# GROUNDWATER EXPLOITATION IN THE AREA OF MAPUTO, MOZAMBIQUE

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## ABSTRACT

Maputo, the capital of the People's Republic of Mozambique, with about 1 million inhabitants, faces serious water supply problems. It is expected that at the end of 1989 surface water supply will be increased to 6 000 $m^3$/hr. This amount will meet the demand of the canalized parts of the city in 1989. Groundwater exploitation contributes another 1 200 $m^3$/hr. Lack of funds and executing capacity for a canalization programme connecting the suburbs forced the National Directorate for Water Affairs (DNA) to start intensive exploitation of the regional dune and (calcareous) sandstone aquifers. Besides this the intensification of agriculture in the coastal zone and a river valley near the city resulted in another groundwater demand. Future urban water supply will also depend partly on the exploitation of groundwater.

The regional aquifers are of limited extension. Analysis of existing and new geohydrological information and geophysical surveys resulted in a detailed knowledge of aquifer parameters, groundwater levels and the position of the fresh/salt water interface. Separate studies gave data on the recharge. A quasi-3-dimensional groundwater model has been applied to evaluate the various extraction policies. Key parameters are groundwater levels and the position of the fresh/salt water interface. Protection areas have been defined. A choice has been made for the restriction of some areas to exploitation of groundwater only for agricultural use. A cost/benefit analysis of this type of exploitation is presented. As a consequence of this decision the costs of future city water supply by groundwater exploitation will increase, as the allocated area for this objective is 30 km north of the city.

To prevent overexploitation of the aquifers DNA introduced a system in which all new boreholes need the autorization by DNA.

## 1 INTRODUCTION

Maputo, the capital of the People's Republic of Mozambique, is situated in the Southern part of the country at the outlet of the Tembe and Umbeluzi rivers into the Maputo bay (see Fig. 1). At present the number of inhabitants is about 1 000 000, about 400 000 more than in 1975 at independence. About 35 % of this number lives in the 4 by 6 km urbanized area. The other part is living in the semi-urbanized areas around up to 20 km from the center of the city.

The increased number of inhabitants and a high priority for water supply in the semi-urbanized areas after independence resulted in the necessity of extension of the old Umbeluzi river water supply system and the investigation

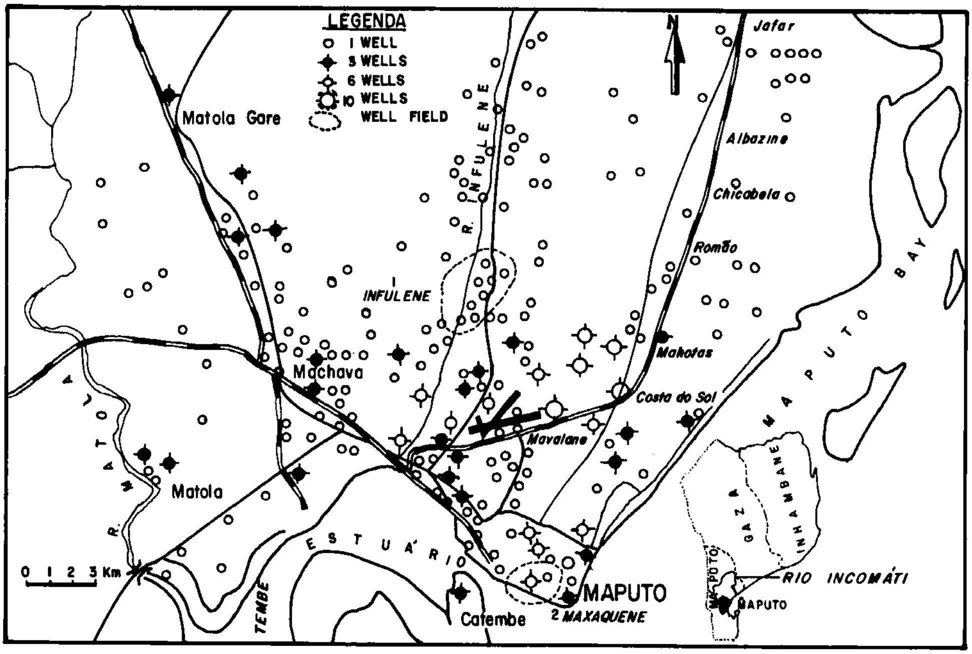


Fig. 1. Location of the area and wells

of alternatives. Several works on the extension and upgrading of the old system are being executed. This will lead to an increase of the water supply with 3 000 $m^3$/hr to 6 000 $m^3$/hr in 1989 which is sufficient for the demands at that time in the part of the city with a good distribution system. However canalization to the semi-urban areas has to be recovered or newly constructed. This led to a growing pressure on the groundwater resources in the area of Maputo. Drilling programs are being executed for several purposes. Being aware of the danger of overexploitation and salt water intrusion the National Directorate for Water Affairs (DNA) set up a system to manage the scarce groundwater resources in the area.

The basis of this system is the hydrogeological knowledge of the area and mathematical models to simulate the effects of groundwater exploitation strategies.

## 2 HYDROGEOLOGY

The area of Maputo forms part of the southern sedimentary basin with eastward dipping deposits. Within the study area the deepest layer of interest is the Grudja Formation of Upper Cretaceous age consisting mainly of clayey sandstones, marls and clays. On top of it the Lower Tertiary Salamanga Formation was deposited. Around Maputo the lithology of this Formation changes from calcareous sandstones in the West via argillaceous sandstones in the

C entral part to calcareous sandstones and sandy carstified limestones in the East (IWACO/DNA, 1986). These formations were covered by dunes during the Upper Pleistocene forming the present landscape.

From the hydrogeological point of view the fine grained Grudja deposits can be regarded as an impermeable base. The Salamanga deposits have moderate to high transmissivities and are indicated as the second aquifer. The first aquifer is the dune formation. In the coastal plain and the river valleys and its borders the two aquifers are separated by semi-impermeable clayey layers creating semi-confined conditions in the second aquifer.

Mean annual precipitation in the area of Maputo varies between 700 and 835 mm. A recent detailed study of the groundwater recharge revealed values between 140 and 185 mm/yr (IWACO, 1985). One year of continuous groundwater level observations and precipitation data served as a base for the calibration of a slightly modified Thornthwaite and Matter soil water model. Using the calibrated model 30 year precipitation data were analyzed with regard to the groundwater recharge. Groundwater balance studies in the area also resulted in the same order of magnitude of the groundwater recharge (DNA, 1986).

The groundwater flow pattern follows closely the surface water drainage pattern resulting in an eastern or western direction of the groundwater flow component. Only in the southern part of the area the direction is to the south. The groundwater component to the annual runoff of the rivers Matola and Infulene and to the Maputo bay in the coastal plain varies between 15 and 20% of the total groundwater flow . The largest part of the drainage water exapotranspirates in the swampy and agricultural areas of the river valleys and the coastal plain. Groundwater levels at the groundwater divides are 50 m in the north of the area and diminish gradually going to the south (see Fig. 2).

Due to its coastal position a notable salt water intrusion in the second aquifer is present along the eastern and southern part of the area. In the area between Maputo and Albazine DNA executed a detailed geo-electrical campaign consisting of 73 Vertical Electrical Soundings in 11 profiles (DNA, 1986). The interpretation showed that the toe of the fresh/salt water interface is situated at 500 m from the coastline in the southern part of the area. The intrusion increases going to the north to a maximum of 4 km.

Salt water intrusion also occurs at the valleys of the rivers Infulene and Maputo (see Fig. 2). A brackish groundwater area exists also in the northwestern part of the area, which origin is still unclear.

## 3 NUMERICAL MODELLING

In its hydrogeological study of the area north of Maputo IWACO/DNA (1986) used the quasi three-dimensional groundwater flow package TRIWACO to simulate and forecast groundwater levels and the position of the fresh/salt interface.

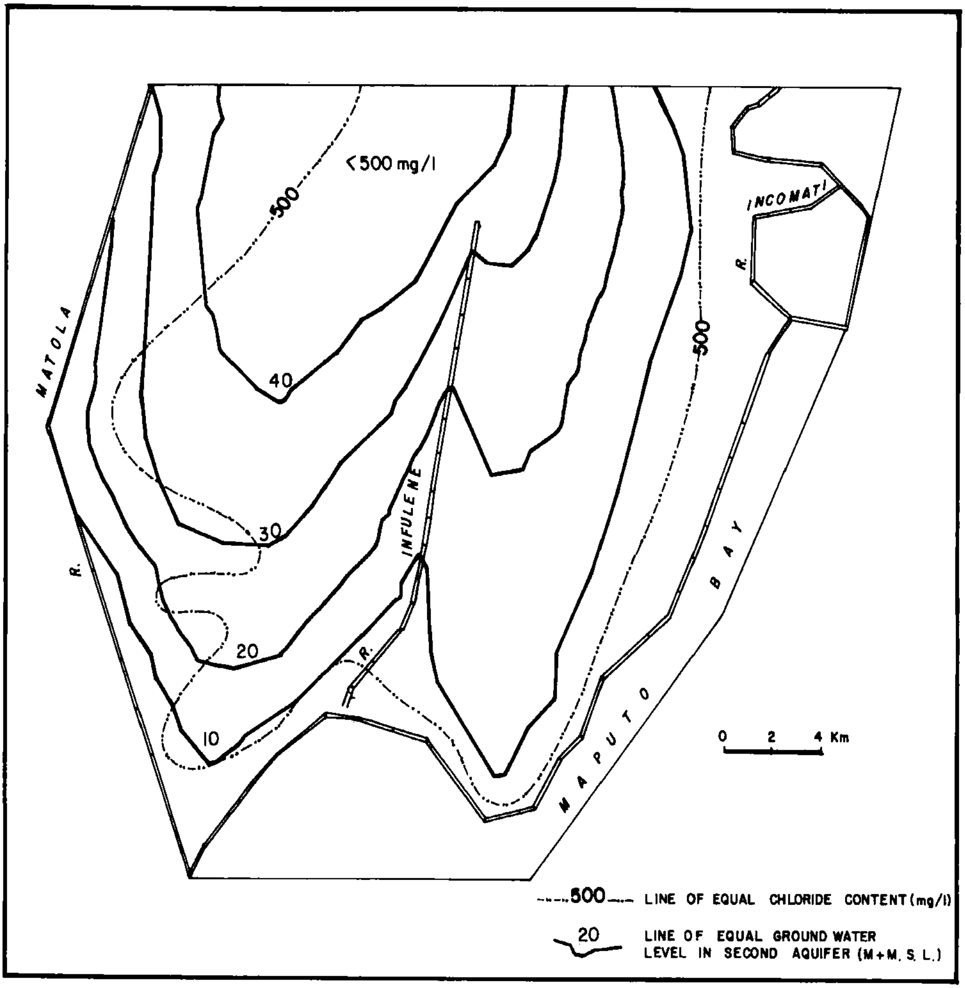


Fig. 2. Calculated groundwater levels in 1964/65 and chloride content

The package proved to be a successful tool. Therefore a separate static two layer model including surface/groundwater relations and salt water intrusion in the second aquifer has been made for the area of Maputo and its neighborhoods (Chutumiá 1987).

A finite element triangular network was designed with 325 nodes and 625 elements (see Fig. 3). Existing wells were introduced as single or multiple extraction points. The applied boundary conditions are that there is no flow at the western and northern limits and constant heads at the southern and eastern limits of the model.

The model has been calibrated using groundwater levels of 1964/65. The general configuration of the groundwater contours in the area was well simulated. In the zones with a lot of borehole data maximum differences between

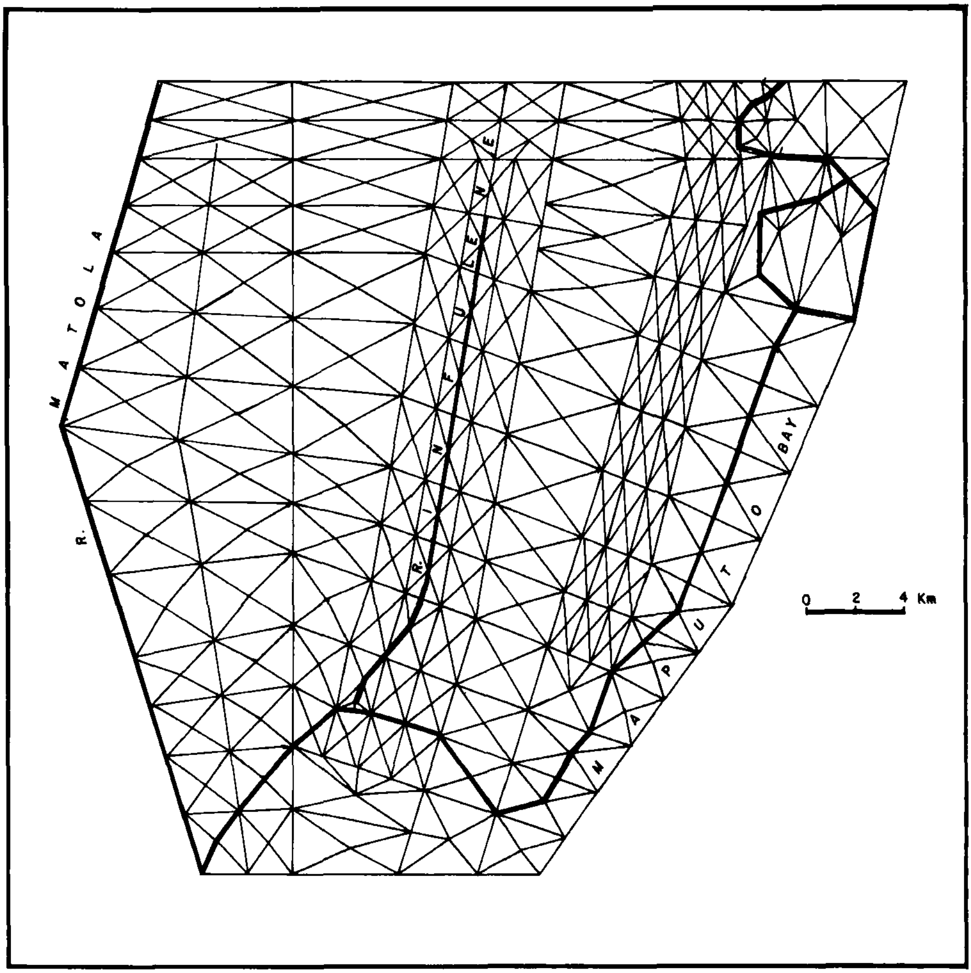


Fig. 3. Finite element grid

the observed and calculated levels were less than 5 m. In the area north of Matola where geohydrological data is very scarce this difference locally increased to 12 m.

Using existing data of several data bases the extraction rate in 1985 has been estimated to be about 12 000 $m^3/d$ of which about 30% is for industrial use and the other part for agricultural and domestic use. Introduction of this number in the groundwater model resulted in lowering of the groundwater level in comparison with the calibration of 2.0 to 4.0 m in areas with high concentrations of wells and 0.5 - 1.5 m in the other areas. The fresh/salt water interface hardly is influenced by this extraction.

Calculations have been made increasing the 1985 extraction rate with 25, 50, 100 and 200%. In these calculations the exploitation of the recently

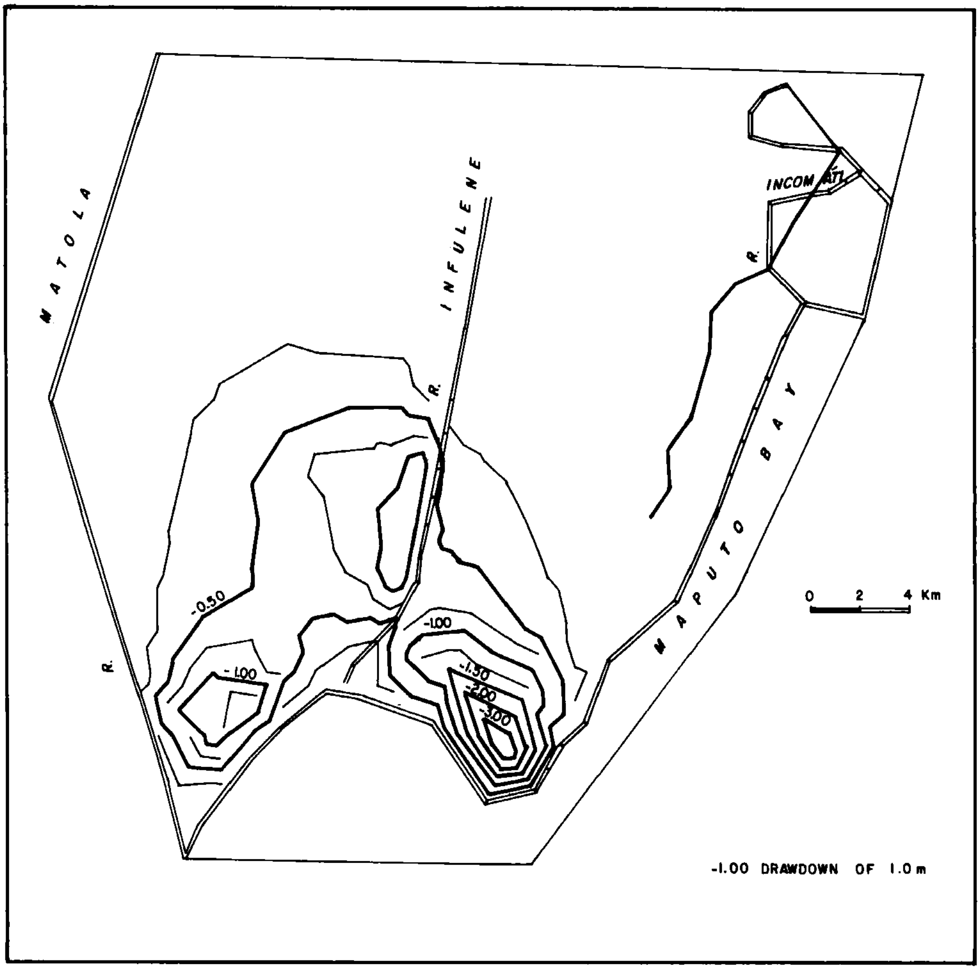


Fig. 4. Additional drawdowns with an extra 50% extraction

constructed emergency well fields is included. Up to 50% increase in exploitation the effects on the groundwater levels are moderate (an extra drawdown of about 3 m in the area with high concentration of wells) (see Fig. 4). The fresh/salt water interface does not suffer a large displacement (less than 300 m).

With an increase of 100% additional drawdowns are 10 m in the areas with a high concentration of wells. This value has to be compared with the height of the aquifer of 25 to 40 m. The fresh/salt water interface intrudes 1 500 to 2 000 m. Both indicators show that this increase will result into a rapid decline of the availability of fresh groundwater resources in the area.

## 4 GROUNDWATER MANAGEMENT SYSTEM

The first steps towards a groundwater management system have been developed. recently. The components of this system are:

- hydrogeological data base compilation
- elaboration of water balance studies
- elaboration of a form for the request of a tubewell
- establishment of agreement with drilling companies
- setting up of an extraction control system

Existing hydrogeological data bases have been used to construct thematic hydrogeological maps and inventories of the pumping data on the existing tubewells.

Apart from the water balance included in the numerical model separated water balance studies have been made (see Table 1).

TABLE 1

Water balance data on selected areas of Maputo

| Area $km^2$ | Flow per m $m^3/d/m$ | Allowed yield $m^3/h$ | Number of wells existing | possible |
|---|---|---|---|---|
| Maxaquene well field | 3.75 | 150 | 7 | 7 |
| Infulene well field | 1.2 | 165 | 9 | 9 |
| Coastal area north of Maputo | 1.3 | 455 | 63 | 271 |

For the coastal area north of Maputo an analysis has been made of the effects of the pumping at the salt water intrusion using a simple analytical model given by Bear (1979). Extraction of 50% of the groundwater recharge will not lead to intolerable displacements of the fresh/salt water interface. A protection zone has been defined of 800 m west of the actual position of the toe of the interface. In this zone construction of tubewells is not allowed. For each km length of the area estimations have been made of the actual exploitation and the possibilities for construction of new wells. Taking into account a safety factor of 100% because of the existence of inhomogeneities in the calcareous sandstones the near future permissible yield is determined as 25% of the groundwater recharge. Taking into account also different yields per well the number of newly to be constructed wells could be determined for each kilometer.

Control of the newly constructed wells is a first prerequisite for an effective groundwater management. Therefore DNA developed a decision making process for the execution of new boreholes in the area of Maputo (see Fig. 5). The system tends to be simple to avoid long waiting times and provides DNA with

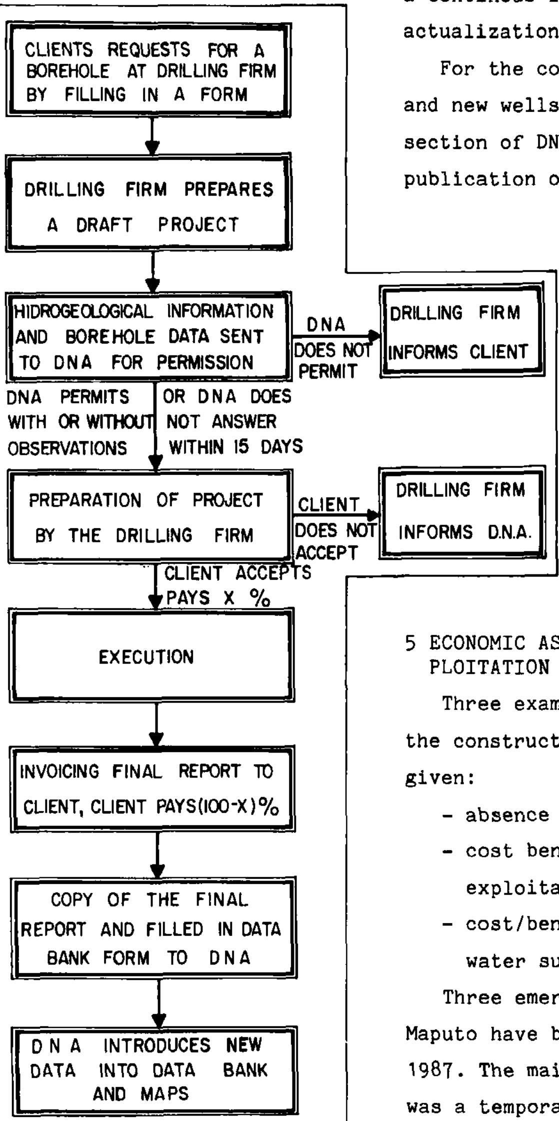


FIG. 5
DECISION MAKING PROCESS ON TUBEWELLS

a continous information flux to guaranty the actualization of the hydrogeological data.

For the control of the yield of existing and new wells personnel of the geohydrology section of DNA is being trained. Until the publication of a new water law DNA has only a limited number of possibilities to interfere in case of not allowed yields. A good control is also hampered by the fact that no obligations exist to install water meters or to provide DNA with data on pumping hours. These instruments will be included in the water law.

## 5 ECONOMIC ASPECTS OF GROUNDWATER EXPLOITATION

Three examples of economic analyses in the construction of wells around Maputo are given:

- absence of economic analyses
- cost benefit analysis of a groundwater exploitation system
- cost/benefit analyses between different water supply systems

Three emergency well fields around and in Maputo have been constructed between 1984 and 1987. The main reason for the construction was a temporary breakdown of the surface water supply system due to flooding of the intake station, resulting in a precarious public health situation. Funds were raised within the international cooperation programs. No economic analysis has been made. The contra-value of the donations in local currency and the exploitation costs of the wells should be included in the water price in Maputo.

The coastal belt to 30 km north of Maputo has been indicated by DNA as an area where groundwater is reserved especially for agricultural use.

The Cabinet for the Green Belts of Maputo executes a project in this area to improve the agricultural outputs a.o. by the construction of wells. In a preliminary economic analysis three different types of irrigation systems were analyzed: tubewells, well points and dug wells. It appears that all systems show -although some low- returns and that the construction of tubewells with PVC casing or with high yields gives the highest annual revenues, followed by the dug well and the well points (see Table 2).

TABLE 2

Economic analysis of groundwater irrigation systems

| Type | Depth | -- Yield -- | | Area | --- Investment costs --- | | | | Costs | ---- Net ---- | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *1000 | | well | pump | ir.eq | tot. | per $m^3$ | revenue | |
| | m | $m^3/h$ | $m^3/y$ | ha | ----- * | 1000 US$ | | ------- | US$/$m^3$ | US$/y *1000 | US$/y/ha *1000 |
| T.W. PVC | 35 | 7 | 8,4 | 2,27 | 4,4 | 5,2 | 1,4 | 11,0 | 0,43 | 3,7 | 1,6 |
| T.W. Iron | 35 | 7 | 8,4 | 2,27 | 6,6 | 5,2 | 1,4 | 13,2 | 0,49 | 3,3 | 1,4 |
| " | 35 | 14 | 16,8 | 4,54 | 6,6 | 5,6 | 4,6 | 16,8 | 0,31 | 9,5 | 2,1 |
| W.P.S. | 6 | 1 | 1,0 | 0,14 | 0,9 | 0,2 | 0,1 | 1,2 | 0,28 | 0,3 | 2,1 |
| D.W. | 5 | 3 | 2,4 | 0,64 | 1,6 | 1,5 | 0,4 | 3,5 | 0,44 | 1,0 | 1,6 |

T.W. = Tubewell W.P.S. = Well Points System D.W. = Dug Well
ir.eq. = irrigation equipment tot. = total

The third type of economic analysis has been presented by IWACO (1986). Untill the year 2000 the water demand of Maputo will increase with 5.500 $m^3$/hr to 12.000 $m^3$/hr. Five alternatives were analyzed (see Fig. 6):

1. A 2.200 $m^3$/hr groundwater system between Mahotas and Pateque (20 km north of Marracuene).
2. A 1.250 $m^3$/hr extension of this system to Manhiça (40 km north of Marracuene).
3. A 1.000 $m^3$/hr extension of the Umbeluzi water works by recuperation of the old plant.
4. A 3.000 $m^3$/hr extension of the Umbeluzi works by the construction of a new plant.
5. A 5.000 $m^3$/hr water supply system from the Incomati river, using water from the planned Corumana dam in a tributary of the Incomati river.

A summary of the results is shown in Table 3. The operating costs include maintenance, energy, raw water, chemicals and personnel costs. An economic lifetime of 30 years and a nett interest rate of 8% is assumed. In the analysis the nett present value method is used to calculate the unuity. The unuity is the nett present value divided by the discounted production (see appendix). It is a measure for the actual costs per cubic meter water. Using the unuity as criterion, the groundwater system north of Maputo would be the cheapest solution followed by the recuperation of the old Umbeluzi plant, the construction of an extension of the Umbeluzi treatment plant, the extension of the new well field to the north and the construction of a water supply system using water from the Corrumane dam.

TABLE 3

Evaluation of alternative water supply solutions (IWACO, 1986. Revised by DNA)

| Option | Capacity $m^3/hr$ | Investment costs • 1000 US$ | Operation costs •1000 US$ | Nett present value * 1000 US$ | Unuity US$/$m^3$ |
|---|---|---|---|---|---|
| 1 | 2.200 | 13.730 | 911 | 24.806 | 0,11 |
| 2 | 1.250 | 12.988 | 934 | 24.344 | 0,18 |
| 3 | 1.000 | 2.519 | 879 | 13.206 | 0,12 |
| 4 | 3.000 | 14.362 | 2.542 | 45.281 | 0,14 |
| 5 | 5.000 | 77.325 | 4.642 | 133.764 | 0,25 |

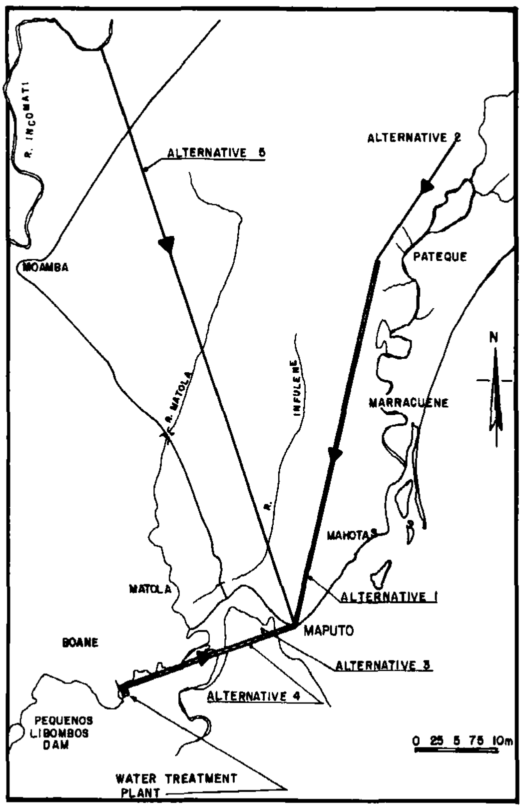


Fig. 6. Water supply alternatives (IWACO/DNA, 1986)

Because of the necessities of agricultural production in the Green Zones of Maputo wich depends highly on the use of groundwater and because of the existence of (future) public water supply alternatives, the coastal aquifer has been indicated by DNA for exploitation mainly for agricultural purposes. As a consequence of this decision the groundwater supply alternative for Maputo will be located further away from the city, thus the costs will increase. Therefore the alternative of the recuperation of the old

Umbeluzi treatment plant will be executed first.

## 6 FINAL REMARKS

The basis for a rational groundwater management is formed by the existence of hydrogeological knowledge and simulation models, management objectives and economic methods to evaluate various groundwater exploitation and water supply systems. For the area of Maputo it is concluded that sufficient hydrogeological data and simulation models are available. The groundwater management objective is clearly defined as the prevention of overexploitation and salt water intrusion. The use of economic methods to evaluate different groundwater exploitation methods or water supply alternatives is still at an initial stage.

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## <u>APPENDIX</u> DEFINITION OF NETT PRESENT VALUE AND UNUITY

### 1 PARAMETERS

| | | | | |
|---|---|---|---|---|
| I = investment | (US$) | i = nett interest | (-) |
| A = annual operation costs | (US$/y) | Q = capacity of the system | ($m^3$/y) |
| n = economic lifetime | (years) | | |

### 2 NETT PRESENT VALUE (NPV)

The NPV expresses all expenditures, discounted to the present (year 0):

- discounted operation cost $= \sum_{t=0}^{n-1} \dfrac{A}{(1+i)^t} = A*\left[\dfrac{1+i-(1+i)^{1-n}}{i}\right] = A*Y$

- NPV = I + A*Y

### 3 UNUITY (U)

The unuity expresses the NPV related to the discounted production to the present:

- discounted production = Q*Y

- $U = \dfrac{I+A*Y}{Q*Y} = \dfrac{NPV}{Q*Y}$ (US$/$m^3$)