLab then makes sure that the SEAWAT code is run with the VDF and VSC package switched off. This answer is then the same as of MT3DMS. This way one can direcly simulate the difference made by adding density (and or viscosity) to the transport simulation. Most of the time this influence is bigger than most people and even modelers think. When running seawat, LMT and FTL packages have no function and it just saves time and space to switch them off; they are only needed in case the MT3DMS code is to be run.

In all model the heads, budgets and concentrations are saved at the end of each stress period only. This keeps the heads, budget and concentration files synchronized. On the other hand, for every desired information point a stress period is required. Hence if the simulation is over 150 minutes, and we want te see the situation every minute there must be 100 stress periods. However, on the worksheet PER in mfLab the user only needs to specify the number of the stress period where something changes. So if stress periods 1:5 are the same, only specify number 5. If the stress periods 6:9 are also the same as are 10:15, then only specify stress period number 5, 9 and 15, mfLab will fill in the missing ones.

Visualization is done in all simulations except Series6 by plotting directly on one of the Penninks photos taken during this test. Only in Series 6 we visualize by plotting full screen to obtain the best view of the results. This is also the most important simulation. For this reason some more effort was put in making a nice picture and video.

Videos can be made in any simulation by setting the parameter film=1 instead of film=0 in their mf_analyze file. This works only on Windows system. In mf_analyze making films on Mac was explicitly excluded because MATLAB has no compression for the MAC which causes the produced AVI file to be of the order of half a gigabyte instead of just 11 MB. So switch to Windows to run mf_analyze to make a movie or stay in Mac OS for Mac users and just watch the succuessive images on screen. Notice that each new frame replaces the children (objecs) of the axis instead of keeping it in memory. A video long of full-screen images is just too volumineous to be kept in memory on most systems. Of course, it is straightforward to change these settings in mf_analuze.

4 Test series 1: From rain to canal, only freshwater

In test Series 1, using the 65x65x2 cm model, water was rained on top of the sand mass over a width of 45 cm at a rate of 4.2 L/h. The location where the rain was applied could be deduced from that of the screws on the photo. The rain was distributed through 18 holes. After the flow was constant, Indian ink was added from the top of the model at two times. This clearly demonstrated the flow path. Using the flow rate and the times of the observations, i.e. the photos taken, it was possible to estinate porosity at about 38%, once the conductivty was determined by calibration using the water level in the right canal that served as an observation well.

5 Test series 2: Freshwater flow between two canals

In test Series2, the same model was used and only fresh water. The water now enters the model from the canal at the right hand side and leaves through the canal at the left hand side. The heads are fixed using the one measered from the photo and the gradient specified by Pennink. The real heads are therefore approximate. During the simulation Pennink doses some drops of Indian ink at different depths so that different flow paths can be observed. This not only allow measuring the velocity of the fronts by comparing subsequent photos, it also allows estimating coarsly the dispersion from comparing the photos with the spread of the mass computed by the model with different dispersivities.

6 Series3: From rain to canal, freshwater flow with interace

In test Series 3 Pennink introduces density differences by allowing milk to enter from the bottom until a layer of 13 cm thickness has formed at the bottom of the model below the fresh water. Then rain is supplied in the same way as was done in Series1, while the water discharge through the canal at the left of the model. It is observed that the interface inclines. After some time, the milk injection is stopped, so that the volume of milk gradually deminishes by the outflow from the canal. However, even after a day of flow not all milk has been flushed out as the lower the volume of milk in the model, the lowe the interface is and the less milk will be entrained and discharged through the exit.

7 Test series 4: V-shaped water table with interface

In this test Pennink uses a new physical sand-box model, 2 cm thick, 97 cm wide and 96 cm high. This model allows him to better study upconing by extracting water from the center. In series 4, the top of the sand mass is V-shaped with the lowest piont in the center of the model. Extraction takes place by an outlet just at the lowest point of the sand surface in the center of the model. The water is added at the sides. It enters the sand from the top and also flows over it, so that the water table equals the top surface of the sand. This way the head gradient of the water is fixed to the inclination of the top of the sand determined by its V-shape, which is 1:16 according to Pennink. He mentions that the flow is 28 L/h, however, given the possibility that the water flows over the top of the model in a thin film makes that the mentioned flow needs not equal the flow through the sand mass. Of course, the actual flow can be estimated by the water budget computed by the model using the calibrated conductivity of 860 m/d.

The model is initiated using a water table above the sand mass, which is, therefore horizontal, and allowing milk to enter through the bottom of the model at the right-hand side. The level of the milk is determined by its head in the milk reservoir visible on the photo to the right of the model and the water level in the model. Once the milk is in place and forming a horizontal interface with the overlying water 25 cm above the bottom of the mdel, the experiment starts at 15:00h by draining the water from the center of the V. This causes a nice, stable, 20 cm high, cone of milk in the center of the model as was photographed the next morning at 11:00h..

8 Test series 5: Upconing below a central canal with ambient flow

The flow through this model of Series4 is entirely determined by the shape of the surface. It is therefore not suitable to simulate a set of varying circumstances. To gain more flexibility and to speed up the tests, Pennink changed his model by adding a "canal" in the center and at both sides. This allowed creation of different gradients and also to install an ambient groundwater flow undernearth the central canal by using a head difference between the two side canals.

At 11:00h, after having initialized a milk-freshwater interface at about 23 cm above the bottom of the model, using a water table above the sand mass, he established a gradient of 1:5 between the side canals and the central canal, which caused a clear and almost needle-sharp cone right below the central canal within 30 minutes as visible on the photo taken at 11:30h. At this moment there is milk entrained in the outflow of the central canal. It is striking how sharp the interface between the milk and the water show on the photo.

From 11:40h colored water enters the model, so that the photo taken at

12:00h reveals the water table between the side and central canals. From the photo I measure 1:6.5 at the left side and 1:4.2 at the right side, but it is difficult to see, so that it agrees with the 1:5 mentioned by Pennink. Also, the ink-colored water table seems about 1 cm higher than the level in the recharging canal on the righ-hand side, which may thus be regarded the capillary fringe of this model.

After 12:10h the level in the right canal was slowly lowered and at the same time that in the left canal raised until the difference was 8 cm. The photo taken at 13:30h shows a sharp bended cone to the right of the central canal pointing to the lower right hand side of the central extraction canal.

From 13:30h the right canal level was lowered and the left canal level simultaneously raised until the difference was 7 cm. The phot taken at 14:10h, 40 minutes later, already shows that the cone has now moved to the left side of the central canal be it, that it is not completly as sharp as the first one. This may be due to the limited time (40 minutes instead of 80 minutes) allowed for the sharp cone to establish itself in a stable position necessary for the needle sharp cone to become clearly visible.

The experiment finishes by settting the side canals again to the same level but with reduced graident of 1:10 with the that of the central canal, which is half the gradient applied in the previous tests of this series. This causes a cone of reduced height with no sharp needle of milk visible. In this last test the water was colored by black ink. This makes the applied gradient visible. On the photo, taken at 15:55h, 30 minutes after coloring started, the colored water has not yet reached the water zone just above the milk, which is just a matter of different travel times of the water in the model. The coloring allows measuring the water table gradient, it is 1:12.5 on both sides of the central canal, but once more difficult to see on the photo. The distribution of ink could actually be simulated with the numerical model. This is confirmed by the last photo, taken at 16:20h, showing that all water is black while a sharp peak of the cone has become visible once more,

It should be noted that in all these tests, milk may flow into and out of the model depending on the head in the model and in the reservoir. This differnce thus determines the total volume of milk in the model during the tests. Therefore, the milk head at the entry point is that of the resrvoir and is an important boundary condition for the numerical simulation. Because Pennink does not detail the milk reservoir elevation, it has to be deduced from the photos and may be iteratively adjusted during trial simulations in order to match the total volume of milk in the model during the differnt tests.

9 Test series 6: Upconing below a well with ambient flow

Series 6 differs from series 5, that instead of a central canal to extract the water, Pennink replace the central canal by a tube well in the center of the model. The tube well has a gauze strainer according to the text, but no details are given, nor about its diameter. It is assumed therefore, that this tube well is a fully screened well between the bottom of the previous canal and the lower end of the well.

The experiment series starts with the well pipe end at 16 cm above the initial milk-water interface, which is 22+16=38 cm above the bottom of the model. The photo taken at 15:00h shows a cone reaching to ... It is not sure that the model would whos the sharp top of the cone given that the well is a cilinder inside the sand mass, which does not hit the glas panels, i.e. near the well, the flow is 3D and not completely visible. But the top of the inerace on the phote does indeed correspond with the elevation of the bottom of the well (point J). The extraction is 60 L/h and the water table gradient 1:9 as measured by the water levels in the canals. (Notice that the center canal does not extract water in these test series).

At 15:00h the well is pulled upward until its bottom is 32 cm above the original interface, i.e. at 22+32=52 cm above the bottom of the model. It is assumed that by virtue of the coarse sand and the extraction the hole that was created below the well due to the pull-up has collapsed, otherwise, the effective depth of the well would have been lower than 52 cm above the bottom of the model. A couple of mm difference, in the order of the radius of the well is still likely to have maintained. The visible cone on the photo taken 1t 15:45 is indeed one or 2 cm lower than the well bottom. as indicated by point F. A water table gradient of 1:4.5 was then installed.

The next step was to raise the left canal water level and to lower the right one until the difference was 6 cm. The photo taken at 15:50h shows the sharp cone pointing at the well from the right.

The side canal water levels were then made equal again and the extraction was 30 L/h. Colored was was added at 16:00h, so that the photo taken at 16:15 reveals the water table. It is no longer a more or less straight line. The central canal is dry. A sharp drawdown is visible in the immediate vicinity of the well. It is not clear how to interpret this.

At 16:20h the recharge from the left canal was stopped. This causes the salt water flow below and around the well and to enter it above its bottom indicated by point F on the photo. The milk creeps slowly up the left wall of the model, which takes time because this is a stagnation zone. Therefore, the photo taken at 18:00h, does show the cone entering the well from the side, but was still too early for the equlibrium to have formed below the left canal.

Flow model did someimes not converge. This happened which specific values of the milk reservoir. This was solved by running the first minutes with the connection with the milk reservoir closed and open it only thereafter.

10 Test series 7: Experimenting with glass tubes

Series 7 experiments with glass tubes with freshwater at their top and milk at their bottom to show true Badon-Ghijben-Herzberg equilibrium without distortion by groundwater flow. These are more or less trivial. The cone obtained was not that smooth due to inaccuarcies of the elevation of the top of the tubes, which are mutiplied by a factor 30-40 due to the density difference between freshwater and milk (density 1029 kg/m3).

11 Test series 8: Upconing below canal and heads near the interface

Series 8 repeats Series 6, but with piezometers installed to measure the head just above the interface as well as near the water table. These tests do not reveal new insights, but the measured heads at so many positions allows for a good calibration of the sand.

12 Test series 9: Floating freshwater lens below dunes, upconing dynamics

Series 9, the last series, demonstrates the floating freshwater lens on saltwater. No milk is used this time. In this series a much finer sand is used, which causes the top of the model to completely fill due to capillary rise. Given the spread of the colored water in it, the water is now saturated upto ground surface. Nevertheless, the flow and the interface position can be demonstrated.

The model was first filled with saltwater. The head of which was 40 mm below the outlets at both sided of the model. Then infiltration of colored freshwater started in the center so that a freshwater lens would form with the outlets capturing the overflow as fixed head boundaries on both sides of the model. After the floating lens had estblished, freshwater was extracted through a small tube halfway the center of the model and the left side. The upconing that it caused is clearly visible on the photo. After stopping the extraction, the interface readjusted to its former equilibrium overnight. The extraction was the repeated once more to show the dynamics of the interface due to varying extraction. The ambient groundwater flow near the well causes the curved shape of the cone with the water approaches the bottom of the extraction tube from the side. Because the extraction tube is a tube and not a screened well, the water could only enter through its open lower end.

The capilary fringe reached the top of the sand mass in this experiment. This conclusion is based on the fact that the injected colored freshwater after some time filled the entire model above the interface. Hence the freshwater is clearly flowing in the negative-head zone and, therefore must have been essentially saturated. Even though the water table reaches ground surface this does not mean that the head of the water equals ground surace. The air pressure on top of the water table is uniform, but the head just below the surface is not, due to the capilarity. The curved interface between the water and the pores at ground surface adjust to the pressure difference caused by the flow of water through the sand. The pressure head difference can be as large as the potential thickness of the capillary fringe, i.e. the air-entry pressure of the applied sand, before the sand becomes unsaturated.

13 Opmerkingem

Pennink is vanaf 1889 bezig geweest met grondwater. Dat is vermoedelijk het waar dat hij in dienst trad bij de "Duinwatermaatschappij", zie opm aan het begin van Penink, 1905.

Pennink (2003) p203: Ider, die zich tehoretisch of praktisch onledig houdt met grondwaterbeweging, heeft zich ook, ten minste in hoofdzaak, vertrouwd gemaakt met het boek van Lueger: "Die Wasserversorgung der Städte". In dit standaard-werk worden de verschillende vraagstukken, die zich bij de grondwaterbeweging voordoen, met groote duidelijkheid mathematisch behandeld. Op bladzijde 465 worden eenige algemeene beshouwingen gegeven over de grondwaterbeweging bij open kanalen, en daarop volgt, bldz. 466, een bewijs, dat de grondwaterbeweging beneden het kanaalbodemvlak in het algemeen is te verwaarloozen voor praktische doeleinden ... .

(Dit verklaart natuurlijk ook waarom men in de jaren negentig van de negntiende eeuw en daarna nog zoveel heil zag in het veder verdiepen van de winkanalen (Advies Theo Stang aan Burgemeester en Wethouders van Amsterdam). "De Ingenieur 1896, Nr. 52, Pennink".

Pennink (1903, p209) "Reeds bestonden er plannen om het hele kanalenneet door draineerleidingen te vervangen. In 1895 werd een totaal verval gemeten van 5.32 m, en in November kwam men tot de ontdekking van en aangroeiing van goote hoeveelheden lepthrix ochracea, een bekende ijderbacterie. Buizen bleken gebroken, na 6 of 7 jaren de druk te hebben weerstaan. Een van de veronderstellingen is dat schelpen als ondersteunende omstorting een slechte keuze zijn bij te grote druk.

"Dat doende werd aangenomen, dat de waterbeweging overeenkomstig de algemeen geldende veronderstelling begrensd moest wezen tot op of even onder het horizontale vlak, gaande door den kanaalbodem." ... en zo bleef mijn niets anders over dan te komen tot de veronderstelling , dat het profiel van de doorstroming ... niet begrensd kon wezen door het vlak ... maar dat het profiel ... ter plaatse mijner beschouwingen 2 of 3 maal grooter moest zijn. Dan evenwel was de ganbare meening omtrent de grondwaterbeweging onhoudbaar, en dit aan te nemen was een al te groote ketterij ! Verbeeld U, het water zou dan dichter bij het kanaal tegen de zwaartekracht in moeten stroomen ! Dit conflict heeft jaren geduurd.

Pennink 1905, p484, spreekt bij zijn sand-box modellen over "een kleine werkelijkheid, die voor elk bijzonder geval slechts met deduld en voorzichtig overleg in de groote werkelijkheid mag worden gesubsitueerd." De eerste serie proeven stammen uit Mei 1904 en dienden de "Bepaling van het lgemeen karaketr der stroombanden bij eenzijdige plaatsing van het verzamel- of afvoerkanaal, ten opzichte van den watertoevoer.

Pennink (1905, p492) Hebben deze uitkomsten uwe belangstelling kunnen opwekken, dan meen ik nog te moeten vermelden, dat alle proeven, waarvoor heel at geduld, nauwgezethi en leifde voor de zaak noodig waren, zin genomen door onzen hoofdopzichter, den heer B.J. Melcher, daartoe bijgestaan door G. Hoogeboom, die ook alle foto's heeft gemaakt. De noodige toestellen hebben zij zelf vervaardigd en geleidelijk verbeterd. Verder kan het U reeds zijn gebleken, dat ik, voor wat mijn werk betreft, krachtig ben geholpen doormijn hydrologische rechterhand, den ingenieur G.J. Hoogesteger.

References

[1] Drabbe, J. & Badon Ghijben, W., 1889. Nota in verband met de voorgenomen putboring nabij Amsterdam. Tijdschrift Konink- lijk Instituut van Ingenieurs, Verhandelingen 1888/1889: 8– 22.

[2] Herzberg, B. (1901) Die Wasserversorgung einiger Nordseebäder. Journal für Gasbeleuchtung und Wasserversorgung. V44, Nr. 44, 2Nov1901, 815-819.

[3] Lueger, O. (1890) Die Wasserversorgung der Städte. 2 Bände (2 Volumes)

[4] Pennink JMK (1915) Grondwaterstroombanen. Stadsdrukkerij Amsterdam, 150p. See http://www.citg.tudelft.nl/live/pagina.jsp?id=68e12562-a4d2-489a-b82e-deca5dd32c42&lang=en

[5] Pennink, JMK (1907) Über die Bewegung von Grundwasser. Zeischrift des Österreichischen Ingenieurs und Architekten-Vereins Nr. 28, 506-510

[6] Pennink, JMK (1905) Over de beweging van grondwater. Voodracht gehouden in de Vergadering van het Koninklijk Instituut van Ingenieurs van 13 Juni 1905. De Ingenieurs Nr. 30, 482-492. (In which he shows the results of his modeling experiments).

[7] Pennink JMK (1904) Prise d'eau der Amsterdamsche Duinwaterleiding. Voordracht gehouden in de vergadering van het Koninklijk Instituut van Ingenieurs van 9 Februari 1904. De Ingenieur, Nr. 12. (In which he announces is modeling experiments)

[8] Pennink JMK (1903) Prise d'eau der Amsterdamsche Duinwaterleiding. Voordracht gehouden in de vergadering van het Koninklijk Instituut van Ingenieurs op 10 November 1903. De Ingenieur, Nr. 13 213-223

[9] Pennink JMK (1896) De Ingenieur, Nr. 52.

[10] De Vries, J.J., 1982. Anderhalve eeuw hydrologisch onderzoek in Nederland (1830-1980). Rodopi (Amsterdam): 195 pp.

[11] De Vries, J.J., 2004. From speculation to science: The founding of groundwater hydrology in the Netherlands. In: Touret, J.L.R. & Visser, R.P.W. (eds): Dutch pioneers of the earth sciences. Koninklijke Nederlandse Akademie van Wetenschappen (Am- sterdam): 139–164.