Guiding Principles for Fresh Water Lens Development, Exploitation and Maintenance in Artificial Islands

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ABSTRACT

A fresh water lens may develop under newly constructed artificial islands in the ocean. The thus developed fresh water lens can be incorporated in the water supply system of the envisaged development on the island. The conditions for fresh water lens development can be optimized in artificial islands, since these islands are designed from scratch and the technical possibilities of dredging material and dredging equipment are large.

However, there is currently little guidance on methods for optimizing artificial islands for fresh water lens development. We address this gap looking at the factors affecting 1) the development, 2) the exploitation and 3) the maintenance of fresh water lenses. Based on numerical analysis of fresh water lens development in three land reclamation projects, we present design principles regarding the shape and characteristics of artificial islands and the capacity and continuity of recharge.

We conclude that optimization of artificial islands for fresh water lens development, exploitation and maintenance is technically feasible.

INTRODUCTION

An artificial island, also called land reclamation, is a newly constructed island in the ocean; the most well-known are the World Islands in Dubai with a mainly touristic purpose. The port of Rotterdam in the Netherlands has a history of land reclamations for port development; the latest is Maasvlakte II which was officially opened in May 2013. The port of Rotterdam is not unique for its reclamation sites since all over the world artificial islands are constructed for port and industrial development.

In recent years, we see a trend of land reclamations for urban expansion in densely populated delta cities. Population growth, urbanization and economic development result in an increasing pressure on available space. Land reclamations are used to meet this growing need. An example is Pluit City in Jakarta.

Water demand on the newly constructed islands includes water for domestic purposes, drinking water, irrigation and industrial purposes like firefighting and dust prevention. Safeguarding the fresh water supply is one of the major challenges. Since the island is constructed in the ocean, there is no fresh water available to meet the water demand of the future land use. Fresh water is usually supplied by pipeline from the main land, or by

desalination of seawater, and some small-scale rainwater harvesting and reuse. It is interesting to have seasonal or emergency storage of fresh water on the island to decrease the dependency on supply from the mainland and/or to decrease the costs related to desalination.

A fresh water lens may develop under newly constructed artificial islands in the ocean. The thus developed fresh water lens can be incorporated in the water supply system of the envisaged development on the island. The conditions for fresh water lens development can be optimized in artificial islands, since these islands are designed from scratch and the technical possibilities of dredging material and dredging equipment are large. However, there is currently little guidance on methods for optimizing artificial islands for fresh water lens development. We address this gap looking at the factors affecting the development, the exploitation and the maintenance of fresh water lenses.

METHODS

Generally loose, medium grained quartz sand is considered to be most suitable for the construction of artificial islands if it is available within an acceptable haulage distance from the project location. The properties of the sand change during the dredging process. The choices for dredging equipment are dependent on water depth, soil type, volume and required accuracy. Depending on site-specific conditions mechanical or hydraulic suction dredging is applied. The sand is transported through a pipeline or by ship from the borrow site to the project site. Ground improvement techniques are often applied to improve the geotechnical properties of the island.

There are no general geotechnical design guidelines. The required geotechnical properties of the island follow from the performance requirements of the future land use and are therefore site-specific. These properties include the strength (bearing capacity), stiffness (settlement), density (resistance against liquefaction), permeability (drainage capacity) and elevation (safety against flooding).

In this research the geotechnical properties and hydrological characteristics of three land reclamation projects are used to study the potential fresh water lens development in land reclamations. The SEAWAT computer code (Langevin et al. 2008) in the mfLab environment (Olsthoorn 2013) was applied for numerical simulations. The three land reclamations are The World in Dubai, Maasvlakte II in the Netherlands and Pluit City in Jakarta.

RESULTS

Island G19 in Dubai is part of the World archipelago. It is a circular island of 3 ha which was constructed in the period 2003-2008. It is composed of sand dredged from the shallow coastal waters. Dubai has a tropical desert climate; hot, humid and extremely dry with five days rainfall per year on average. On the island are an estate and a palm plantation which is irrigated with desalinated water.

Maasvlakte II in the Netherlands was constructed in the period 2008-2013. It is an island of 2000 ha composed of sand from a borrow pit 11 km off the Dutch coast. Canals of 20 m depth for sea-going vessels are dredged and therefore Maasvlakte II may be considered as

strip islands with typical widths of 1000 m. The Netherlands have a moderate climate with a relatively equal precipitation distribution throughout the year. At the moment three container terminals are constructed on Maasvlakte II. Water for industrial purposes is supplied by pipeline.

Several islands will be constructed in Jakarta Bay as part of the Jakarta Coastal Development Strategy. Pluit City is designed for commercial and residential purposes; it is envisaged to inhabit 200.000 inhabitants. Jakarta has a tropical monsoon climate with distinct wet and dry seasons. Water for the future city will be supplied by pipeline or desalination.

The specific characteristics of the islands and the results of the numerical simulations of lens development will be presented at the Salt Water Intrusion Meeting for the three reclamation projects including measures for optimization. One of the optimizations is the application of subsurface cut-off walls (Des Tombe et al. 2012). Based on the numerical analysis, we will present general design principles regarding the shape and characteristics of artificial islands and the capacity and continuity of recharge. The best solution for a specific case is dependent on site-specific circumstances.

An especially interesting aspect is how the fresh water lens can be exploited and maintained. The modeling results show that the fresh water lens in the three land reclamations is thin and fresh water recovery will soon result in salt water upconing. From literature we know that horizontal wells (for example Stoeckl and Houben 2012), shallow skimming wells (see for example Sufi et al. 1998 and Zuurbier et al. 2014) can be applied to diminish the effect of salt water upconing. This effect can also be reduced by horizontal layering with layers of higher and lower conductivity, which can be constructed during the reclamation works. Simulation results will be presented at the Salt Water Intrusion Meeting.

It is worthwhile to have a permanent measurement system to operate and maintain the fresh water lens as optimally as possible. Options for a permanent measurement system with electromagnetic cables constructed in the subsurface of the island will be presented.

DISCUSSION AND CONCLUSIONS

In this research the geotechnical properties and hydrological characteristics of three land reclamation projects were used to study the potential fresh water lens development in land reclamations. We conclude that optimization of artificial islands for fresh water lens development, exploitation and maintenance is technically feasible. The best solution for a specific case is dependent on site-specific circumstances. It is worthwhile to link the civil engineering design and water management for future functions in an early design phase. The business case determines whether the optimizations for fresh water lens development, exploitation and maintenance will actually be applied in specific cases.

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