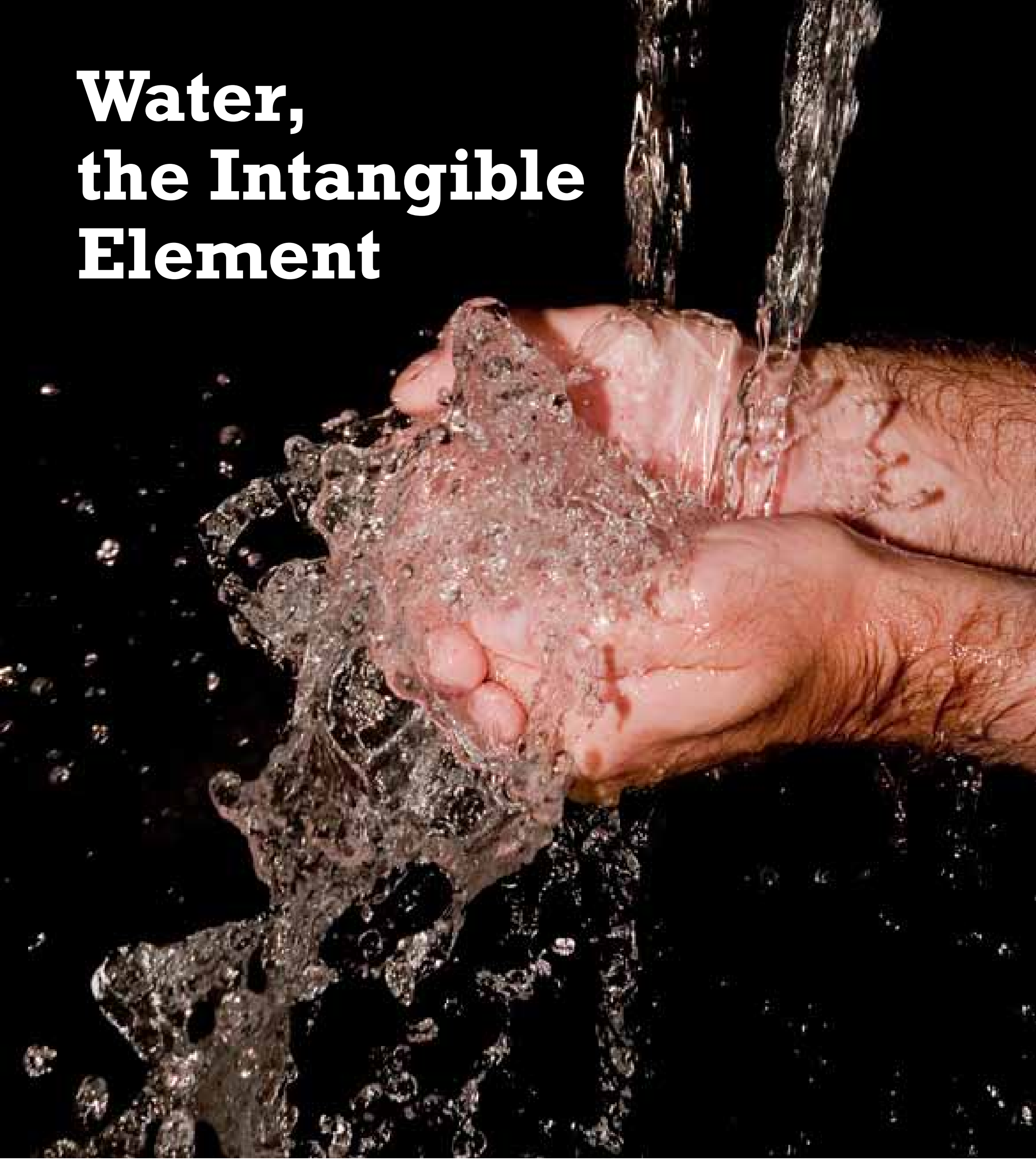
Water, the Intangible Element



Sultan Qaboos Academic Chair

Inaugural Lecture Prof. Dr. Ruud Schotting

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Water, the intangible element

Your Highness, Your Excellencies, Mijnheer de Rector, Ladies and Gentlemen,

How on earth can somebody devote his full working life to a substance that has no smell, no taste, no color and is intangible? Now what is intangible? I'll show you! [*Empties a glass of water with one hand and tries to grab the falling water with the other hand*]. It is also intangible in a scientific context. So in the coming forty five minutes I am going to talk about water. I hope to share with you my scientific enthusiasm for this intangible element.

In the late seventies I studied applied physics and graduated on a laser physics project. By coincidence, in 1980, I got my first temporary job and it had something to do with water. Actually the job was related to the design and construction of the Oosterschelde storm surge barrier, i.e. in the context of the so-called Delta Plan. That was the first occasion water became part of my professional interests. Since then twenty nine years have passed. Looking back I can come to only one conclusion: water is the leading element in my career. A 'blue line', connecting almost all my scientific and applied activities.

The Raft of the Medusa

In this speech I would like to guide you through the beautiful and highly interesting world of water science. Fortunately my world! In particular I would like to focus at water management in coastal regions. Coastal regions play a key role in fresh water production in many parts of the world. One might state that coastal regions are of vital importance to drinking water supply. Most people have been to coastal areas as a child, and quite probably have good memories of the two most striking substances present: water and sand. Everybody who has tasted the water in the sea knows that there is one more substance prominently present: salt. Remember the disgusting taste when swallowing a small amount of seawater? Sand and water do not only provide fun but are also basic ingredients of water management and hydro(geo)logical science in coastal regions.

Water, sand and salt

Water can be a source of life but also a deadly enemy. This paradox comes to life in the horrific over-life-size painting 'The Raft of the Medusa' (1818) by the French romantic painter Théodore Géricault. It depicts a moment from the aftermath of the wreck of the French naval frigate Méduse, which ran aground off the coast of today's Mauritania on July 5, 1816. At least 147 people were set adrift on a hurriedly constructed raft. Next morning, when the sun came up they were extremely happy to be still alive, but when they looked around the only thing they could see was water. Water everywhere, but no drop to drink… All but 15 of them died in the 13 days before their rescue and those who survived endured starvation, dehydration, cannibalism, and madness. All due to the tiny amount of dissolved salts in seawater.

If you look at water facts then it is immediately clear that almost all water on earth is in the oceans, i.e. approximately ninety seven percent of which zero percent is fresh water. Approximately two percent of all water is in ice and snow, containing almost seventy percent of all fresh water on earth. Groundwater is extremely important for drinking water production. However, less than one percent of all water available on earth is fresh groundwater, to be more precise: approximately 0.76 %. So it is quite remarkable that mankind has to rely on a water resource that is relatively scarce.

Three ingredients are essential in water management in coastal regions: without any doubt water, sand, but also salt. Salt is of vital importance for the human body. The body does not produce salt and almost all life processes are impossible without salt(s). Human blood consists of 0.9 % of salt. Seawater contains approximately 3.5 % of salt. Seawater is classified as highly saline.

At the Medusa raft, the first thing they did to survive was to drink seawater. This was an extremely bad idea. Apart from the disgusting taste of course! Cells in the human body start to dehydrate as a result of chemical osmosis, leading to seizures, and in the end the kidneys will give up because they cannot deal with high amounts of salt. Eventually this leads to a certain death.

Twenty percent of the world population face serious shortness of water. This number is still increasing and most alarming. Over three billion people worldwide suffer of water related diseases. These people have in general more than enough fresh drinking water, but still they get sick of the bad water quality. A striking example is Bangladesh. Before the seventies Bangladesh relied on fresh surface water resources. However this surface water was highly contaminated, in particular by hazardous biological substances causing a variety of life threatening diseases. After the seventies, Bangladesh started to explore and produce the shallow fresh groundwater, which was widely available all over the country. Unfortunately, after a few decades it became clear that although the shallow groundwater was assumed to be potable, it contained high concentrations of naturally occurring arsenic causing the arsenic disease. Nobody expected the groundwater to contain high arsenic concentrations, which has led to one of the worst environmental disasters in the history of mankind.

Water has many metaphors. One of the most popular metaphors is 'Blue Gold'. If you google Blue Gold you'll get 105 million hits! In my opinion this is an extremely bad metaphor. First of all water is not blue, but transparent. Secondly a human being can live its entire life without any gold at all. But three days without any water is definitely lethal. In my opinion a much better metaphor for water comes from Sultan Qaboos of Oman. He stated that water is a 'Natural Wealth'.

Two third of all Dutch drinking water finds its origin in groundwater. Groundwater is relatively easy to produce, it has a very good quality and needs only moderate purification before it can be distributed as drinking water. Only iron and chalk have to be removed. Groundwater can be produced from deep aquifers (> 100 meters). In general this is 'old' water and therefore vulnerable to exhaustion due to slow recharge. Shallow unconfined aquifers, as present in coastal aquifers, are more suitable for sustainable drinking water production. This is due to the more or less continuous recharge of the aquifers. One of the big disadvantages of fresh water production in shallow coastal aquifers is seawater intrusion.

Most coastal aquifers consist of sand, i.e. loose granular unconsolidated sediments. Between the solid grains a connected pore space exists that allows groundwater to accumulate and also to flow. In this water-saturated pore space all kinds of interesting processes can occur that need to be taken into account when attempting to model the flow of fresh and saltwater in coastal regions. These processes range from physical processes like fluid flow and mixing, to (geo)chemical and even (micro) biological processes. In particular I would like to confine myself to the physical processes as they play a key role in management of fresh water resources in coastal areas. The typical distribution of fresh and salt(sea) water is depicted in Figure 1a. Due to the fact that seawater is heavier as compared to freshwater it has the tendency to intrude land inward. In particular in the Netherlands, rain (recharge) replenishes the fresh groundwater and some fresh water discharges to sea such that a more or less stationary situation occurs. The mixing zone between fresh and salt water does not move in that situation. The freshwater body is a potential source for drinking water production, leading to installment of shallow water supply wells. This does not only result in fresh potable water production, but also in the land-inward advancement of the mixing zone between the fresh and saltwater, and

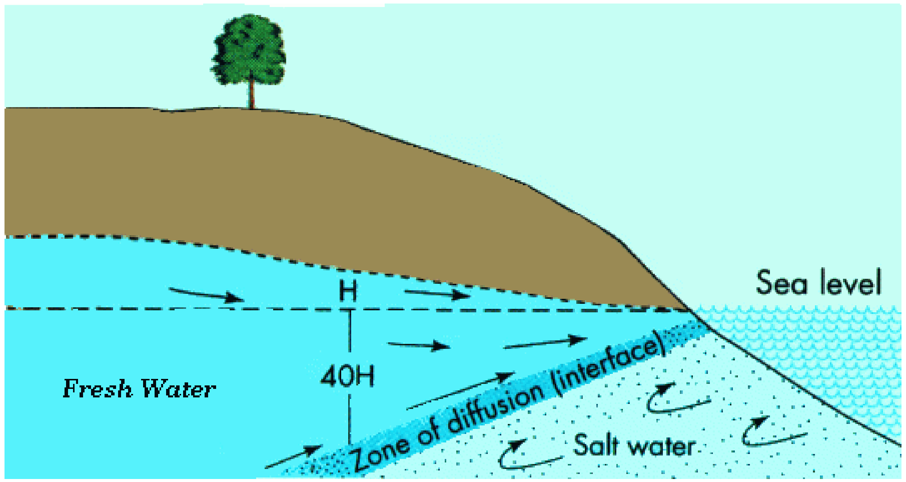


Figure 1a

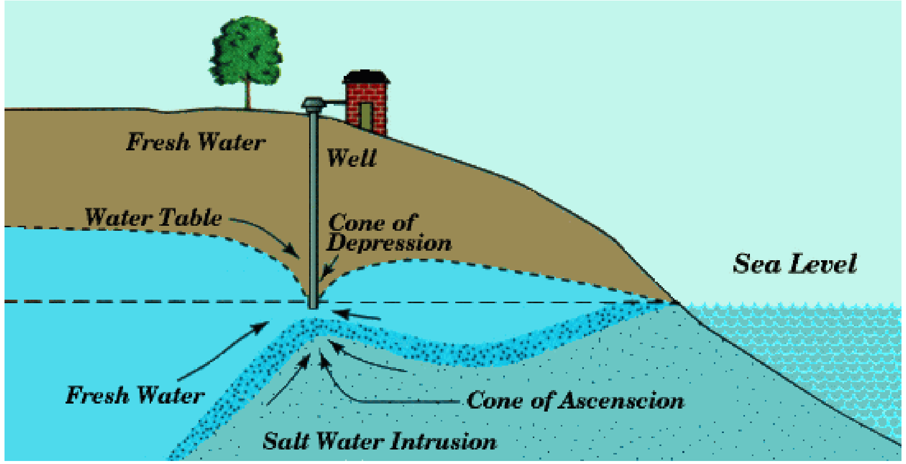


Figure 1b

moreover, to upconing of this mixing zone towards the filter screen of the water supply wells. See Figure 1b. The recharge due to rain is crucial. Without recharge, one would simply 'mine' the fresh water, eventually leading to inevitable salinization of water supply wells. This implies that sustainable fresh water production in coastal zones relies on quantitative water management and optimization such that seawater intrusion can be marginalized or completely avoided. To this end we need physically based mathematical models to predict the behavior of such a system.

Our scientific insight in the relevance of fresh water bodies goes back to 1888, when W. Badon-Ghijben, and later independently in 1901 A. Herzberg, showed that for every meter elevation of the groundwater table with respect to sea level, almost forty meters of fresh water body is present. They derived their equation based on a simple stationary hydrostatic pressure equilibrium at the interface between freshwater and seawater.

If we want to predict the movement, i.e. the dynamics, of a fresh-saltwater interface we need to include the relevant underlying physical processes. The first step in modeling is always to translate the physics – and/or (geo)chemistry and (micro)biology – into mathematical equations. One of the most important processes in flow and transport of salt in groundwater is advection. The dissolved salt is simply dragged along by the flow. But how do we model flow of groundwater? Actually, the French engineer Henry Darcy came up with the definitive answer in 1856 when he studied flow through a water-saturated

sand column. He did this work in the context of designing waterworks for the city of Dijon and resulted in what we now call Darcy's Law[1] for groundwater flow. Another process is molecular diffusion which is the result of local concentration differences and the so-called chaotic Brownian[2] or thermal motion of molecules and ions in the fluid phase. Therefore, molecular diffusion is typically a mixing process, which occurs in the pore-space of the coastal aquifers. However, in most cases even more important is mixing of fresh and salt water due to mechanical dispersion. Mechanical dispersion is macroscopic mixing of miscible fluids due to local fluid velocity variations, which are in turn the result of local permeability variations in a porous medium. The famous Dutch researcher Professor Gerard de Josselin de Jong[3], was one of the scientists to fully understand the nature of mechanical dispersion in porous media as a highly relevant mixing process. His research with respect to dispersion started in the late fifties and he is still considered one of the greatest pioneers of this hydrogeological subject. One more physically relevant process has to be added in order to create a mathematical model for the movement of a fresh-saltwater interface: the action of gravity forces due to density differences between fresh and salt water. As a result of the dissolved salts in seawater, a cubic meter of seawater weighs more than a cubic meter of fresh water. The relative density difference is approximately 0.025 (= 1/40). Due to gravitational forces, fresh water has the tendency to move upward and salt water to move downward, in general resulting in a rotational motion of the mixing zone, i.e. the interface, between fresh and saltwater. So the elements for the model are: advection, molecular diffusion, mechanical dispersion and flow due to density differences. Quite simple processes, but if we add this all in a mathematical model we end up with a coupled system of nonlinear partial differential

1. Darcy's Law states that the specific discharge through a porous medium is proportional with the hydraulic gradient and a proportionality factor, known as the hydraulic conductivity. Note that Ohm's Law is an electrical analogon of Darcy's Law.
2. Note that Robert Brown was a botanist, not a physicist. In 1827, while examining pollen grains and the spores of mosses and Equisetum suspended in water under a microscope, Brown observed minute particles within vacuoles in the pollen grains executing a continuous jittery motion. He then observed the same motion in particles of dust, enabling him to rule out the hypothesis that the effect was due to pollen being alive. Although Brown did not provide a theory to explain the motion, and Jan Ingenhousz already had reported a similar effect using charcoal particles, in German and French publications of 1784 and 1785,[9] the phenomenon is now known as Brownian motion. In his 1905 paper, Albert Einstein was the first scientist to suggest a physical theory for the experimentally observed Brownian motion.
3. Note that Gerard de Josselin de Jong was Professor of Soil Mechanics at Delft University of Technology, and not a hydrogeologist.

equations. In general: this is where the real trouble begins! How to solve these equations to provide us with reliable predictions of the movement of a fresh-salt interface under freshwater pumping conditions? Without any doubt we need boundary and initial conditions to solve the equations. These conditions relate e.g. to the geometry of the coastal region and to the initial state of the system. In most cases, if we are interested in the dynamics of a fresh-salt interface, we have to rely on (powerful) computers to solve the equations numerically. In particular when we are interested in solutions in the three-dimensional space. This is one of the approaches. Let me give you an example of a realistic numerical experiment to understand the impact of fresh water production in a coastal aquifer. The simulation starts with a stationary fresh-salt interface. At t=0 the well starts pumping resulting in seawater intrusion and upcoming, as to be expected. The upcoming is so severe that after 10 years of pumping, the well is saline, i.e. the saltwater front has reached the well screen. After this period of 10 years we shut down the pumping well and observe what happens to the fresh-salt interface. It takes more than 50 years for the interface to return to its initial position! I think this is a nice example of the numerical prediction of how a hydrogeological system reacts to human activities.

The beauty of mathematics

It is also possible to analyze the governing equations mathematically. Mathematics is extremely important in understanding the nature and behavior of physical and hydrogeological problems. And actually there is a real beauty in mathematical analysis. I'll try to convince you of the beauty of mathematical analysis by giving two examples. The first example dates back to 1980 when, again (!) Gerard de Josselin de Jong published a paper related to the movement of a fresh-saltwater interface in an infinitely extended horizontal confined aquifer. Assuming that the flow of fresh and salt water is essentially horizontal (the so-called Dupuit approximation) he was able to derive a single equation that describes the motion of a fresh-salt interface. Mathematically, his equation can be classified as a 'nonlinear degenerated partial differential equation'…! For most people a real nightmare! But not for mathematicians! They simply love to analyze this type of equations. One of the interesting things they found is that this equation has an extremely simple closed-form analytical solution: a rotating straight line! Actually this solution is a so-called similarity solution. Similarity solutions are important to get insight in the large-time behavior of the solution of a partial differential equation: whatever initial interface shape is considered, the large-time solution will always converge towards the similarity solution, i.e. in this case a rotating straight line. Beautiful!

How beautiful, even how emotional, mathematics and mathematical discoveries can be is probably best illustrated in the BBC documentary about the proof of one of the most famous 'open' problems in mathematics: Fermat's Last Theorem[4]. Around 1637, Fermat wrote his Last Theorem in the margin of his copy of the Arithmetica next to Diophantus' sum-of-squares problem: ''It is impossible to separate a cube into two cubes, or a fourth power into two fourth powers, or in general, any power higher than the second into two like powers. I have discovered a truly marvelous proof of this, which this margin is too narrow to contain''. In 1995, after struggling almost solitary for more than ten years, the Brittish mathematician Andrew Wiles came up with an extremely complex but correct proof of Fermat's last theorem.

Wiles explains his mathematical adventures as follows in the BBC documentary:
''Perhaps I could best describe my experience in doing mathematics in terms of entering a dark mansion. Because, when one goes into the first room and it's dark, completely dark, one stumbles around bumping into the furniture. Gradually you learn where each piece of furniture is, and finally after six months or so you find the light switch, you turn it on, and suddenly it's all illuminated and you can see exactly where you were. Then you move into the next room and spend another six months in the dark. So each of these breakthroughs, while sometimes they're momentary, sometimes over a period of a day or two, they are the culmination of, and couldn't exist without, the many months of stumbling around in the dark that precede them. At the beginning of September I was sitting here at this desk when suddenly, totally unexpected, I had this incredible revelation. It was the most important moment of my working life. Nothing I ever do again will… I'm sorry….''. Wiles could not control his emotions any more and started crying…

In my opinion Wiles points out what scientific research is all about. Struggling hard for a (very!) long time in the dark, and all of a sudden you switch the light on and understand what it is all about.

I was fortunate to have such an experience. Of course, not with the

4. **Fermat's Last Theorem** states that no three positive integers a, b, and c can satisfy the equation $a^n + b^n = c^n$ for any integer value of n greater than two.

tremendous impact of the discovery of Andrew Wiles but more moderate. I was on a train to Stuttgart visiting Professor Rainer Helmig, and I learned from a paper of Professor Peter Grathwhol at Tubingen University that he conducted laboratory experiments to determine the length of contaminant plumes in the subsurface. Actually, from the environmental point of view, an important problem. He analyzed stationary contaminant plumes and came to a very odd conclusion. Although the flow of groundwater is (say) in the horizontal direction, and the length of the plume is also measured in the horizontal flow direction, the length is completely determined by the hydrogeological mixing processes perpendicular to this horizontal direction. Professor Grathwhol showed this experimentally, but it was absolutely not what most of the hydrogeological scientists expected to be realistic. This inspired me to write down the governing equations while traveling to Stuttgart by train. Note that this trip takes at least 4.5 hours, so plenty of time to study this problem. After a few hours I had this 'Aha-erlebnis'. I could mathematically prove that the experiments conducted by Professor Grathwhol were indeed correct. When back in Utrecht, together with one of my PhD students Phil Ham, we fine-tuned the proof and did in addition numerical computations. The mathematical analysis gave us insight in the rather odd and unexpected behavior of contaminant plumes in the subsurface. Moreover, the analysis yielded a simple 'engineering' formula to predict stationary plume lengths. The nice thing about this research was that it comprised a perfect mix of physical laboratory experiments, numerical computations and mathematical analysis.

Recharge in semi-arid coastal regions

The climate of the Netherlands is such that we have on average approximately 770 millimeter of rain per year. This is a perfect source for recharging the fresh water resources in the dune areas of The Netherlands. And if this is not enough, because the fresh drinking water demand exceeds the natural recharge, we artificially infiltrate fresh surface water from rivers and streams. A nice example in the Netherlands is the well-known infiltration area between the cities of Zandvoort and Noorwijkerhout, also known as the 'Amsterdamse Waterleidingduinen'. In this approximately 3400 hectares wide area, the natural recharge (rain) is not sufficient to replenish the freshwater resources below the dunes, due to the high demand of drinking water of the city of Amsterdam. That's why surface water from the river Rhine is used to artificially recharge this area. After pre-purification it is distributed over the area by kilometers long infiltration canals such that the Rhine water can infiltrate and replenish the freshwater body.

In a semi-arid coastal region the situation is completely different. Recharging the coastal freshwater aquifers is hardly possible due to the lack of (sufficient) rain. Nevertheless the freshwater in these aquifers is produced for e.g. agricultural purposes. So how can we recharge these freshwater bodies? The answer is quite simple: in the mountain areas close to the coast short but intensive rain events take place. The rainwater runs down the mountain slopes towards the sea, in general in so-called 'wadis'. Wadis are natural canals, which are the result of erosion processes due to flow of water. Most of the year these wadis are dry. After an intensive rain event in the mountains, they can be suddenly filled with water, resulting in so-called 'flash-floods'. Without any artificial measures, part of the water will evaporate due to the high atmospheric temperatures, and part of the water will end up in the sea. Only a small amount of water will infiltrate in the subsurface to recharge the freshwater bodies. A well-known method to increase the infiltration is to build recharge dams. These dams basically collect the mountain run-off, such that the freshwater gets time to infiltrate into the subsurface. An example of such a dam is the Hilti/Salahi Recharge Dam in Batineh Area in the Sultanate of Oman. This is one of the oldest and longest recharge dams in Oman. It can contain approximately 0.55 million cubic meter of water and has a length of a little more than 9 kilometers. This example shows that although the climatological conditions in wet-deltaic regions and in (semi) arid regions might be completely different, the solutions to replenishing fresh water resources in coastal zones are quite similar: artificial recharge.

Another issue that deltaic and semi arid regions have in common are flood disasters. Almost one third of the surface of the Netherlands is below sea level. The fact that Dutch people can live and work in these low parts of the Netherlands is due to the so-called 'polders' that have been created and maintained since the thirteenth century. A polder is a low-lying piece of land, which in general has been reclaimed from the sea (or from lakes) and is enclosed by man-made dikes. Traditionally, these polders are maintained by so-called 'Waterschappen' or 'Hoogheemraadschappen'[5-6]. The reclaimed land is drained by an ingenious system of canals and

[5] It is rather difficult to translate 'Waterschap' or 'Hoogheemraadschap' into the English language. 'Water Board' or 'Water Control Board' comes to mind, but this refers to a public organization also in charge of water supply, which is not the case in the Dutch context.
[6] Note that these Hoogheemraadschappen/Waterschappen were the first democratic organizations in the Netherlands.

pumping stations. Currently, more than twenty five percent of the Netherlands is below sea level.

Actually I live a few kilometers away from the lowest point of the Netherlands: - 6.76 meters below sea level, which is in Nieuwerkerk a/d IJssel[7]. Sometimes I bring foreign visitors to my house and I explain that we are having dinner almost 6 meters below sea level, and they ask me: ''Are you sure it is safe…?''.

Without any doubt, this polder system makes large parts of the country extra vulnerable to flooding. An infamous and dreadful example of a storm surge event is the 1953 North Sea flood, which happened in the night of 31 January – 1 February. A combination of springtide and heavy windstorms caused the water level to rise more than 5 meters above average sea level, causing over eighteen hundred casualties and approximately seventy thousand people had to be evacuated. Over thirty thousand animals drowned and the total damage to buildings and infrastructure added up to almost one billion Dutch guilders. The Dutch government took drastic measures to prevent future flooding of the country. Twenty days after the flood the so-called Delta Commission was inaugurated and in 1955 they formulated the final version of the Delta Plan. This plan comprised shortening of the Dutch coastal line by means of damming a series of sea arms with (semi-permeable) dams, as an alternative to increasing the height of more than one thousand kilometers of dikes. Since then, the Delta Plan has been successfully implemented: total cost almost one billion Euros and the plan is sometimes referred to as: ''The Eighth World Wonder''. Not only because of the enormous endeavor but also because of the ingenious water management insights underlying the plan.

In June 2007, the tropical cyclone Gonu caused floods in the Sultanate of Oman, in particular in the area surrounding the capital Muscat. Strong winds (> 175 km/hr) and waves up to ten meters high were reported. More than seventy people lost their lives and over twenty thousand people were affected by the storm. The total damage added up to approximately 4 billion US dollars, which makes it one of the biggest natural disasters in Oman since 1945. Oman's Ministry of Regional Municipalities and Water Resources has outlined plans to construct a network of dams to regulate floodwater rushing through wadis (dry river-beds) that crisscross the capital Muscat. Two sets of flood protection schemes are planned by the authorities with the aim of securing major commercial and residential areas of the capital from future flooding.

Once again, although the climate in the European deltas and the climate in the Gulf Region is extremely different, the hydrological and environmental problems are quite similar. The same holds for the solutions to these problems. We have a lot in common, implying that we can learn a lot from each other with respect to water management.

Oman is amongst the first countries in the world to face a serious decline of the oil production. Currently, in Oman almost all oil is produced using secondary (and tertiary) oil recovery techniques, which indicates that the oil reserves are decreasing rapidly. This is why His Majesty Sultan Qaboos has developed a strategy for economic diversification. The availability of fresh water is identified as one of the key issues in this strategy, not only for future agricultural and industrial developments, but also to increase the attractiveness of the country for international tourism.

Recently, in November 2008, I visited Sultan Qaboos University (SQU) in Muscat. One of the distinguished SQU professors asked me the question: ''What is THE solution to the freshwater problem in Oman?'' I replied that in my opinion there exists no single solution to the freshwater problem in Oman. The solution will be the sum of all kinds of small (but inventive!) solutions. This is quite similar to the situation with respect to the world-wide energy problem: The global usage of fossil fuels cannot be replaced by a single energy source, but will be the sum of all kinds of more or less sustainable solutions like solar energy, wind and water power, geothermal energy, aquifer thermal energy storage systems, etc. With respect to freshwater solutions, one could think of artificial recharge of domestic/industrial wastewater in coastal regions, optimization of recharge dams using flashflood infiltration wells, coupling of desalination plants with aquifer thermal energy storage systems, optimized irrigation techniques that could save up to 50% of the usual freshwater usage, and even, condensation of water vapor from the atmosphere to stimulate growth of trees in (semi-) arid regions and mountain areas[8]. And let's not forget

7. Close to the decoy (Dutch: eendenkooi) in the Zuidplaspolder near the Derde Tochtweg in in the municipality of Nieuwerkerk aan den IJssel.

8. A very nice example of a simple but effective invention is the Water Boxx by the Dutch inventor Pieter Hoff. The Water Boxx allows trees to grow under harsh desert and mountain conditions by providing them just sufficient water, and moreover, a protective environment that is needed to survive the first root-developing months. The box does not involve any mechanical or electrical parts and is based on extremely simple physical principles.

the ancient but highly valuable 'aflaj' systems that have been and still are supplying freshwater for domestic and agricultural use. The total amount of aflaj in Oman is estimated to be 11000 of which approximately 4000 are constantly flowing.

Without any doubt desalination of seawater and brackish/saline groundwater remains an important technique for the future of fresh drinking water production in semi-arid regions. The current techniques are rather energy consuming and therefore expensive. International scientific collaboration to improve desalination techniques is high on the research agenda of many Middle Eastern and North African counties, which is reflected in their joint initiative: the Middle East Desalination Research Center (MEDRC)[9].

Scientific challenges

In particular in semi-arid regions, it is of vital importance to combine freshwater production and renewable energy solutions. Both are in the equation. Let me give an example. Aquifer Thermal Enegry Storage (ATES) is a widely accepted technique to reduce the energy consumption of large buidings for cooling and heating purposes. This works fine under the climate conditions of e.g. Western Europe. During summer, cold groundwater is produced to cool a building. The heated groundwater is injected into the aquifer again at a different location. During winter, the process is reversed: warm water is now produced and used for heating purposes in the building. The cooled water is injected again into the aquifer, etc, etc. But can we also apply this technique under the climate conditions of e.g. Oman? Not really cold winters and extremely hot summers! This is where the challenge comes in: how can we modify ATES, such that it can be used in semi-arid regions? What do we have to modify? Can we combine ATES with desalination plants that operate on excess heat of power plants? ATES is just one example of a sustainable technique that might be applicable in semi-arid regions.

From the applied-scientific point of view I expect a lot from the new so-called SmartSoils developments as they take place at the Deltares[10] research institute in the Netherlands. In particular, SmartSoils intend to modify physical properties of the subsurface by using e.g. bacteria or super absorbing polymers. Unconsolidated lose granular sediments can be altered into geo-mechanically solid 'sandstone' and leaking subsurface water retaining constructions can be sealed by simply activating micro-bacterial activity. Many laboratory and field experiments have been successful and it is of vital importance to fully understand the underlying processes. Reliable practical (e.g. civil engineering) applications of these techniques are only possible when we gain more scientific insight in these physical, (geo)chemical and (micro)biological phenomena. Understanding, modeling and predicting these interactive, coupled and competitive processes is from my point of view a true scientific challenge!

Another development that is worth mentioning is the (renewed?) interest in geothermal energy in the Netherlands. Not only for heating purposes of e.g. greenhouses, but also for electricity production. Many of my students are now involved in this interesting and challenging research subject. Not only challenging from the Earth Sciences/ Hydrogeological point of view, but also challenging with respect to sustainable development and the reduction of CO2 emissions into the atmosphere.

What really intrigues me is the subject of density-dependent flow and transport in porous media. My interest in this subject goes back to the mid-eighties. The coupling between flow and gravity forces is complex and leads to rather intricate and beautiful mathematical problems. In particular the upscaling of density-dependent flow and transport processes in heterogeneous porous media is an exciting subject. The ultimate goal is to construct a physically based theory that is able to model/predict the movement of dispersive mixing fronts in heterogeneous porous media. Recent developments show that the so-called 'homogenization theory' can lead to such an upscaled density-dependent model. This homogenization theory involves the physics at the local (pore) scale as a starting-point, and provides, after applying the straightforward homogenization technique, equations/expressions

9. The mission of MEDRC is to contribute to the achievement of peace and stability in the Middle East and North Africa by promoting and supporting the use of desalination to satisfy the needs of the people of this region for available, affordable, clean fresh water for human use and economic development. This is done through the advancement of desalination technology, education in the technology and training in its use, technology transfer, technical assistance, and building cooperation between nations to form the joint projects and international relationships necessary to meet the needs for fresh water. The head quarter and joint research facility is based in Muscat.

10. DELTARES consists of the following (former) Dutch applied scientific research organizations with respect to (ground)water and the subsurface: WL | Delft Hydraulics, GeoDelft, TNO Business unit Subsurface and Groundwater, and a part of Rijkswaterstaat.

that are valid/applicable at a higher (averaged) scale. This is typically a subject where mathematicians and hydro-geologists have to join forces to achieve the desired scientific advancements.

Weapons of Math Destruction

As we all know, former US president George W. Bush went to look for 'weapons of mass destruction' in Iraq[11]. If you go to our Dutch high schools you'll find 'weapons of math destruction'.

I have the privilege to teach the first-year mathematics course to all geosciences students in our faculty and I must admit that I really love to do that. However, the first time I entered one of the exercise classes connected to that course something really weird and unexpected happened! I saw a girl apparently struggling with one of the exercises so I walked up to her.

From what she had written down I could determine that she almost found the answer to the exercise. What was remaining to solve was, and I can assure you, this is a true story (!):

$$X - 2 = 9$$

So I asked her, "What's the next step?" And she replied: "Wait a second" and she grabbed her bag, which was on the floor. What she pulled out of the bag was a so-called 'graphical calculator', a GC. She continued: "There must be a button for this! Somewhere there must be a button at this GC to solve this problem, but I cannot exactly remember which one it is!" I could not believe my eyes, neither my ears. I was flabbergasted! Then she asked me: "Do you know which buttons I have to press?" I replied: "I do not have a clue!" She said: "You do not know!!!?" Then she said: "Fortunately I brought the manual of the GC, so let's have a look! For certain, the answer will be in the manual". So once again she grabbed her bag. This time she pulled out the manual of the GC and started to flip desperately through the pages. And after a while she panicked and started to shed tears over her GC. "I do not know what to do now!" I tried to calm her down by explaining that the answer is actually fairly simple: just bring the minus two to the other side of the equal sign and add the now positive two to nine, which gives: $X = 11$.

[11] President Bush later said that the biggest regret of his presidency was "the intelligence failure" in Iraq, while the Senate Intelligence Committee found in 2008 that his administration "misrepresented the intelligence and the threat from Iraq".

How on earth is it possible that, in the Netherlands, somebody who has successfully passed a high school examination in mathematics does not know how to solve such an extremely simple problem without relying on a GC? This girl had a real diploma, stating that she passed the required mathematics exams to get access to BSc-courses in geosciences. The girl cannot help it. She is simply one of the many victims of the everlasting urge in the Netherlands to reorganize teaching methods in mathematics. How is it possible that in the Netherlands, the manual of an electronic device, such as the GC, has become part of the compulsory mathematics literature at high schools? Part of the math curriculum?!

Why is actual repetition almost gone in the 'new' type of arithmetic and mathematics educational systems at primary, secondary and high schools in the Netherlands? Why is it virtually impossible for students to solve two equations with two unknowns without a GC? Why is it so difficult to handle brackets? Why is it so hard to divide fractions? Handling square roots properly seems to be too hard nowadays. Why are the algebraic skills so poor? Why does more than half of my students not have a clue what a 'long-division' is? Unbelievable! How is it possible that in most high school mathematics books almost half of the exercises have a symbol in the margin, indicating: 'GC is necessary to solve this problem…' When I announce in my calculus class that it is not allowed to use the GC panic strikes. Students start to hyperventilate. What the hell is going on?!!!

The 'weapon of math destruction' waiting to be smashed with a hammer by Prof. Schotting

The first thing that should be done is to get rid of the graphical calculator at high schools! This machine does not add anything significant to the process of learning and understanding mathematics. They just blur the intrinsic nature and beauty of mathematics. We should protect our young generation against this harmful machine. Why not create a new national law declaring that young people under 18 years old are not allowed to posses or to use a GC? Or let's put warnings on the GC, similar to the warnings

graphical calculators can seriously damage your mathematical skills

we find nowadays at packages of cigarettes and cigars? The legal age for using and possessing graphical calculators should be 18 PLUS! Let's get a hammer and say goodbye to this true weapon of MATH DESTRUCTION: the Graphical Calculator!

Your local mathematician can help you stop using your graphical calculator

At our high schools we should teach the basics of mathematics (and of course physics!) by getting rid of all the blurring applications, by getting rid of the GC, and, by bringing back repetition and real insight in what it is all about. That will be a true revelation for the students.
I am really convinced that they will LOVE IT!

Hydrologists urgently needed/wanted

There is one more problem that I would like to share with you. Indeed: again a problem. It is a problem that has been on my mind already for many years. It has something to do with the number of academic water experts we produce in the Netherlands and the increasing amount of water-related jobs. Until the seventies, the 'market' for academic hydro(geo)logists was more or less constant. The emphasis was on water quantity and water management. Typical employers were water supply companies, the Dutch water boards, and of course water research institutes. In the early eighties the situation drastically changed due to the impact of the Lekkerkerk soil and groundwater pollution problem. Remediation and management of contaminated groundwater was all of a sudden one of the new subjects that hydrogeologists had to deal/cope with. A few years later, new techniques emerged to save energy: aquifer thermal energy storage systems. Typical issues that are connected to the 21st century are the various effects of global climate change, CO2 storage in abandoned oil and gas fields, storage of radioactive and highly toxic chemical waste in salt domes or clay cavities, exploration of geothermal energy for electricity production, ecological changes in view of civil engineering water management solutions, natural in situ attenuation of organic contaminants, SmartSoils, etc, etc. All these new water-related and environmental subjects lead to new job opportunities for hyro(geo) logists, i.e. on top of the traditional demand for this type of water experts/scientists. When I look at the enormous amount of requests I get in e-mails, by phone, in letters and during meetings from companies and research institutions to send my students for job interviews, internships and MSc/BSc research, I can only come to one conclusion: we are no longer able to educate enough young water academics/ experts to satisfy the needs of the job market. This is really alarming; in particular in view of the water management reputation we (still) have worldwide.

One of the problems is that we are not able to mobilize young people to get interested in the water business and science. When you are sixteen years old, and you live in Europe, water is definitely not a sexy subject. You open the tap: there it is! There seems to be no 'rocket science' connected to water. Why study something that is available everywhere and completely uninteresting? A substance that has no smell, has no color and has no taste! Come on!

So one of our big challenges is to attract more young people to study water-related issues in geosciences. This is not only beneficial for our Geosciences faculty, but in particular beneficial for society and last but not least for the students!

One of the initiatives to increase the interest of young people in geosciences is actually standing outside this building: the so-called 'GeoTruck'. You must have seen and/or even visited this truck when you entered the main entrance.
It consists of a mobile classroom where high school students can play a geosciences related game: Earth Quest. GeoTruck is an initiative of DELTARES, Utrecht University, Delft University of Technology, Wageningen University (WUR), Vrije Universiteit, Kadsters, and many more geosciences-related institutes. Ten thousands of high school students have already visited the GeoTruck and have played the Earth Quest game. Almost all students were very positive about their experiences, so hopefully this strengthens their interest in geosciences and in hydrology.

A second initiative that I think is worth mentioning is the fact that finally Hogeschool Zeeland (HZ) in Vlissingen and Roosevelt Academy (RA) in Middelburg started negotiations to realize the first BSc-program exclusively related to water management and hydro(geo)logy. This is unique, because such a BSc program still does not exist in the Netherlands. Isn't it remarkable that we are known worldwide for our water management knowledge and that we do not have a BSc-program on water? To give you an example: if a student wants to study hydro(geo) logy at the academic level, he or she first has to obtain a BSc-diploma in Earthsciences (VU and UU), a BSc-diploma in Civil Engineering (TU Delft), or a BSc-diploma in Subsurface, Water and Atmosphere (Wageningen University). HZ and RA are now joining forces to bridge this gap in the educational water landscape of the Netherlands. Not only at the academic BSc-level, which is characteristic for RA, but also at the applied sciences/ management BSc-level, which is characteristic for HZ. I foresee a unique collaboration between HZ and RA! Initially, they named it 'Water Academy', which I really loved. However, now they have changed it into 'Delta Academy', which is also a beautiful name. But ''what is in a name?'' It is all about content!

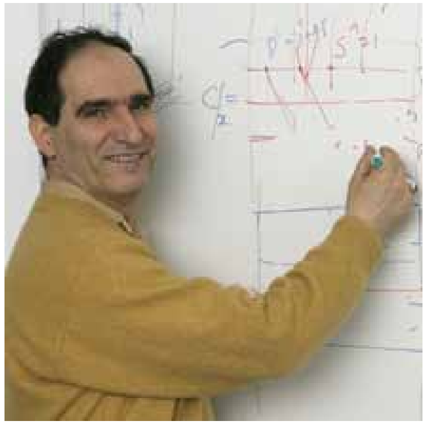
Who are in my equation?

It is obvious that I did not follow the normal path towards the place I am standing now. No way! I started studying applied physics at a Hogeschool (HTS Dordrecht) and graduated in laser physics, got a first job in water-related engineering subject (Oosterschelde stormvloedkering, GeoDelft), was able to get a PhD in applied groundwater-related mathematics (TU Delft), and became a hydro(geo) logist (TU Delft, and later at UU and Deltares/TNO).

Without any doubt, Professor Hans van Duijn has played an extremely important role in my life. The first time we met was at GeoDelft in the early eighties and this became the basis of a valuable and unique collaboration and friendship. He introduced me to his world of mathematics and to the analysis of flow problems. I am still very grateful that he did this! Hans, I am so happy that you are here today! Thanks!

Prof. Hans van Duijn

One of the most unconventional professors I know is my dear friend Professor Hans Bruining! Actually, I was introduced to Hans Bruining by Hans van Duijn somewhere in the mid eighties. Hans Bruining works at the Geo-Engineering Department of Delft University of Technology. We have a lot of joint scientific interests and we always have a lot of fun when being together. Hans is a unique scientist and a unique person.



Prof. Majid Hassanizadeh

The first day I walked into my new office in the Mathematics Department of Delft University of Technology, somebody was already sitting there at one of the desks. It was Professor Joost Hulshof. We became friends almost immediately. But at that time we did not have a clue what type of adventures the future had in store for us!

And there is somebody that is more or less central in my equation! For many years, up to this very day, Professor Majid Hassanizadeh is my deeply respected colleague and friend. We share ideas, dreams, visions, and interesting science. We have made small steps, big steps, in all kinds of almost random directions, but when we integrate all the steps in a proper mathamatical way, we always have the tendency to go 'forward'. So let's continue to share this adventure together. I still love it! I am very grateful to you Majid!

Of course it is virtually impossible to thank everybody who has contributed to my professional and personal life. I am extremely happy and thankful that both my parents are here today to witness this special event. I would like to mention Margreet Evertman, our secretary, who is one of the few people that is able to create some structure in my chaotic life!

And I would like to thank Mr. Rio Praaning and everybody at PA International for the confidence and

Mrs. Kitty Schotting

support they have given me. Rio was the 'driving force' behind the creation of the Sultan Qaboos Chair for Quantitative Water Management. Rio, thank you very much for all your efforts and ideas!

Living together with a scientist, and in particular with me, is not always as easy as it seems! Let me introduce three real experts on this matter who are present here today: My beautiful wife Kitty, our daughter Sanne and son David.

And I almost forgot something: the students! For me, the nice thing of working in an academic environment is that it combines both scientific research and educating young people. Teaching our students complex issues related to hydro(geo) logy and mathematics is a real privilege for me, and I love doing it! I would like to end by quoting an old Chinese saying: ''Find a job that you love and you will never work a day in your life again!''

Ik heb gezegd.