THE GUARANI AQUIFER PROJECT - DETERMINATION OF GROUNDWATER RECHARGE AND DEVELOPMENT OF GROUNDWATER- AND DRINKINGWATER PROTECTION

Hans Frisch[1]

Key words - Parana Basin, Guarani Aquifer, groundwater recharge, groundwater protection, drinkingwater protection

1. INTRODUCTION

The Paraná Basin with the famous Guarani aquifer keeps the most important groundwater resource of South America. This aquifer serves for public water supply as well as for industrial water supply. With respect to a sustainable utilization of this valuable groundwater resource for comming generations a thorough investigation of the hydrogeological situation and conditions is unavoidable. In an international meeting in São Paulo at the end of November and the beginning of December 1999 in seminars, workshops and roundtable discussions the main fields of investigations and activities necessary for the Guarani Aquifer were worked out:

- Transparent determination of groundwater recharge
- Professional and administrativ development of groundwater- and drinkingwater protection
- Development of a data banc for groundwater management

[1] Bavarian State Office for Water Resource Management; Lazarettstrasse 67; D-80636 Munich - Phone: 002149-89-9214-1252 - E-mail: fachbereich-b@lfw.bayern.de - Fax: 002149-89-9214-1435

Figure 1: Location of the Guarani Aquifer in the Paraná Basin
(After Araújo, L.M., et alt., 1999)

Two specialists of Bavaria/Germany took part in the meetings and brought in their experience gathered during a long time of various professional activities in the field of groundwater resource management. The cooperation between the Secretaria do Meio Ambiente do Estado de São Paulo and the Bavarian State Office for State Development and Environmental Affairs has just started and will continue on the basis of a detailed program in groundwater resource management.

2. GEOLOGICAL AND HYDROGEOLOGICAL SURVEY OF THE GUARANI AQUIFER

The following description is taken from the paper of Araújo, L.M. et al. (1999).

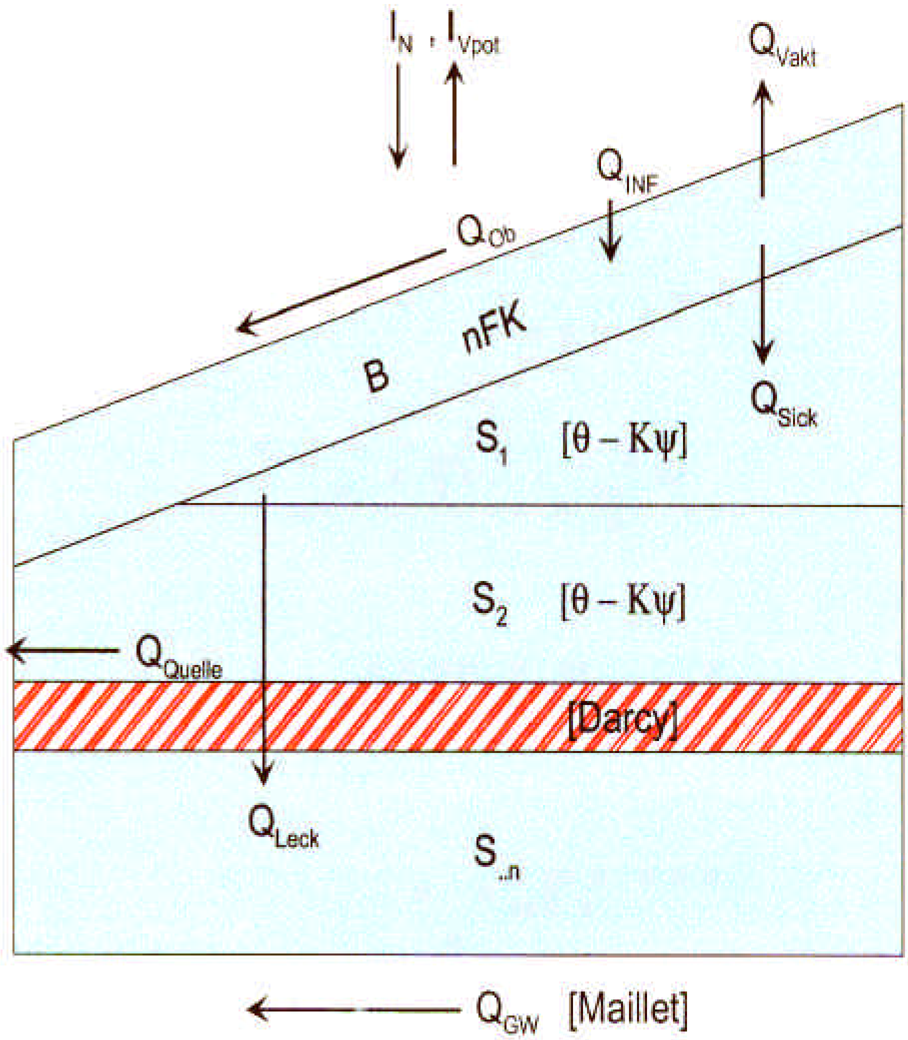
The giant Guarani Aquifer consists of Triassic-Jurassic eolian-fluvio-lacustrine sandstones confined by Cretaceous basalt flows, and it covers about 1.195.500 km^2 (461.583 $miles^2$) in South America. The aquifer system encompasses all of the Paraná Basin and is one of the largest in the world. The eolian Botucatu Sandstone and its equivalents form an important part of this system. The Guarani Aquifer is divided into two domains - the larger and better understood Paraná Basin and the smaller and less well understood Chaco-Paraná Basin. Most of the northern part of the Paraná Basin has axially-directed groundwater flow, whereas the southern part of the aquifer discharges mostly to the southwest into the Corrientes Province of Argentina, with negligible discharge into the Atlantic Ocean. The Guarani Aquifer is conservatively estimated to have been flushed at least 180 times since deposition. Various factors are responsible for this flushing, including appreciable rainfall since the end of the Cretaceous Period, probable uplift of the basins' borders in Late Cretaceous time, simple basin geometry, long-term riverine and groundwater flow to the southwest (ancestral and present Paraná River Systems), and stable cratonic setting.

3. THE DETERMINATION OF THE GROUNDWATER RECHARGE

The determination of the groundwater recharge must not use a black-box method as it was done some years ago by evaluating the runoff of rivers and creeks in dry periods. This method contains uncertainties as in many cases the catchment area of the river doesn't coincide with the catchment area of the groundwater. Nevertheless the area of the superficial runoff is used for the calculation of the specific groundwater recharge.

New methods as for example that one which was developed by Udluft, P. (2000) respect

Figure 2 : The principle of MODBIL - A Ground - Water - Balance - Model Developed by Peter UDLUFT 2000



- A model on the basis of climatic daily values
- A model on the basis of physical soil properties
- A model on the basis of topography and landuse

Explanation :

I_N = Precipitation

I_{vpot} = Potential evaporation

Q_{Ob} = Surface runoff

Q_{INF} = Infiltration

Q_{vakt} = Actual evaporation

B = Soil

nFK = Effective field capacity

S_1, S_2, S_3 = Hydrostratigraphic units

Q_{sick} = Seepage

[Θ - Kψ] = Relation between watercontent and permeability in the unsaturated zone

Q_{quelle} = Spring

Q_{leck} = Leakage

Q_{GW} = Groundwater flow

all the parameters defining the groundwater recharge. Thus the way of calculation is clear and transparent and the different steps can be understood and followed easily.

The Groundwater-Balance-Model (MODBIL) of Udluft is based on

- daily climatic values
- physical soil data
- topography and landuse

In a rough explanation the method contains the following steps:

- Meteorological basic program
  This part of the program calculates the „quasi"-potential evaporation according to Haude (1952, 1959). The formula of Haude uses the temperature of 2 o'clock p.m. and the relative humidity at the same time. The potential evaporation is directly respectively inversely proportional to the temperature and the relative humidity. The program uses calculation steps which were proposed by Damman (1965) and März (1977).

- Calculation of the water flux in the soil
  The infiltrating (effective) precipitation is defined by the so called contact permeability at the soilsurface. The contact permeability depends on the permeability of the soil and the landuse (plowed field, meadow, forest, etc.). In addition the contact permeability is defined by the inclination of the landsurface and the degree of the water saturation of the soil. A surface runoff results, if the precipitation is higher than the „real" contact permeability. The difference of these two values causes the infiltration.

- Calculation of the water flux beneath the zone of the roots
  The fundamentals of the calculations of the flux beneath the roots of plants are the relations between water content and permeability in the unsaturated zone. As the water contents of most of the relevant soils can be determined also the relation between water content and permeability can be worked out for the interesting and relevant soil section. The following data must be available:

- thickness of the interesting zone
- k_f -value under saturated conditions
- water content under field capacity
- water content under saturated condition
- water content before precipitation

– Water flux in hard rocks with/without leakage

  The flux through the leakage layer (impervious layer) ist defined by the permeability (k_f -value) of this layer. For the flux „piston flow" conditions are supposed. The velocity of the fluxes is defined by the water content respectively by the water column above the leakage layer.

  The following data must be known:

  - thickness of the layer above the impervious bottom
  - k_f -value of the hard rock
  - water content during drainage
  - water content under saturated conditions
  - water content at the beginning
  - k_f -value of the impervious layer

– Calculation programs

  For the calculation of the individual steps detailed programs exist and are available from:

  Prof. Dr. Peter UDLUFT

  E-mail: udluft@mail.uni-wuerzburg.de

4. THE DEVELOPMENT OF AN EFFICTIVE AREAL GROUNDWATER PROTECTION

Groundwater is the best resource for water supply of the public. Thus our activities should be focused on two main goals:

– Protection of groundwater as an important natural resource

- Sustainable utilization of groundwater for the public water supply, for agriculture and for the industry

The german requirements for a progressive (forward-looking) groundwater protection policy is based on the following principles:

- Groundwater is to be protected everywhere, since it not only forms the basis of our drinkingwater supply, but also, as part of the hydrological cycle, contributes to the surface water. This water therefore could be adversely influenced by groundwater pollution. Groundwater also possesses important ecological functions. Effects on the groundwater ecosystem are still largely unknown.

- The groundwater is to be retained as far as possible in ist natural state, existing polluted groundwater shall be decontaminated. Any groundwater quality objectives not based on ist natural state would lead to a sanctioning of pollution

- For the protection of our drinkingwater supply more far-reaching measures within drinkingwater catchment areas must be taken. This should not result in first or second class groundwater protection, it is only to be seen as an instrument to reduce still remaining risks to our groundwater or to eliminate them by prohibiting certain actions.

- Groundwater pollution causes long-term damage, which can take a long time to be eliminated and with the application of considerable technical know-how and financial expense, if at all. The ground-water must therefore be protected by preventive measures. A prerequisite is adequate protection of the soil. That means, for example:

    - The highest demands of safety must be placed on plant and equipment in which substances posing a threat to the water are produced, used, stored or transported. These requirements must prevent substances emerging from such plant or equipment and contaminating the soil or the groundwater. That applies equally to malfunctions.

- Agricultural use of the soil must be carried out such that the runoff of nutrients into the groundwater is minimized as far as possible. Pesticides must have no harmful effect on the groundwater when used properly and responsibly.
- When disposing of waste, protection of the groundwater must be assured by the choice of sites with a suitable subsoil and additional technical sealing measures.
- Contaminated sites are to be cleaned up in such a way that no hazard to the groundwater can result from them.
- Sewers must be leak-proof and inspected regularly.

– Groundwater management must be assigned to public authorities. Extraction of groundwater must be approved by statutory authorities as a matter of principle. Groundwater shall be managed to preserve the natural water balance and the related ecosystem. Quality management of the groundwater is not permissible.

– Regular systematic monitoring of the groundwater is indispensable. Only in this way can potential hazards and existing pollution be recognized and countermeasures initiated in good time.

5. DRINKINGWATER PROTECTION

– Basic ideas
Drinkingwater is one of the most important part in human nutrition. Therefore this valuable good asks for a specific protection. Experience of about 50 years in Germany shows that common water laws can't grant such high expectations. This situation asks for special legal regulations: the installation of drinkingwater protection areas.

– The delimitation of drinkingwater areas and their regulations
First of all the delimitation of drinkingwater areas demands for the determination of the groundwater catchment areas of the wells which shall be protected.
In general drinkingwater areas consist of 3 zones:

- Zone I
  This is a small zone around the well of about 20 m x 20 m. This zone is also called the „capture zone", it should be surrounded with a fence, entrance is only

allowed to the staff of the water supplier.

- Zone II

  This zone follows around the zone I, its outer borderline is the so called „50-days-line“. This means that the groundwater must have a flow time of 50 days from this

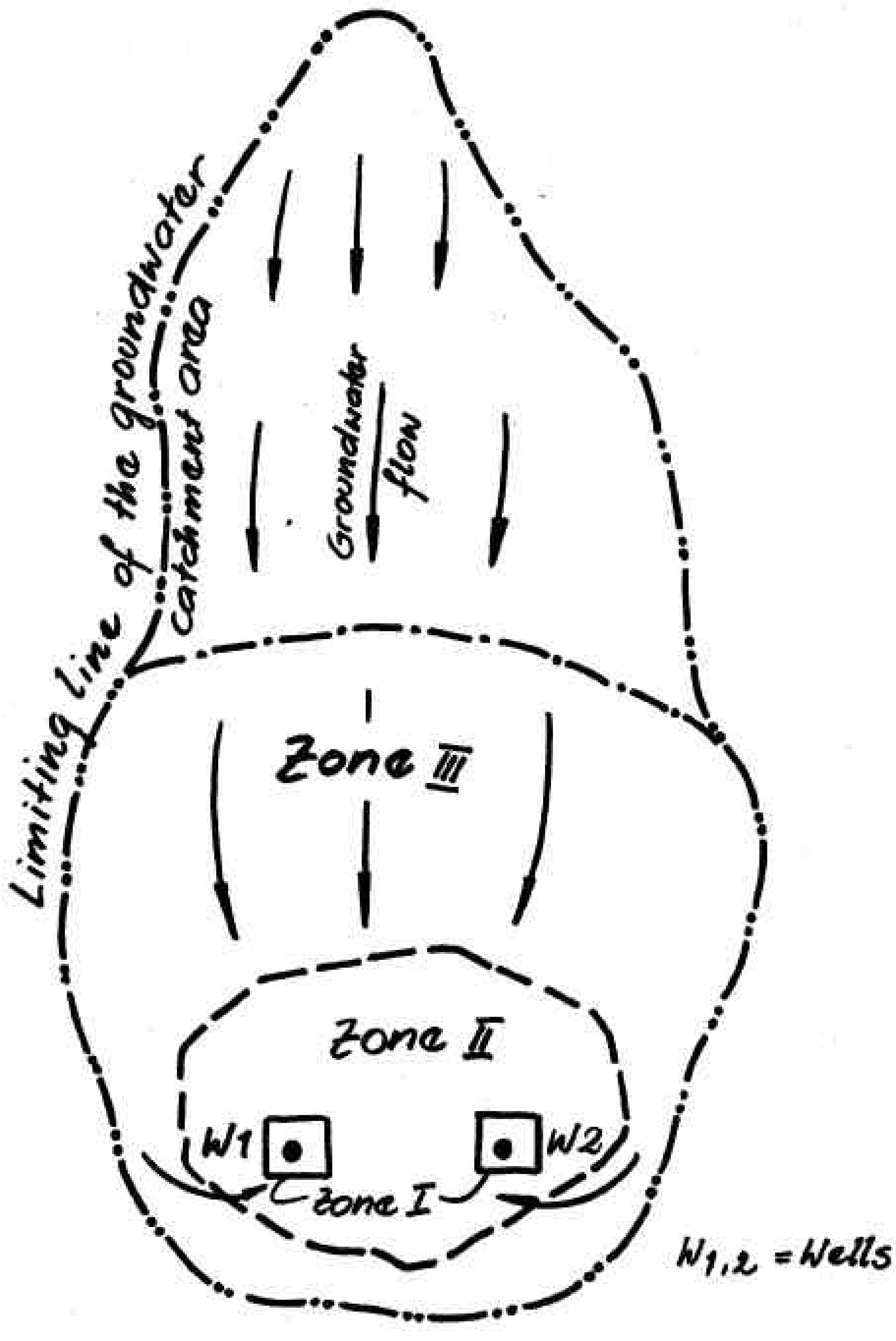


Figure 3 : Sketch of the individual zones of a drinking water protection area

line to the wells. The determination of this zone thus asks for a hydraulic calculation.

- Zone III
  This zone, which is also called „outer protection zone“, is surrounding zone II. Zone III must include that part of the groundwater catchment area, which can’t be protected by the common water laws and in which the remaining risk is too high without special legal regulations.

The three protection zones show specific regulations for

- Agriculture, forestry and horticulture
- Excavations (f. e. sand- and gravel pits, quarries)
- Handling of hazardous substances
- Sewage disposal and sewage structures
- Transportation and places with certain determinations
- Structures in general (housing development)

– The administrative procedure

The administrative procedure in Bavaria includes the following steps:

- Elaboration of application documents by a consultant for the water supplier for the installation of a drinkingwater protection area

- Application for a drinkingwater protection area on the basis of the just mentioned documents at the responsible Local Administration Authority (County Government)

- Official report about the documents by the responsible Local Office for Water Resource Management

- Granting a notification for the installation of a drinkingwater protection area by the Local Administration Authority to the water supply company

- Possibility of contradiction against the official notification at the Administrative Courts

6. DEVELOPMENT OF A DATA BANC FOR GROUNDWATER MANAGEMENT

Working thoroughly on groundwater recharge questions as well as on groundwater- and drinkingwater protection requires a well fed data banc for groundwater management. For this purpose all the data spread over various state offices must be brought together in a central institution. This in general is a tough task which demands for a clever organization and coordination. In our meetings in São Paulo we already started a discussion about the structure and the content of such a groundwater resource management information system. The main points of the content should be the following:

- Identification
- Depth and lining of the well or groundwater gage
- Geological profile of well, groundwater gage or other exposure
- Depth, thickness and state of the aquifer
- Type of the aquifer
- Number of groundwater storeys
- Results of borehole-geophysics
- Results of pumping tests
- Permeability
- Porosity
- Conductivity
- Observations in the course of drilling work
- Vulnerability of groundwater
- Potential endangering of groundwater
- Gradient of groundwater table
- Hydrographs
- Hydrochemistry
- User/owner of the well
- Kind and data of legal permission
- Groundwater recharge data
- Area of recharge
- Other users of the aquifer
- Links to other objects

7. REFERENCES

Araujo L M, França A B, Potter P E (1999):
Hydrogeology of the Mercosul aquifer system in the Paraná and Chaco - Paraná Basins, South America, and comparison with the Navajo - Nugget aquifer system, USA. Hydrogeology Journal 7 : 317 - 336

Damann W (1969):
Meteorologische Verdunstungsmessung, Näherungsformeln und die Verdunstung in Deutschland. Die Wasserwirtschaft 55 : 315 - 321

Haude W (1952):
Verdunstungsmenge und Evaporationskraft eines Klimas.
Ber. Dt. Wettd. US-Zone 42 : 225 - 229

Haude W (1959):
Über die Verwendung verschiedener Klimafaktoren zur Berechnung potentieller Evaporation und Evapotranspiration. Met. Rdschau 12 : 11 - 17

März K (1977):
Hydrogeologische und hydrochemische Untersuchungen im Buntsandstein und Muschelkalk Nordbayerns. Hydrochem. u. Hydrogeol. Mitt. Inst. f. Wasserchemie TU München, 2

Udluft P (2000):
MODBIL - Water-Balance-Model. Universität Würzburg. Unpublished