Groundwater Flow and Solute Transport Modeling in the Karst System Ox Bel Ha, Tulum (Mex)

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The following Master thesis is conducted in the Swiss-Mexican-Austrian project 'Xibalba' (FWF I994-N29), an international research cooperation of the Geological survey of Austria, the NGO Amigos de Sian Ka'an in Cancun (Mex) and the University of Neuchâtel (CH). Main project objective is to simulate the development and actual structure and dynamics of the complex coastal karst system in Tulum area (Quintana Roo, Mexico), by a new numerical modeling approach (Schiller and Lopez-Tamayo, 2016).
The Ox Bel Ha system, located in Tulum on the limestone platform of the Yucatán Peninsula, is among one of the world's largest karst network of 267 km of karst conduits (QRSS, 2015). This coastal aquifer, bordered by the Caribbean Sea, is characterized by a low hydraulic gradient and a thin shallow lens of 30 meters thick. Its advanced stage of karstification development allows for almost instantaneous infiltration and rapid transport of contaminants to subsurface.
A groundwater quality campaign was carried out in March 2016 to provide the punctual sources of anthropogenic contamination. Thirty-nine points were sampled and analyzed for Escherichia Coli (E.Coli) and anions concentrations. According to the NOM-127-SSA1-1994, only the Chloride concentration was exceeding the 250 mg l−1 authorized limit almost everywhere due to saline intrusion. Peaks are observed near the coast, where the halocline is shallow. Furthermore, E.Coli concentration was exceeding everywhere with preferential punctual source in the city of Tulum (from 2 to 1400 CFU/100ml). Upstream samples were low in concentration (0-2 CFU/100ml), aside some points not so far from landfills of the city. The concentration obtained to the outlets into the sea was around 14 - 30 CFU/100ml (with a high concentration of Chloride implying dilution with sea-water). This current state of groundwater contamination encourages to build a numerical model to assess the vulnerability of the aquifer.
A piezometric network installed between 2013-2015 allows to analyze hydrodynamic tidal fluctuations. A net tidal fluctuation is recorded in a sinkhole up to 10.1 kilometers inland which attests of the well-developed karst Ox Bel Ha system. Main harmonics components observed are the diurnal tide O1 as well as the main semidiurnal tide M2, S2 and N2. A stochastical approach, subnetwork percolation clusters (Hendrick and Renard, 2016b), is used to generate unexplored karst networks connecting to conduits already mapped. Thus, the real conduits density could be overestimated, but the network connectivity is respected. A tidal hydrodynamic calibration are done with the M2-harmonic-amplitude set as a initial boundary condition on the Finite-Element Mesh created on FEFLOW7.0 (Diersch, 2014). Karst network is integrated as 1D discrete features as turbulent flow (Maning-Strickler law). Hydraulic parameters are calibrated based on the observation points of the piezometric network. A roughness coefficient of 0.5 m1/3s−1 and a cross section area of 19 m2 are obtained. Finally, a hydrogeological model is built adding the upstream recharge and the sea-level recorded to Puerto Moreles (ninety kilometers northeast of Tulum) with the calibrated hydraulic parameters. Respecting the hydraulic gradient ⇡ 10 cm km−1 (Bauer-Gottwein et al., 2011) by means of the observation points, a discharge at the coast of 5.39 to 10.42 m3d−1m−1 is observed according to the used generated karst network. A advective transit time between 6 to 14 days occurs from the city of Tulum to the coast for a flow velocity between 0.37 to 0.92 cm s−1. These narrow intervals according to the generated karst networks, based on 5 realizations in this study, are encouraging to carry out simulation on hundreds different karst networks providing more reliable informations on contaminant transport.