Proposal of a Methodology for the Optimal Design of Monitoring Networks Coastal Aquifers Management

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ABSTRACT
In many coastal areas with a great density of population water supply depends, to a great extent, of groundwater, for this reason a monitoring network for coastal aquifers based in a reduced number of monitoring wells can represent an important alternative, because of the economical savings of this type of project. Therefore it is necessary to optimize number of sampling points when choosing suitable sampling times and positions.

A method for the design of an optimal network monitoring of a coastal aquifer is proposed here. The objective is to adecuate and use the methodology proposed for groundwater quality network monitoring design, that uses Kalman's filter in combination with stochastic simulation of the groundwater flow and the transport of solutes. This methodology is implemented using a computer program called GWQMonitor which uses ArgusOne as a graphical interface that controls only the first three parts, but it is also possible to use Ground Water Vistas as graphical interface.

In order to take into account variable water density, we are planning to use SEAWAT, developed by Guo and Bennett, (1998); Guo and Langevin, (2002) that is a combination of MODFLOW and MT3DMS (Zheng y Wang, 1999).
Keywords: coastal aquifers, monitoring network

INTRODUCTION
In many coastal zones with great density population, water supply depends to a great extent on groundwater, frequently coastal aquifers are over exploited and additionally present contamination problems, from industry and other sources (for example: diminution of charge as a result of the increase in urban establishments or marine intrusion because of its proximity to the sea).

Consequently, the planning, development, protection and handling of this aquifers is an important task. An alternative to solve this problem is based upon groundwater monitoring programs implementation (in number and quality), with the purpose of anticipating or controlling contamination sources and problems related with over exploitation or degradation of this resource. This task can be carried out through the use of tools such as the monitoring networks and mathematical simulation methods.

JUSTIFICATION
Groundwater monitoring network design, is indispensable to study and solve aquifer contamination problems, but at the same time represent a significant economic burden, because of the expenses associated with the monitoring wells operation, and those related with the sampling analyses obtained from observation wells. An alternative to diminish this economic impact consists on the reduction of the number of samples to collect. Such reduction can be obtained sampling fewer wells or sampling the same number of wells with less frequency, or by a combination of both strategies.

The main objective of this work, is to adapt and use a methodology proposed and developed for the efficient design of a water quality monitoring network, which considers an algorithm that helps to determine where and when to sample wells, in order to define groundwater polluting agents behaviour. This work is a contribution for the design of an optimal coastal aquifer monitoring network. Because there are few investigations related to this subject, we had to take into account information related to the design of the optimal monitoring groundwater quality, which can be carried out using a variety of approaches.

METHODOLOGY

In this work we try to adapt and use methodology of water quality monitoring network design, known as GWQMonitor, the methodology can be divided in four parts: in the first three parts, actual data are not required, just positions and times in which the underground water could be sampled. When we refer to the positions or times of sampling, these are the positions of possible monitoring wells and the possible monitoring times for each one of those wells. This methodology is implemented through a computer program GWQMonitor that works with a graphical interface called ArgusONE, which controls just the first three parts, but it is possible to adapt this program into Ground Water Vistas.

Part I: Calculation of an initial estimation for the concentration covariance Matrix of a transport stochastic model

An stochastic simulation is made using a transport stochastic model, in order to obtain a prior concentration estimation in space and time and its covariance matrix.

Part II: Covariance matrix calculation for the estimation of concentration error given positions and times

Initial estimated covariance matrix is combined with positions and monitoring times information through the Kalman's filter to obtain a new error estimation of the covariance concentration matrix. As far as the selection of the positions and times of sampling, the method uses an iterative algorithm in which chooses a position in space and time in a simultaneous form.

Part III: Construction of the sampling network

A sampling network is constructed by means of an optimization method that diminishes the estimation function of the estimation of the variance that is obtained in part II. To choose well positions and sampling times for the network and monitoring frequency, a function of estimation of the uncertainty is used. The function used, depends on the design objectives. In order to diminish the function, different optimization procedures can be used. The function used to measure the uncertainty associated with a given sampling plan, is the sum of the considered error of the variances in the positions and times of interest, this function is called total variance of the concentration error, and it is denoted by:

$$\sigma_T^2(n) = \sum_{i,p} \sigma_{ip}^2(n) \qquad (1)$$

where: $\sigma_T^2(n)$ is the variance of the error of estimation in the *i-th* position in Kalman's mesh and estimation time *p-th* when *n* samples are used. The $\sigma_{ip}^2(n)$ are obtained from Kalman's filter, the variances after taking *n* samples are the elements of the covariance diagonal matrix P^n.

$$P^n = E\left\{(C - \hat{C}^n)(C - \hat{C}^n)^T\right\} \qquad (2)$$

Part IV: Postprocessing

Postprocessing procedure allows a real time update of concentration estimate. It uses the mean contaminant concentration obtained by averaging the realizations from the stochastic simulation as an initial estimate of the contaminant concentration. The newly available concentration data are then used to update the prior estimate using Kalman's filter. As additional data become available Kalman's filter is used again to update the estimated concentrations.

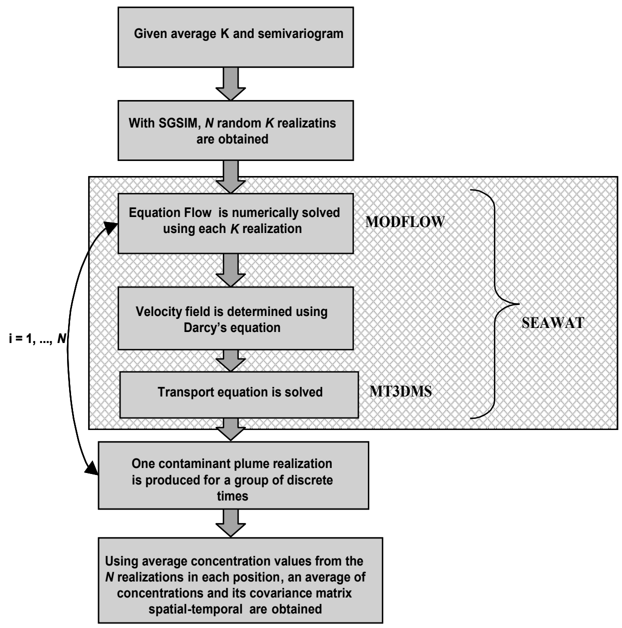

Figure 1. Flow chart of Variable density groundwater flow and transport solute simulation, used to obtain input files for GWQMonitor program.

In figure 1, the process of stochastic simulation is illustrated, using SEAWAT, in order to obtain the average concentrations and the space-time covariance matrix, that makes part of the Herrera-Pinder (1998) methodology. The procedure's results will be used as input data for GWQMonitor program, in order to obtain the optimal design of a coastal aquifers monitoring network.

CONCLUSION

Monitoring networks based on a reduced number of sampling wells can represent an important alternative in face of economic restrictions, therefore it is important to optimize the number of sampling points, choosing adequately times and sampling positions.

In this work a methodology for optimal coastal aquifers monitoring network design is proposed, constituting itself as an important contribution for the management of this type of groundwater resources.

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Mechanisms Driving Submarine Groundwater Discharge and Associated Radium Flux: Implications for Use of Radium as a Tracer

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Groundwater is an important source of nutrients and contaminants to coastal waters (e.g., Valiela et al., 1990; Slomp and Van Cappellen, 2004; Kemp et al., 2005), and quantification of submarine groundwater discharge (SGD) is the first step toward understanding its potential impact on nearshore marine ecosystems. The diffuse and heterogeneous nature of SGD makes it difficult to quantify directly, so geochemical tracers with high concentrations in groundwater relative to surface water, such as radium and radon isotopes, barium, and methane, are often measured in coastal waters to estimate the fluid flux (e.g., Moore, 1996; Moore, 1997; Swarzenski et al., 2001; Burnett et al., 2006). These methods, while potentially extremely useful for making integrated large-scale discharge estimates, are dependent on knowledge of the tracer concentrations in groundwater. In the case of radium specifically, and likely other tracers, porewater concentrations are highly heterogeneous, particularly in coastal systems where salinity gradients are high. Concentrations may differ between locations because redox chemistry changes along flowpaths (e.g., Charette and Sholkovitz, 2002), subsurface residence times are variable (e.g., Robinson et al., 2007), and mixing between groundwater and surface water is significant. Consequently, the groundwater that contributes most to submarine groundwater discharge could have different tracer concentrations than the average concentration in groundwater for the region.

Detailed direct measurements of groundwater discharge and salinity were made with seepage meters in Waquoit Bay, MA over a period of five years (Michael et al., 2003; Michael et al., 2005). The mechanisms driving groundwater flow at the coast can explain, at least in part, the observed spatial discharge patterns. Discharge attributed to each of the primary driving mechanisms believed to be operating in Waquoit Bay were identified and quantified. Components of discharge likely driven by the upland freshwater hydraulic gradient, run-up of tides and waves onto the beachface, dispersion along the freshwater-saltwater interface, and seasonal hydraulic change were 0.004 m^3/s, 0.024 m^3/s, 0.023 m^3/s, and 0.026 m^3/s, respectively.

The activity of four radium isotopes, ^{226}Ra, ^{228}Ra, ^{223}Ra, and ^{224}Ra (with half-lives of 1600 years, 5.8 years, 11.4 days, and 3.7 days, respectively) was measured in 42 porewater samples (some of which are published in Abraham et al., 2003), and in water collected from 40 seepage meters combined into four zones over three time periods. The radium flux into Waquoit Bay associated with each zone of groundwater discharge (as opposed to each driving mechanism, the associated discharge of which overlap spatially in some areas) was calculated by integrating fluid discharge, salinity, and radium measurements. Results indicate that while discharge of groundwater in the brackish zone offshore of the freshest discharge comprises approximately 40% of the total SGD, 80% of the total ^{226}Ra discharge occurs in this zone. Offshore saline discharge, likely driven in part by seasonal motion of the interface, contributes 34% of total discharge, but only 6% of ^{226}Ra flux. Nearshore discharge of circulated saline water due to tides and waves contributes about 5% of fluid flux and 6% of ^{226}Ra flux, and discharge of groundwater from the freshest zone is 20%

of total fluid flux and only 8% of ^{226}Ra flux. The fluxes of other radium isotopes are similarly proportioned, though isotope ratios are somewhat spatially-variable.

This study indicates that radium activities vary in groundwater and are dependent to some extent on the forcing mechanism driving groundwater discharge. Detailed measurements of fluid flux and radium activities have allowed quantification of radium flux into Waquoit Bay, which displays significant spatial heterogeneity. This has implications for the use of radium as a tracer for total SGD, integrated over all components. Care should be taken that porewater radium activities are sufficiently sampled to understand heterogeneity within and among types of discharging groundwater. If radium activities are highly variable and the relative magnitude of fluid flux among different groundwater types is unknown, then bulk groundwater discharge is difficult to estimate by knowing only the radium flux to the surface water. Results suggest that brackish groundwater discharge offshore of freshwater outflow is the dominant contributor of radium to the Waquoit Bay estuary. Thus, radium could be most effective for estimating discharge of brackish groundwater driven by dispersion along the freshwater-saltwater interface, and perhaps for indicating motion of the interface. In addition to improving the use of geochemical tracers as indicators of groundwater discharge, understanding of the primary mechanisms driving flow and the concentrations of solutes associated with each type of groundwater could greatly improve our ability to predict the discharge of important nutrients and contaminants to coastal waters.

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