PROTECTION OF THE GROUNDWATER RESOURCES OF METROPOLIS CEBU (PHILIPPINES) IN CONSIDERATION OF SALTWATER INTRUSION INTO THE COASTAL AQUIFER

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INTRODUCTION

The world, particularly the developing countries, is experiencing shortages of potable and clean waters. For the effective management of water resources it is necessary to understand the natural systems affecting the groundwater.

Saltwater intrusion is common in coastal areas where aquifers are in hydraulic contact with the sea. A zone of contact (salt-freshwater interface) is formed between the lighter freshwater flowing to the sea and the heavier, underlying, seawater (specific weight $\gamma_s > \gamma_f$). Even under natural conditions without any anthropogenic activity the freshwater from the aquifer flows into the sea (outflow face), while in greater depth saline water penetrates into the pore space of the aquifer. The saltwater wedge at the bottom of an aquifer may move long distances against the natural gradient of the freshwater table. Additional pumping of groundwater induces upconing and further movement of seawater inland towards the groundwater extraction (Figure 1). The mixing of seawater with groundwater affects the quality and the normal usefulness of groundwater.

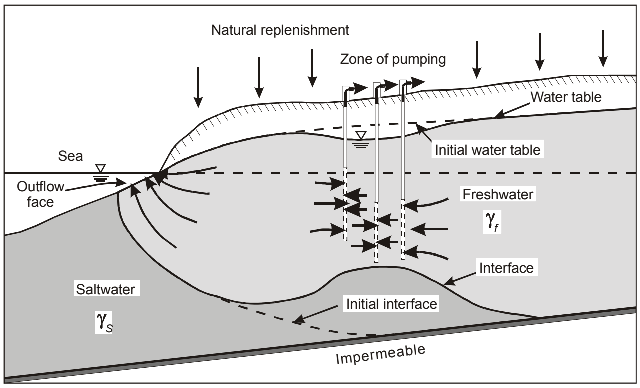

Figure 1 *Cross-section in a coastal aquifer with saltwater upconing.*

Metropolis Cebu in the Philippines is located in a coastal area and has a problem of freshwater supply. The intrusion of saltwater into the aquifer system has led to a decrease of freshwater resources since several years. Some wells in the downtown area are already abandoned because of saltwater intrusion and the extraction rates of other wells had to be reduced to prevent saltwater upconing.

Within this context, in this research project it is proposed to construct a density-dependent numeric model to simulate the saltwater intrusion phenomena in the coastal aquifer of Metro Cebu in consideration of different scenarios of groundwater extraction and increase of water consumption.

DESCRIPTION OF THE STUDY AREA

The island of Cebu in the centre of the Philippines is part of the Visayas. Together with a number of smaller Islands such as Bantayan in the north and the Camotes Islands and Mactan in the east, it forms the province of Cebu (Figure 2).

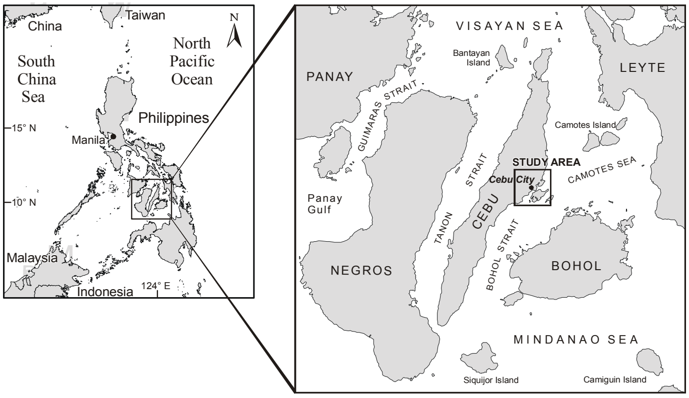

Figure 2 *Location of the study area.*

Located at 123° to 124° eastern longitude and 9° to 11° northern latitude, its area is 4,320 square kilometres. The island of Cebu is 215 km long and just 35 km across at its widest width. Cebu's topography is mountainous, with a major mountain range running parallel to the islands north-northeast to south-southwest axis. Despite the island's narrow width, its steeply sloping mountain range rises to heights of more than a thousand meters. Rivers run from the main water divide in the island's centre in either northwestern or southeastern direction to the coastal plains, which are up to five kilometres wide.

Metro Cebu is located in the eastern part of Cebu province and defined as being composed of the four chartered cities Cebu City, Mandaue City, Talisay City and Lapu-Lapu City and the six municipalities Cordoba, Compostela, Liloan, Consolacion, Minglanilla, and Naga. The study area of this project focuses on the coastal aquifers of Compostela, Liloan, Consolacion, Mandaue City, Cebu City, and Talisay City.

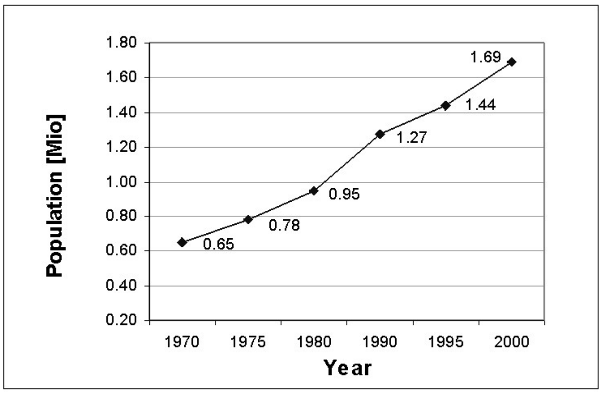

Figure 3 *Population growth of Metro Cebu*

Within the last 20 years processes of urbanization and industrialization have taken place in the eastern coastal region of Cebu. Based on the 2000 Census of Population and Housing, 1.69 million people are living in Metro Cebu (Figure 3). Cebu was the fastest growing province in the region with an average annual growth rate of 3.07 percent (National Statistics Office, 2000). As a result of the population growth, the groundwater requirement enormously increased in the urban agglomeration Cebu's.

HYDROGEOLOGICAL DESCRIPTION

The hydrographic network (i.e. rivers draining different watersheds) within the area of Metro Cebu is illustrated in Figure 4. Comparing the drainage network with geology and geologic structures indicates that the drainage directions are influenced by fault systems. On Cebu Island these systems generally emerge in a southwest–northeast or northwest–southeast direction. The rivers in the central part of the island flow either northeast or southwest and abruptly turn towards the coast. There are three river basins draining water within the area, which are defined as topographic divides. The Mananga River Basin drains the northwestern part of the area through the Talisay municipality. The northern part of the area, the Kotkot River flows through a gorge north of Liloan before discharging into the ocean. The third river basin is called Coastal Aquifer Watershed and has a contributing area of approximately 264 square kilometres. It consists of 11 subbasins, which are oriented parallel to each other and drain into the sea. The Coastal Aquifer Watershed is the main contributor of groundwater to the Coastal Aquifer.

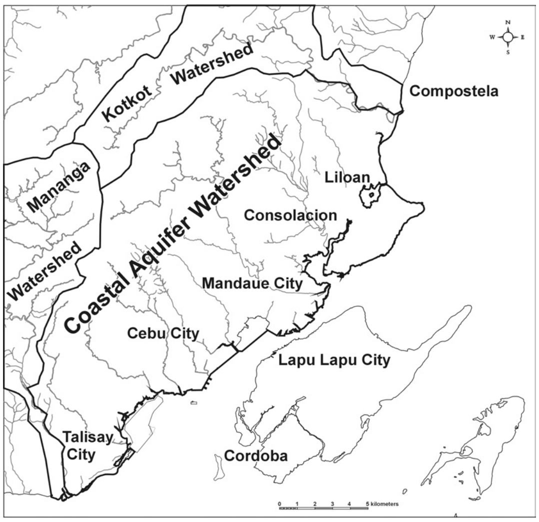

Figure 4 *Watersheds and hydrographic Coastal Aquifer Watershed*

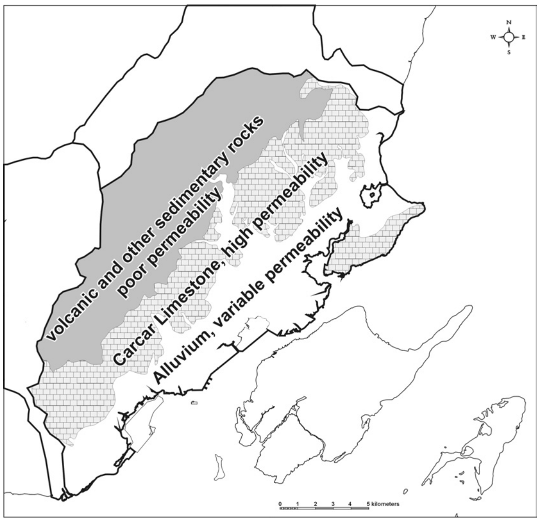

Figure 5 *Geologic formations in the network*

The Coastal Aquifer Watershed can be subdivided in three geologic formations: the alluvial sediments, the Carcar Limestone, and volcanic and other sedimentary rocks (Figure 5).

The region near the coast is covered by alluvial and recent unconsolidated sediments forming the flat land areas. These deposits, of Pleistocene and Holocene age, consist of undifferentiated, alternating layers of gravel, sand, clay and silt. The lateral extent exceeds 1 – 2 km from the coast only in a few locations e.g. the Mandaue area. The thickness of the alluvial sediments is a few meters but can extend down to 80 m deep in Mandaue area probably within earlier drainage channels (Kampsax-Krüger, 1980). Underlying these alluvial sediments is a semi-consolidated to consolidated limestone. Further inland, up to 8 km from the sea, the Carcar Limestone forms a hilly part of the coastal area with elevation up to 200 m. The Carcar Limestone Formation is a corraline limestone, which builds an almost continuous margin around the island and was deposited during a Plio- Pleistocene period of marine transgression and regression. The Carcar Limestone is the major aquifer in the Metro Cebu region and is heavily developed by the Metropolitan Cebu Water District (MCWD) and private users. The Corraline Limestone and massive limestone are karstified (very porous) and contain interconnected fissures, fractures, and dissolution channels, which are products of tectonic activity and weathering.

Flow logging tests carried out by Kampsax-Krüger (1980) in exploratory and production wells, indicate that the Carcar Limestone is weathered down to more than 50 m below sea level. Below this depth the permeability and porosity diminish because of an increased silt content and greater degree of consolidation. Transmissivity, which is concentrated in the upper part of the aquifer, has been found to range from 20 m²/d to more than 4000 m²/d. The specific yield of the Carcar Limestone has been estimated in the range of 0.1 – 0.15 on the base of water level changes (Kampsax-Krüger, 1980). The Carcar Limestone can be divided into reef debris of considerable thickness and reef core unit. In some localities, the outcrop of thin, more consolidated and corraline limestone can be seen with a dip of approximately 15 degrees seawards (Kampsax-Krüger, 1980). The total thickness of the Carcar limestone is unknown but from geological data it is estimated to be about 500 m near the coast. The limestone overlies metavolcanic, plutonic and other rocks forming the core of Cebu Island.

The older strata and the lower Miocene sedimentary strata occupy the higher central area of the island. These rocks are poorly permeable and cannot be used for intense groundwater supply.

SEAWATER INTRUSION

Seawater intrusion and its related effects with saline groundwater were observed in Cebu City's coastal aquifer for the past three decades. Complaints of brackish groundwater in the downtown area of Cebu City led to the first study in 1973 by Bruell (Bruell, 1973) on the intrusion of seawater into the groundwater of Cebu City. The study by Bruell was limited to a small area and was more exploratory in nature. Several studies about saltwater and progress reports were undertaken in the following years. These studies arise from observations and further verifications on the distribution of the chloride content in the aquifer of Metro Cebu (e.g. Engelen, 1975; Kampsax-Krüger Lahmeyer International, 1980; Walag, 1984; Water Resources Center 1984, Water Resources Center 1985, National Environmental Protection Council 1987).

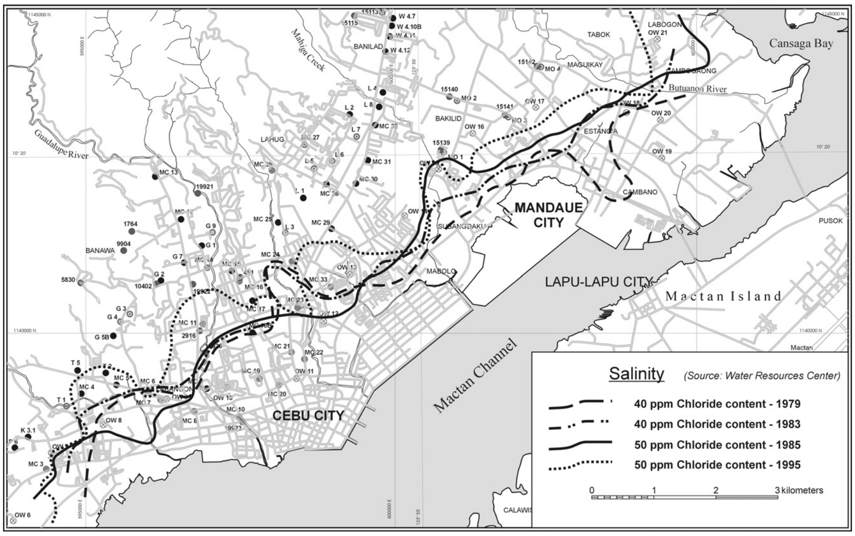

Figure 6 *Seawater intrusion in the Center of Metro Cebu.*

Two institutions in Cebu City have been monitoring saltwater intrusion. Since 1975, the Water Resources Center (WRC) of the University of San Carlos has been measuring the chloride content in approximately 180 wells nearly every year, thus documenting the progress of the saltwater intrusion in the coastal aquifer. The Metropolitan Cebu Water District (MCWD) has also been measuring its observation and production wells (~ 110 wells) on a monthly basis to determine water quality. The data gathered by both institutions, WRC and MCWD, revealed the progress of saltwater intrusion. The 50 ppm chloride concentration iso-line, which was defined as salt- freshwater interface, encroached one to three kilometres inland in Metro Cebu. The available data of the WRC at the University of San Carlos (Engelen, 1975; Walag, 1984) confirm an advancing salinization of groundwater in the Cebu City region. In some areas the 50 ppm chloride concentration iso-line of 1995 progressed two kilometres inland when compared to the data collected in 1979 (Figure 6).

AVAILABLE GROUNDWATER

The water supply of Metro Cebu depends mainly (98 %) on groundwater. Areal rainfall on the coastal area is 1.6 m/a and percolation is estimated at 30 %. Thus the groundwater recharge of the coastal aquifer of Metro Cebu is 86.4 millions m^3/a. Major extractors of groundwater are the Metropolitan Cebu Water District (MCWD), a group of industries, private and government wells. Based on the statistics of groundwater extraction MCWD pumps 100,000 m^3/d while the other users pump 128,000 m^3/d. This is equivalent to 83 millions m^3/a. Thus, the rate of pumped groundwater is almost the amount of groundwater recharge. The hydraulic balance between groundwater renewal and discharge in Cebu City region is disturbed. Detailed calculations of future demand by MCWD, incorporating data for private abstractions indicate the demand will continue to grow rapidly with the population.

FIELDWORK

All water samples for previous studies were collected by pumping water out of the observation wells. Therefore, the water of various depths was mixed as a result of pumping. It was not possible to determine the distribution of saline groundwater inside the well, caused by the different densities of fresh- and saltwater. To gain more information about the three-dimensional distribution of the saltwater intrusion it was necessary to obtain depth-dependent data.

Fieldwork has been conducted during the project. Depth-dependent measurements of the electrical conductivity were performed to acquire more detailed information on the distribution of the chloride content. This fieldwork was the first study offering information on the three-dimensional distribution of the chloride content in the coastal aquifer of Metro Cebu (Scholze, 2001). The results of the measurements show for some wells an increase of the chloride content over depth. Figure 7 illustrates the measured electrical conductivity at observation well K 2.3 in Canduman, Mandaue. The log shows a drastic increase of the electrical conductivity at a depth of 82 mbmp (53 m below sea level). This could be caused by the upconing of saltwater in this area because of pumping.

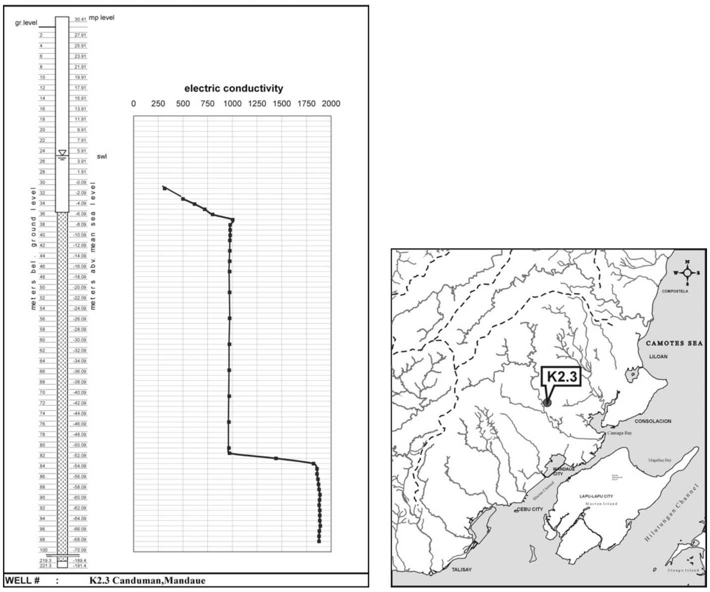

Figure 7 *Electrical conductivity at observation well K 2.3 in Canduman, Mandaue.*

RESEARCH PROJECT

A groundwater model is the best tool to help hydrogeologists to predict the behaviour of a groundwater system. The coastal aquifer of Metro Cebu is a complex system with an area of 180 km², 240 production or monitoring wells and an unknown number of private wells.

Within this context, in this research project it is proposed to construct a density-dependent numeric model to simulate the saltwater intrusion phenomena in the coastal aquifer of Metro Cebu in consideration of different scenarios of groundwater extraction and increase of water consumption. Opportunities will be shown how the groundwater resource can be protected by skilful water management in the Metro Cebu and how to avoid further seawater intrusions into the coastal wells. The results of these investigations will lead to practical recommendations in this area for the long-term protection of the water resources in the region of Cebu City.

In a first step a groundwater model was developed using the software SHEMAT (Simulator for Heat and Mass Transport) that is based on finite differences. Groundwater flow, heat transfer and multi-species transport are mutually coupled and simulated simultaneously. The aquifer of the Carcar Limestone and the alluvial sediments are taken as the modelling area, which is bordered in the northeast by the Kotkot River and in the southwest by the Mananga River. The model grid is aligned to the expected main flow directions (NW-SE), to meet the requirement of flow in principle directions. The hydrogeological data (e.g. recharge, extraction rate, hydraulic conductivity, porosity) were assigned to the model grid and the present groundwater flow was simulated. The objective of this simulation was to check the data basis for the study area. As displayed in Figure 8 it was possible to simulate the saltwater intrusion in the coastal aquifer.

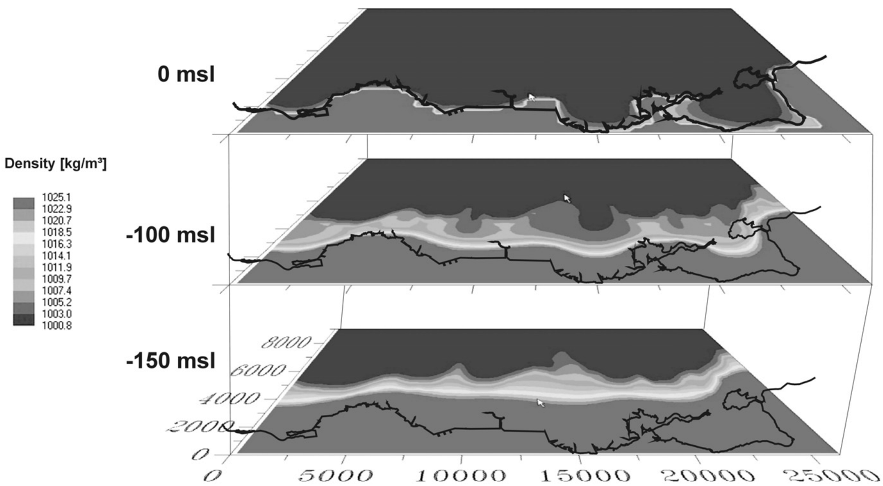

Figure 8 *Simulated distribution of groundwater density in the aquifer for different elevations.*

The next step will be to transfer the model to the modelling code FEFLOW for transient calibration. Using this model the development of the groundwater system of the last 30 years and different scenarios of groundwater extraction will be simulated.

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