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Tampere University of Technology
Department of Civil Engineering
Water Supply and Sanitation
Post Graduate Course in Water Supply and Sanitation 1984-86

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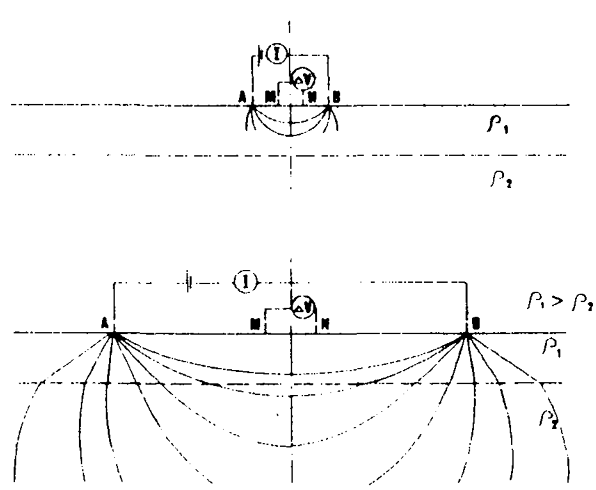
Ground Water Exploration and Assessment in Developing Countries

Workshop Report



Tampere 1984

GROUND WATER EXPLORATION AND ASSESSMENT IN DEVELOPING COUNTRIES

Report on the Workshop held 28 Nov 1984
at Tampere University of Technology (TUT)

Edited by Mr. T.S. Katko

December 1984

GROUND WATER EXPLORATION AND ASSESSMENT IN DEVELOPING COUNTRIES

WORKSHOP 28 Nov 1984

TABLE OF CONTENTS

GROUND WATER EXPLORATION AND ASSESSMENT IN DEVELOPING COUNTRIES

Workshop 28 Nov 1984 at Tampere University of Technology (TUT)

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Prof. Matti Viitasaari
Tampere University of Technology (TUT)

OPENING SPEECH

As a part of the programme of the "Postgraduate Course in Water Supply and Sanitation 1984-86" we will discuss, in more detail, some special questions in the form of workshops. The first workshop of this kind "Ground Water Exploration and Assessment in Developing Countries" is to be held today.

Ground water is generally utilized to quite a limited extent for drinking water supplies in developing countries. It is true that in some areas ground water contains too much chloride and fluoride. However, the advantages of ground water compared to that of surface water are generally clear and therefore ground water utilization should be encouraged.

Proper investigations are necessary for locating ground water deposits as well as for making it possible to use feasible technology when exploiting the aquifers. Investigations might be costly but for reliable ground water resources management they are necessary. To my mind, it is appropriate to use the high and most developed technology in ground water investigations.

Finally I would like to point out to the course participants that in this occasion you have a unique chance to ask questions from senior experts with experience in ground water exploration in developing countries and therefore I hope there will be lively and fruitful discussion.

CONCLUDING REMARKS

by the chairman
Mr. H. Wihuri

The seasonal fluctuations of rainfall are quite important when we consider the availability of water resources. The fluctuations of the annual rainfall values in Dodoma, Tanzania and Stockholm, Sweden are presented in Figure 1.

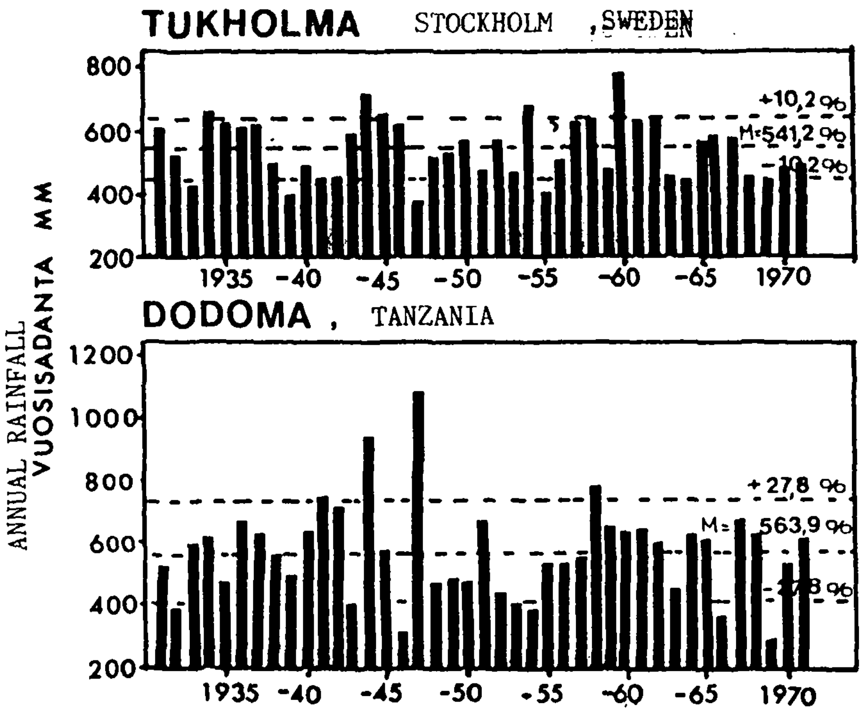


Fig 1. Fluctuation of annual rainfall values in Stockholm and Dodoma.

The fluctuations of rainfall are much higher in Dodoma than in Stockholm. Ground water is therefore more important as reservoir in Dodoma.

Figure 2. illutstrates the relative values of how much water is consumed of total water resources in Africa and Europe as well as the future prospects.

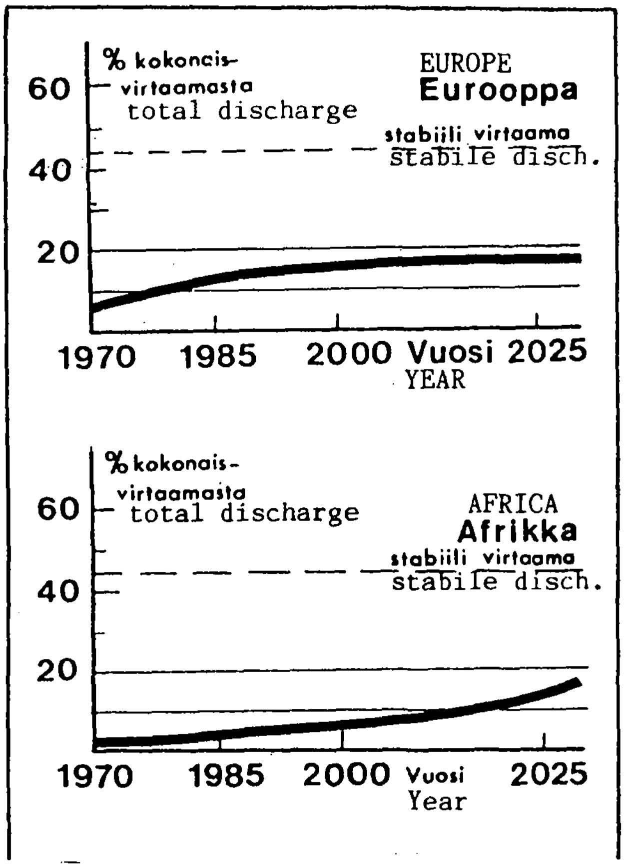


Figure 2. Estimated water demand in Europe and Africa as percentage of the total discharge.

Commonly 20 % is seen as a critical value, 5...10 % can cause temporary problems and values under 5 % do not bring any problems. In northern Africa already in 1975 over 40 % of the flow was utilized and in eastern and central Africa about 10 % respectively. Therefore the importance of water resources management and ground water utilization as a part of it will become more and more important.

Based on papers and discussions of the seminars the following remarks can be concluded

1) Proper ground water investigations have to be carried out before drilling. The use of "hit and miss" -method is not acceptable.

2) Recent trends of ground water utilization seem to have been like pendulum. In 60's the enthusiasm was high towards deep ground water but in 70's the shallow ground water was partly overemphasized.

3) The geophysical prospecting data is information of secondary character and they have to be properly interpreted. The soil and rock properties have to be studied in combination of different methods.

4) It is essential to remember that very seldom the reliability of 100 % is reached in geophysical studies but the bigger the percentage the better. As an individual suggestion 10 % of the total construction costs was suggested for geophysical investigations in ground water projects.

5) Systematic collection of data and the accuracy of this data were pointed out both by projectwise and permanent ground water data banks.

6) It was noted that there are different potential sources of ground water pollution in developing countries. In some places it will be difficult to arrange proper protection because of different interests of different economic sectors.

7) The users (that is we) have to pay for water supply. The most economical solutions should be chosen and quite often this means proper financial input for ground water investigations.

Groundwater is a renewable natural resource. It is valuable and worthy of proper management and protection. As foodstuff, it should be our precious priviledge to use it. The safe source of life - groundwater.

Dr. Esko Mälkki
Kuopio Water District Office
National Board of Waters

IMPORTANCE OF GROUND WATER INVESTIGATIONS AND UTILIZATION

General

The population has always settled in areas where there is possibility to get water, practically only there. In earlier times times the term "get water" also meant that water was available or near the ground level, either in the form of surface or ground water or both.

In many regions - apparently without any visible, permanent water sources - ground water can be found, but only in deeper horizons. In other words, we have deep ground water potential which is often unknown.

This situation exits even in arid regions if the ground water flow conditions allow the long distance water transport from any recharging area. Well-known examples are the oasis in deserts, actually they are only outcrops of long distance ground water flow or "stream". We can, however, concentrate on "normal" hydrological conditions with sufficient rainfall. This means nearly always good possibilities for ground water reservoirs. The only question is whether it is possible to utilize the reservoir or not.

The Complicated Ground Water Conditions

In surface water basins the water is visible and its behaviour can be more or less easily estimated or investigated. This does not apply to ground water. Except for discharge areas or outcrops of water (like pits) the ground water is "concealed" from direct observation and the rules regulating it are complicated.

The most important factor is the geological environment. We can recognize large geological and hydrogeological units (Fig 1) where the ground water occurrence and utilization possibilities differ extremely from each other. By concentrating on some of the most common hydrogeological units it is possible to compare the conditions between the basement and sedimentary rock areas by using the most important hydrogeological parameters (table 1).

Table 1. Comparison of hydrogeological parameters in sedimentary and basement areas.

Parameter	basement	sedimentary
size of the hydrological circulation	small	large
parameters of the water balance		
- evaporation	high	low
- runoff	low	high
size of water reservoir	small	large
total GW potential/ basin	small	large
yield of single well	low	high
depth of the GW level	shallow	deep
springs	low yielding	can be high yielding

We can observe that the investigations as well as utilization of the ground water presupposes quite different technology depending on hydrogeological conditions.

Ground Water Investigations

When speaking of the ground water investigations we have to define what we want to do. Do we make investigations in deep or shallow water conditions? What kind of technology is to be applied? What is the accuracy necessary in investigations? General inventory or detailed investigations?

The drilling of a single borehole is always expensive. Therefore we have to avoid it as far as possible. Before drilling, any "lighter" investigation operations must be performed.

Ground water investigations can be general or they can include detailed investigations. The areal work is usually the first step before detailed investigations because - if performed in a general way - it is cheap and gives outlines for the water utilization possibilities and detailed investigations (Figs 2 and 3).

The more detailed technical investigations are always performed in areas (1) with satisfactory groundwater potential, or better, in probable aquifer areas and (2) where water demand exists. Any systematic water prospecting by technical methods without the knowledge of water demand is out of the question.

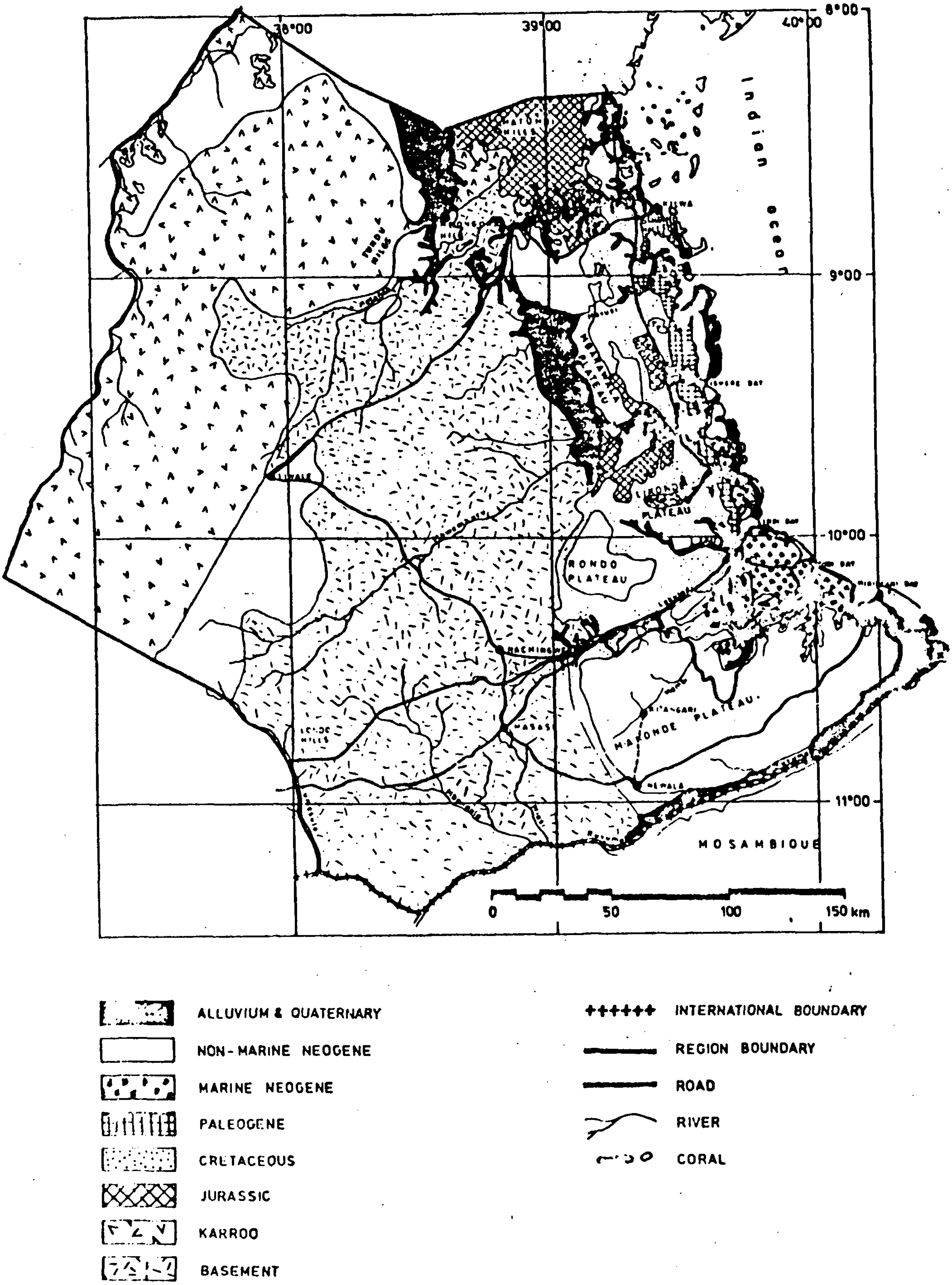


Fig.1. Geological map of Mtwara and Lindi regions

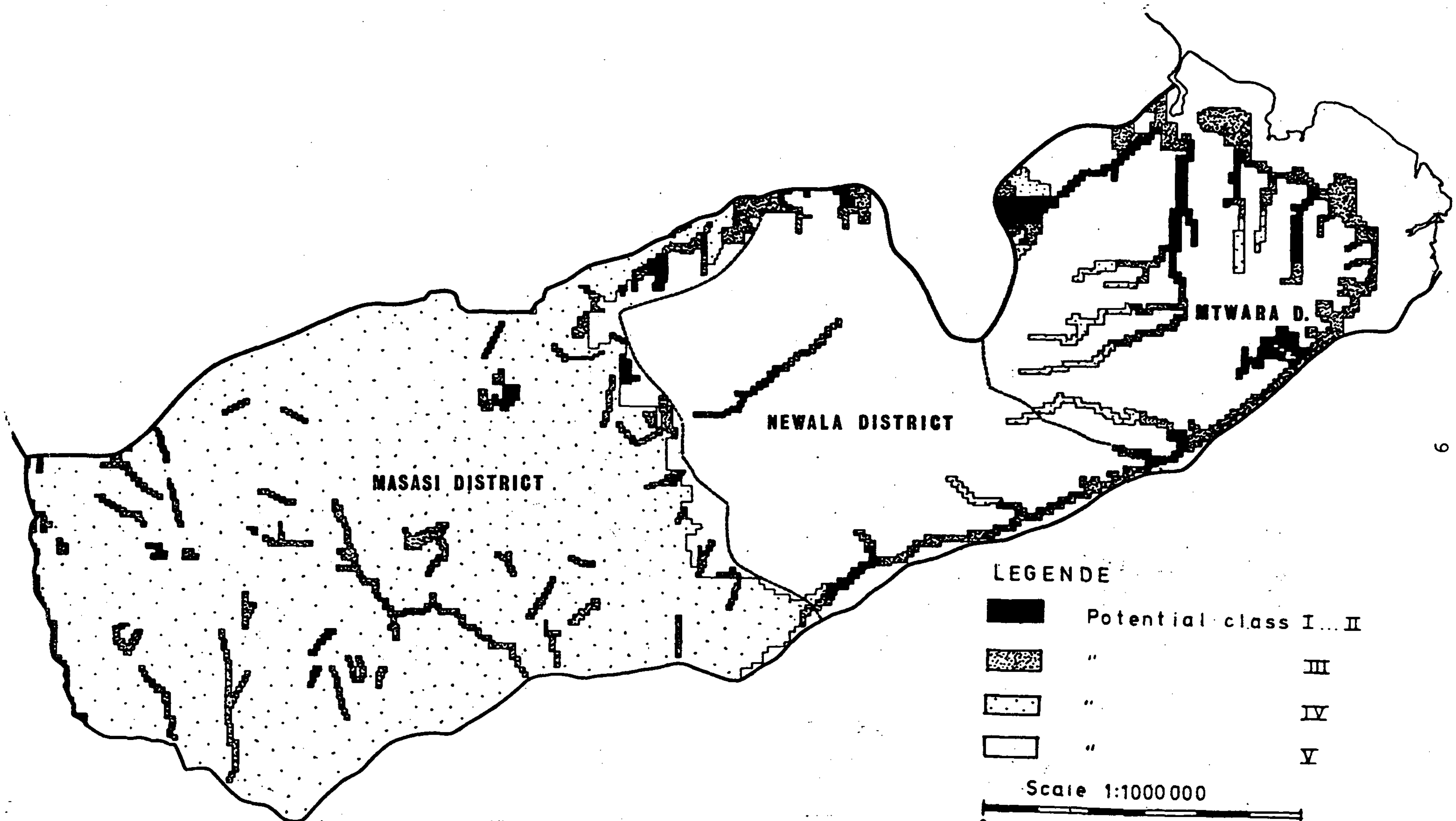


Fig.2. Deep Ground Water Potential Classes in Mtwara and Lindi Regions in Tanzania

Ground water investigations can never be regarded as easy operations. Even the finest geological starting point can be deceptive because so many factors influence simultaneously the final results. For instance, the best aquifer conditions in the basement area can, at the same time, mean the conditions of saline water occurrence. Therefore the choosing of the investigation points is more or less a compromise between the amount and the quality of water.

The Importance of Ground Water as a Water Source

Numerous diseases are caused by unhealthy water. Above all, surface water sources deserve a mention. We know that even our surface sources in Finland can contain microbes which make the water unsafe (if not treated). In tropical conditions the influence of the living organisms in water can be extremely strong.

Ground water can also be dangerous in this sense. All open water like water pits, can catch impurities from air, animals and man in many different ways. During the work of the Mtwara-Lindi WMP in Tanzania it was observed that over 100 000 people or over one third of the whole population living in rural areas used this water.

There is, however, the question of artificially polluted ground water. Natural ground water is pure and safe to use. Ground water is the key word in water supply. It is naturally protected from impurities and, as a healty water source, can have a remarkable influence on decreasing the number of different diseases. Because ground water resources are more common and more available than commonly understood, they can be the basis for water supply especially in rural areas.

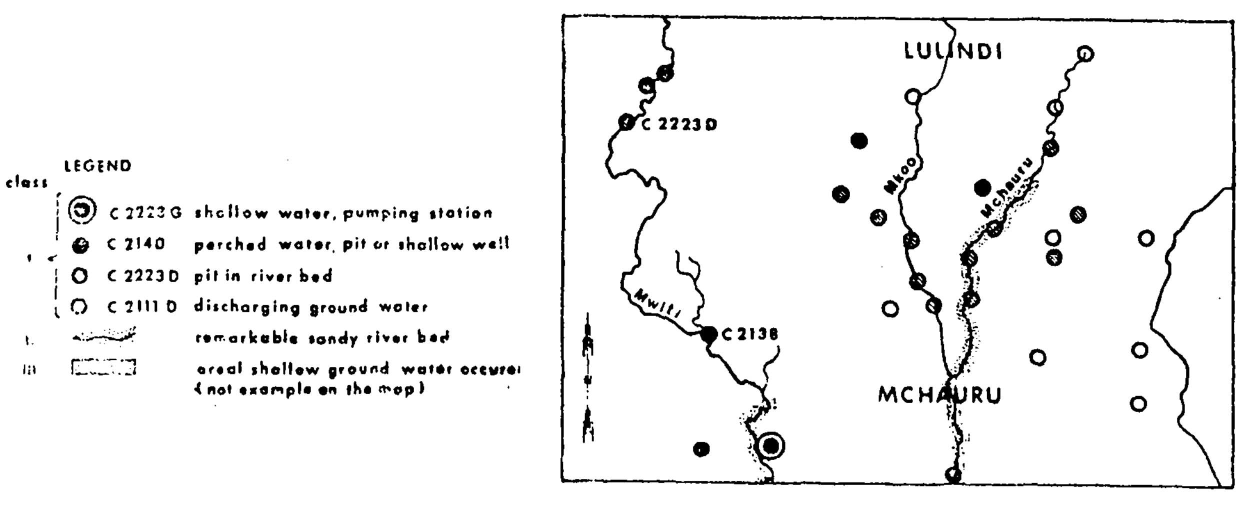


Fig 3. Example of shallow ground water occurence in Mtwara region in Tanzania

DISCUSSION

Professor Viitasaari wondered how to locate the shallow wells in the easiest way. The speaker replied that the best method is to ask the local people for those aquifers or traditional water sources which will not dry or will be the least likely to dry up during the rainy season.

Mr. Jalkanen pointed out that by using air-photos or satellite photos we can study the general conditions determining ground water existence. Generally the airborne methods are the only applicable ones for large areas under survey.

Professor Viitasaari reminded that the local technicians or foremen can be trained to be capable of independent field work of e.g. seismic or electrical resistivity sounding.

Mr. Heikki Wihuri
Soil and Water Ltd.

RECENT TRENDS IN GROUND WATER RESOURCES UTILIZATION IN AFRICA

The existence of populous ancient civilizations is linked to the presence of large rivers. Away from the great rivers, Africa does not have a great many surface-water sources, especially during the dry season. Until recently ground water was taken only from relatively shallow holes dug in alluvial beds where the surface water disappears during the dry season.

During the second quarter of the present century there has been progress in the exploration of groundwater resources as a result of experiences in oil exploration in the Middle-East and the expansion of drilling equipment industry. The first "boom" was just after the Second World War. We can say that generally the modern ground water drilling technology started in 1960's in Africa, Europe and northern America. This exploration meant mostly percussion drilling by "hit or miss" method. In Africa the anglophone and the francophone countries have had a bit different approach to ground water utilization.

Along with drilling and investigation methods the calculation methods of ground water deposits were developed. The need for cooperation between civil engineers and hydrogeologists became evident but for some reason it took too long for them to find each other.

The next boom was the very high interest on the use of shallow ground water which took place in the 70's. It seems obvious that the interest went a bit too far because the development of deep ground water knowledge was more or less neglected. This boom also contributed to the underestimating of the importance of proper ground water investigations. The oscillation of the pendulum has thereafter changed its direction and now we are perhaps in a situation where the importance of both "types" of ground water is understood. This means advanced technology especially when investigating deep ground water deposits.

In ground water investigations like in all human activities the 100 % success is not possible. At the present we are perhaps at the success rate of 75 % and I believe we should be able to raise it up to the level of 85...90 %.

When arranging water supply systems, the economical aspects have to be kept in mind. The unit cost/capita must be affordable for the consumers not forgetting the costs of operation and maintenance. Ground water, especially shallow wells, are cheaper for rural people who cannot afford nor operate huge surface treatment plants. However, in cases when the aquifers are not big enough especially around large cities there are not many choices and sometimes it is possible that the surface water source with treatment is the only alternative.

DISCUSSION

In discussion the questions of shallow well siting and construction during different seasons were raised. It was noted by Prof. Viitasaari that in most cases, for practical reasons, it is not possible to construct wells only at the end of a dry season although this would be preferable to secure the yield of a well. This can be partially solved by constructing the well in two phases and making it deeper by excavating and installing a smaller diameter ring inside the previous ones.

Dr. Mälkki pointed out that in some conditions, especially in basement areas with aquifers of limited size it is not possible to use the suggested method.

Mr. Erkki Jalkanen
Georesearch

GEOPHYSICAL INVESTIGATION METHODS

Examples of failures of geophysical methods

The following fictitious examples will expose how it is possible to fail with geophysical investigations, especially when combinations of different methods are not utilized, and preinformation of the geological conditions is inadequate.

For the sake of simplicity the examples deal with certain dike-shaped formations.

1. There is magnetite concentrated into a dike in the bedrock. The resistivity profiling will give an anomaly of low resistivity because of the high metallic conductivity of the magnetite. An additional magnetometric survey on the same profile would save the investigator from failing.

   In this case the formation is hydrogeologically unusable, if there is no fracturing in the dike or in the surrounding (Fig A and B).

2. In this case the formation contains fragmented sulphides in it instead of magnetite.

   The electric conductivity is high due to the metallic content of the material, causing again a low resistivity anomaly. If the magnetometer is used additionally, no special anomalies will be observed.

   From this viewpoint the signs would allude to hydrogeologically favourable situation.

   However, an extra seismic or gravity survey will expose the "solid rock" character of the material (Fig A,C and D).

3. This is a case of slight magnetite concentration in a fracture zone, which could be basically usable for a borehole. The resistivity survey will give an anomaly of low resistivity due to the metallic conductivity of the material and also due to the electrolytic conduction in the presence of the groundwater in the fissures of the rock.

   An anomaly of higher magnetic permeability would be observed with magnetometric survey.

   The investigator might refer to the 1. case, in case he has this knowledge, and exclude the site for further study.

However, the seismic or gravity survey could expose the secondary permeability (secondary porosity favoring groundwater) of the formation, due to the lower velocity of seismic waves, or lower density detected by the gravity survey, (Fig A,B,E).

4. In this case there is a heavily weathered, originally granitic zone, the weathering grade, of course, not being known beforehand. Due to the electrolytic conduction (the presence of water is assumed) the resistivity survey will show an anomaly of low resistivity, nothing special will be observed with the magnetic survey, the velocity of the seismic waves is low and lower density will be observed with gravimetric survey.

   All of these signs together are indicating basically favourable conditions for groundwater existence in the bedrock. However, abundant formation of clay during the weathering process has made the formation almost completely impermeable, considering water, and the site cannot be used for water production (Fig A,C,E).

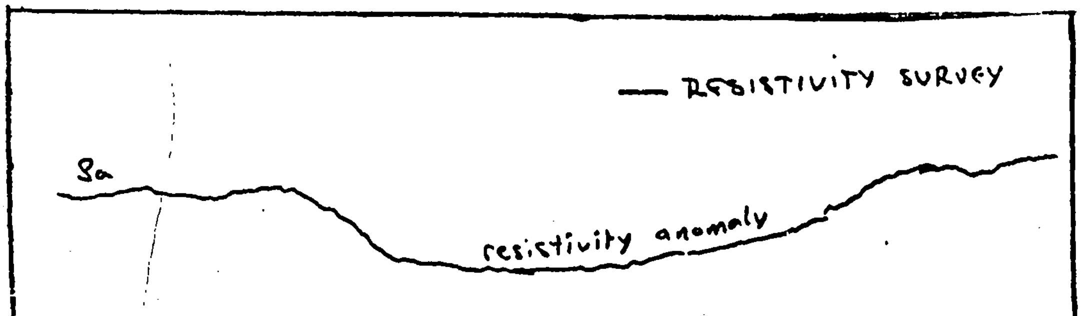


Fig A. Resistivity survey

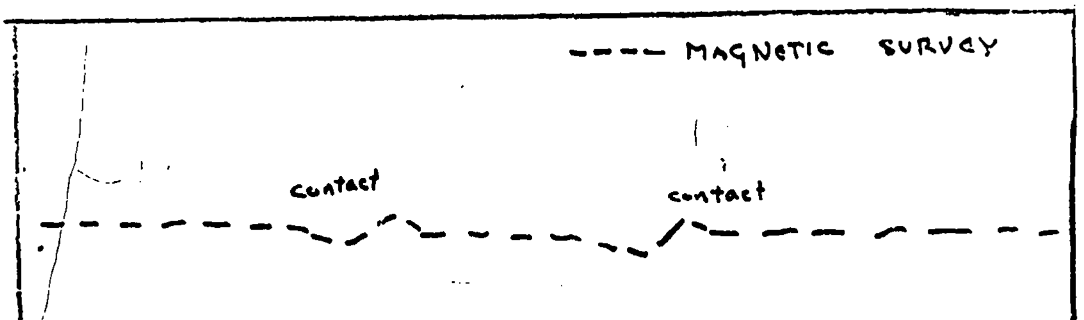


Fig B. Magnetic survey

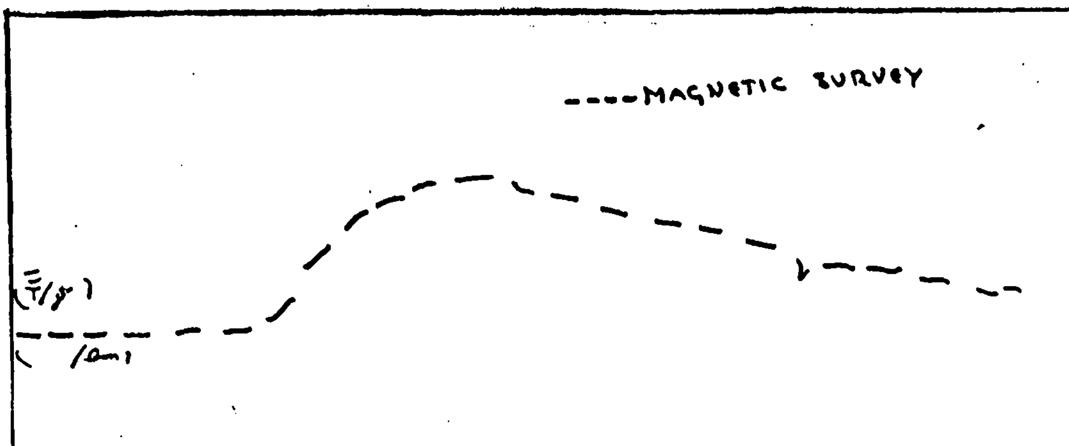


Fig C. Magnetometric survey

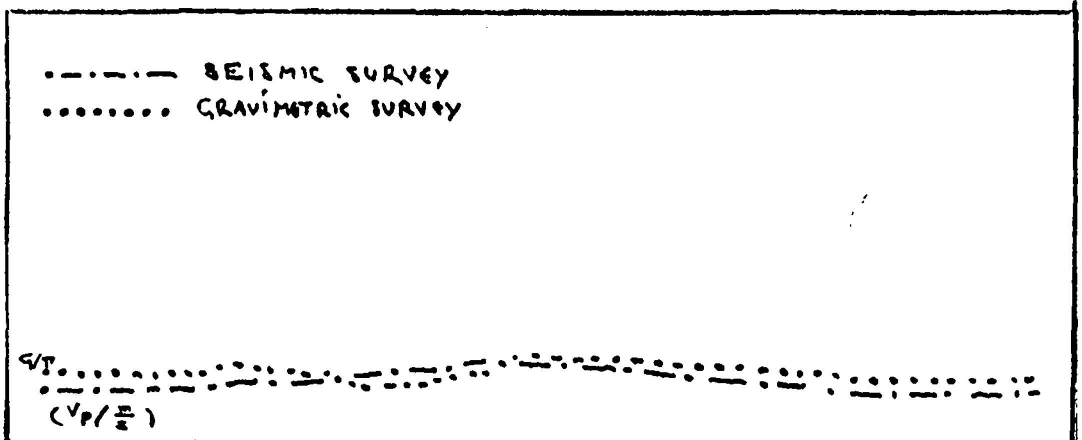


Fig D. Seismic and gravimetric survey

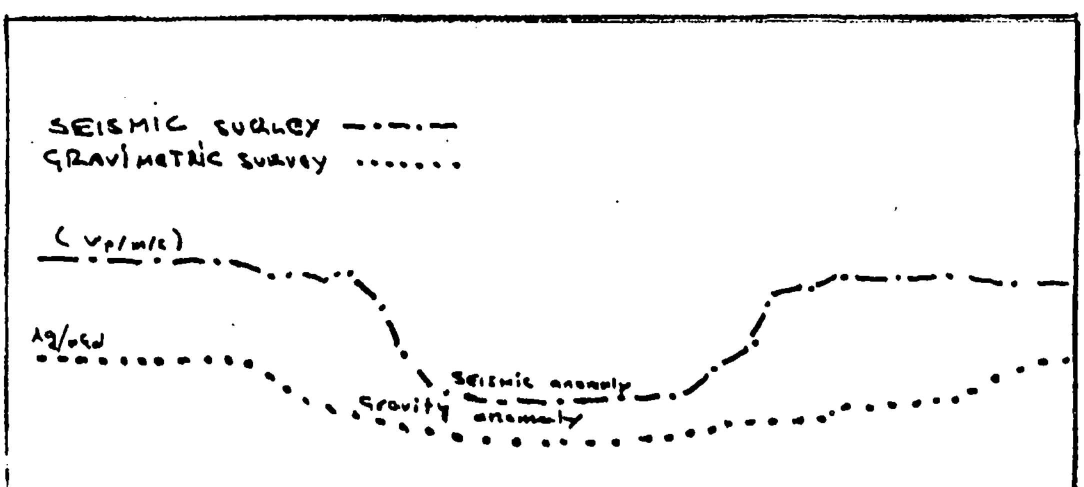


Fig E. Seismic and gravimetric survey

Physical properties of geological environment

The physical properties of the geological environment sensed by the geophysical methods depend much on the total geological prehistory of the area in question. Considering groundwater, the investigation puzzle can be more complicated than one could suppose at first sight.

Some measured properties can in some cases indicate hydrogeologically favourable conditions, but in other conditions they can indicate completely opposite features, which cannot be known beforehand. For this reason, using only one method with groundwater investigations is playing roulette with somebody else's money.

In addition, the range of variation of a certain physical property of a certain type of earth material varies a lot depending, not only on the material itself, but also on the location of it and the secondary characteristics in the surroundings of the geological milieu.

The variation ranges of the same physical property of different materials overlap with each other to such an extent that no straightforward conclusions to bridge the results of the measurements and the properties of the formations should be made without considering secondary regional effects, typical of each area.

If we look at the physical properties of different rock and soil types, we easily note that the density of different soil and rock-types are quite close to each other (Fig 1.)

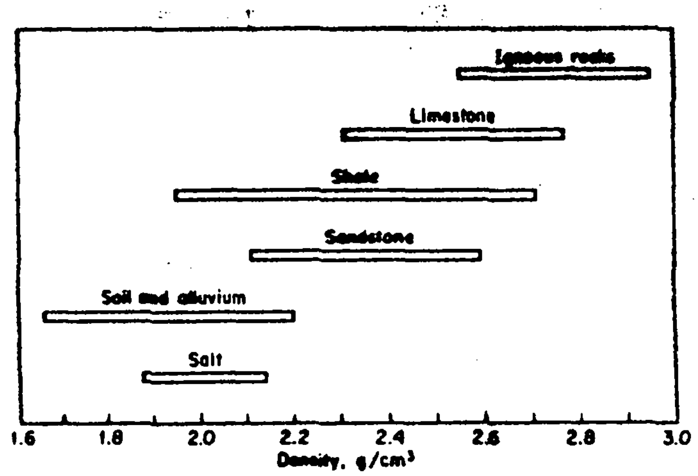


Fig 1. 80 percent fiducial limits of small-specimen bulk densities of various kinds of rocks.

The average resistivity values of different types of rocks and soils are in the same range as well as shown in Figure 2.

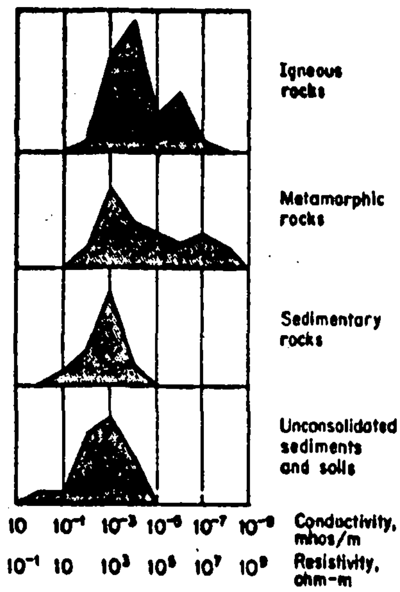


Fig 2. Histograms of resistivity measurements

It is of great importance to understand that there are no direct links between one rock and soil type and one physical property but each rock and soil type has got a different variety of physical properties.

REMARKS

Finally I want to present the following six remarks concerning the geophysical investigation methods.

1. The metallic mineral potential should be considered, even if the project is for groundwater.

2. The ranges of different rock and soil properties overlap with each other.

   There is no direct correlation between a certain physical property and the geological formation (as one to one mapping).

3. The actual properties of soils and rocks tend to depend more on the circumstances on the site than on their geological classification.

4. The geophysical properties of soils and rocks should be studied as having their global location as a parameter and the classified spesific type as a constant.

5. There is no method which can solve the problems when used alone. It is possible that there is no selection of methods which can solve the problems together, each new method brings new parameters to the system, which can be more than it rejects out.

6. No more new methods! More basic research and brainwork.

DISCUSSION

The chairman pointed out that "a tailor of 2 marks makes easily a five marks' error". It is normally the cheapest way to get information on ground water existence by geophysical methods. This information is, however, of secondary character and therefore the most important phase is the interpretation of data.

The speaker answered to a question made by Mr. Mashauri that it is better to restrict the geophysical investigations to prechosen methods. These methods have to be chosen so that they support each other.

Mr. Luonsi wondered if it is possible to say e.g. that resistivity sounding is more applicable in sedimentary than basement areas. The speaker said that methods to be used depend very much on the environmental conditions and it is difficult to give any general rules on methods to be used for different geological zones. If no geophysics is used there is no hope but if geophysics is used there is some hope for finding ground water.

Dr. Rönkä asked whether we are able to say which is better, seismic or resistivity sounding method for a borehole 30...50 m. The speaker said that resistivity method is much cheaper and it is good in some conditions. However, with this method we have more possibilities for failures than with seismic sounding.

Mr. Teizazu wondered if there are any links between remote sounding and geophysics. The speaker answered that remote sensing is meant to cover large areas and it serves more as preinvestigation where as land based geophysical methods are meant for other purposes.

GROUNDWATER INVENTORY IN SRI LANKA

Mr. Aarno Särkioja
Water District Office of Lapland
National Board of Waters

Introduction

Within the context of the agreement of the development co-operation between the governments of the Democratic Socialistic Republic of Sri Lanka and the Republic of Finland, Plancenter Ltd has been carrying out water resources inventory, design, and construction work in the Kandy District since September 1981.

The hydrogeological investigations were carried out in connection with the Harispattuwa Water Supply and Sanitation Project. The expanded groundwater supply programme was developed during the Appraisal Mission's visit in May/June 1982. The purpose of these extension studies was to obtain information about the occurrence and possibilities to extract groundwater in the southern half of the Harispattuwa project area especially with a view to possible piped groundwater schemes. In the original feasibility study, this area was planned to be supplied with surface water from the Mahaweli Ganga river, and therefore the groundwater studies were planned to cover only the northern half of the project area plus the marginal areas left outside the area serviced by the surface water treatment plant.

However, due to the high cost of the surface water treatment plant compared with the cost of supplying groundwater, it was decided to supply groundwater for the whole Harispattuwa area. This being the case, groundwater would be supplied from the weathered surface layers by shallow wells and from bedrock by deep wells.

The small yield shallow wells would be constructed in the low population density areas and the high yield deep wells with piped groundwater schemes in the high population density areas (see Fig. 1.).

In addition to these, there will also be a few small gravity schemes in the high level mountain areas.

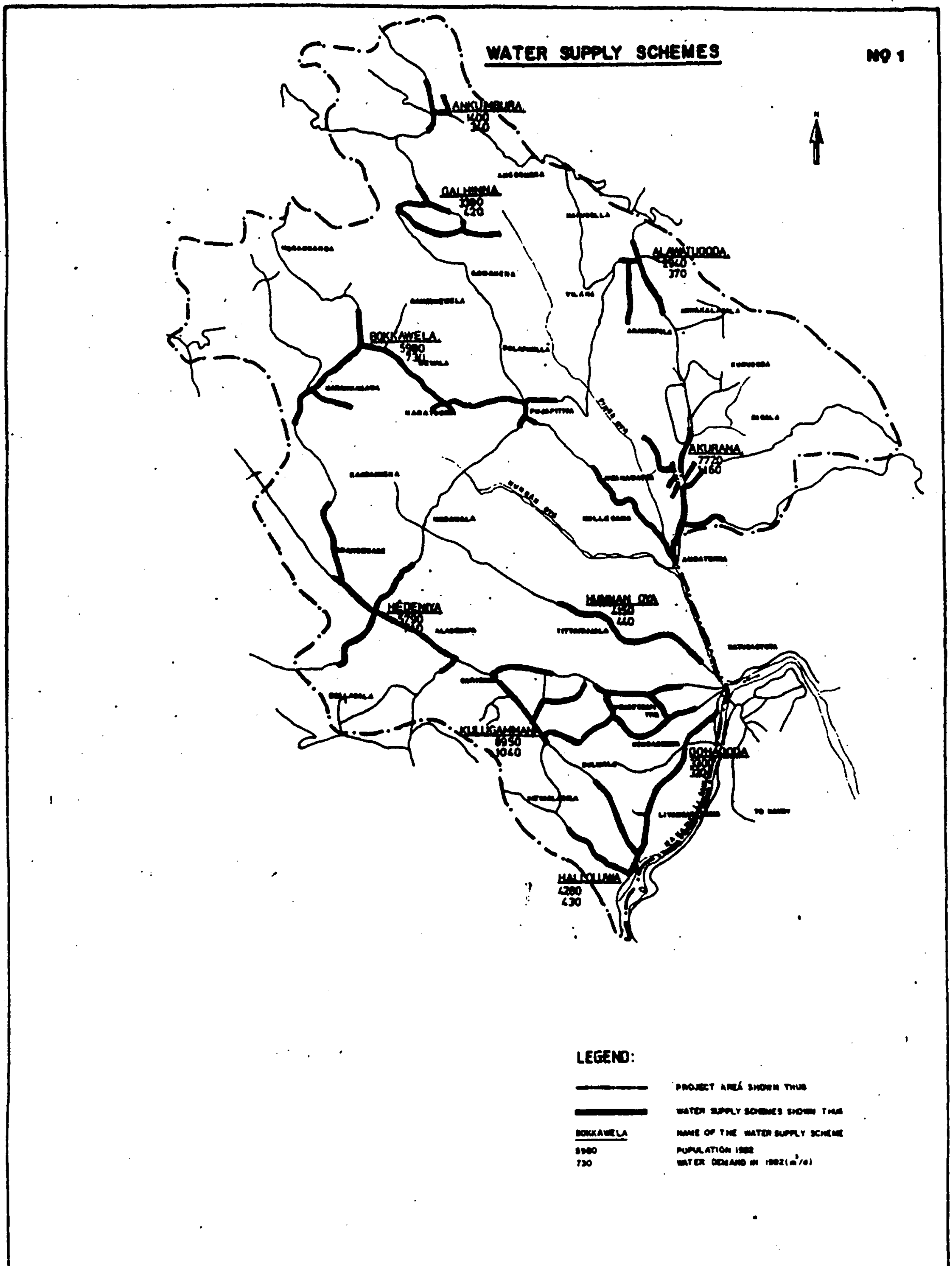


Fig. 1. Water supply schemes.

General Description of the Project Area

Geology and geomorphology

Geologically the area is situated in the Highland series of Sri Lanka which is underlain by precambrian crystalline hard rocks. Morphotectonically, the area is situated in the Uplands of Sri Lanka as part of the Kandy plateau region which is characterized by ridge and valley morphology. The highest parts of the area are approximately 750 m above sea level while the lowest parts along the Mahaweli river in the south and southeast are approximately 445 m above sea level (see Fig. 2).

Climate

Harispattuwa belongs to the Wet Zone. The average annual rainfall is 2400 mm. Most of the rainfall occurs during the inter-monsoonal periods, that is in April-May and October-November. The driest months are March and August. The temperature shows very little variation. The monthly mean temperatures in Kandy range from $23^{o}C$ to $26^{o}C$.

Groundwater surveys

Hydrogeology in the project area is complicated. Complicating factors include the metamorphic rock mass basement which in bulk is considered as an impermeable media. Another important factor is the morphology of the region with its striking elevation differences and steep slopes etc. These affect groundwater recharge and also access to the preferred drilling sites. Among the other complicating factors which can be mentioned are the rainy seasons and the cultivation of rice on low elevation valleys. All of these restrict the carrying out of the drilling programme.

Deep groundwater survey

Hydrogeological investigations have been comprised of the following activities:

- study of the geological and topographical maps as well as aerial photo interpretation.

- field reconnaisence to complete the photo interpretation by detailed observations of soil, rock types, contacts of the different rock types, lineaments, jointed or fractured trend lines in the bedrock.

- locating the suitable sites for seismic investigations and test drillings.

- preparing of site maps of the most important areas with hydrogeological data and location of seismic profilings and test drillings.

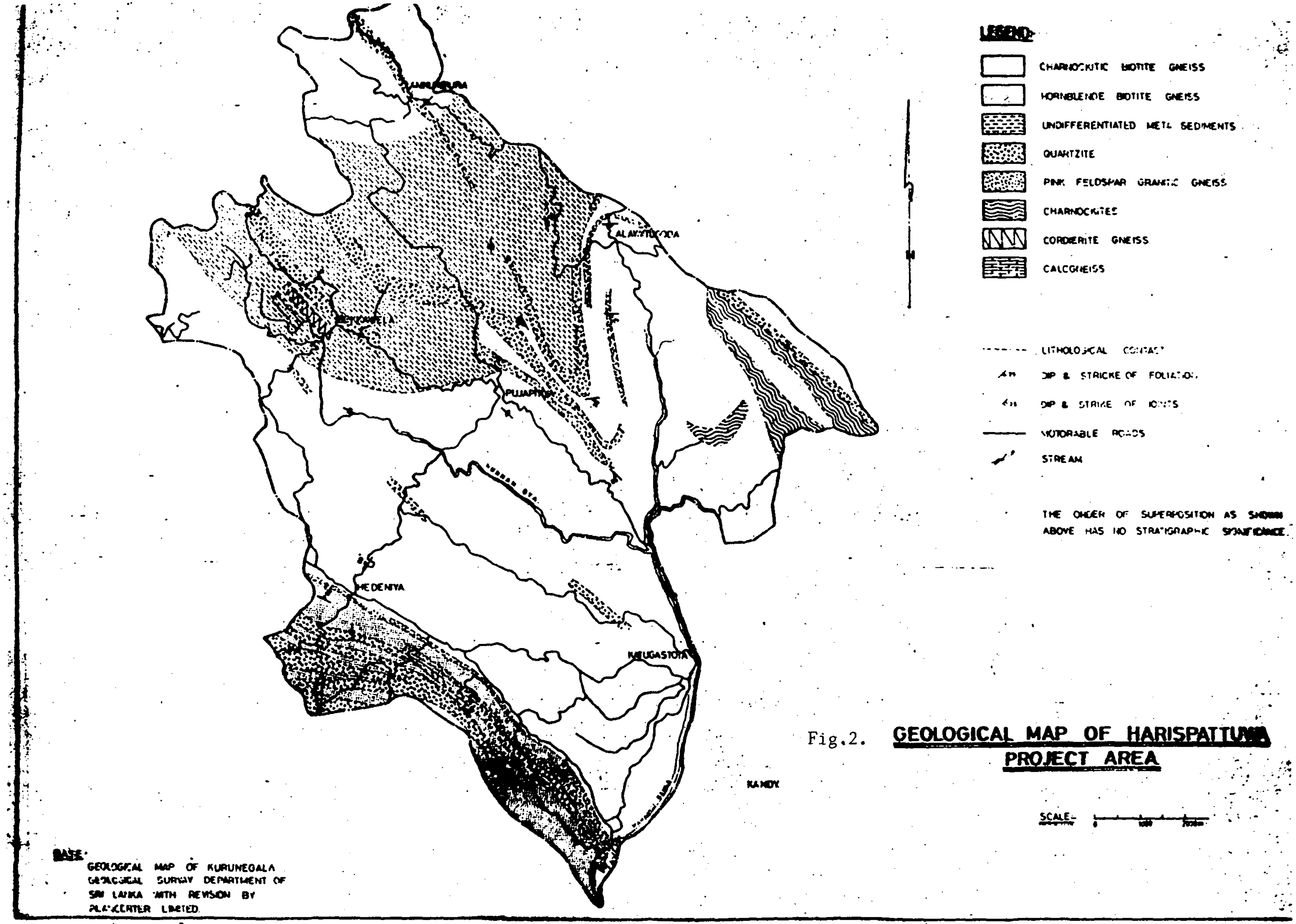


Fig.2. **GEOLOGICAL MAP OF HARISPATTUWA PROJECT AREA**

- the test pumpings of boreholes, monitoring of the groundwater level, and analysing the groundwater samples.

- long-term pumpings of production wells.

Groundwater in Bedrock

The main stress in the deep groundwater survey has been laid on the detection of broken bedrock and favourable rock types to supply water. The work hypothesis has been that the lineaments in general represent zones of weakness (that is jointed or fractured trend lines in the bedrock). Special attention has also been given to the occurance of the contacts of favourable rock types. Some of these rocks which are important in groundwater exploration are described separately.

All the rock types present in the area belong to the Precambrian crystalline rock group of Sri Lanka. The principal rock types are:

1. Charnokitic and migmatitic boitite gneiss.
2. Pink feldspar granitic gneiss.
3. Quartzites and quartz schists.
4. Hornblende biotite gneiss.

1. Charnokitic and migmatitic biotite gneiss

More than half of the Harispattuwa area is underlain by charnokitic biotite gneisses. This rock type is varying in properties from the massive dark coloured rock of amphibolitic or migmatitic with straight or contored foliation.

For hydrogeological purposes, these rock types are not generally favourable because there is no proper weathering or favourable fracturing found in these rock types.

In the southern parts of the area along Pinga Oya lineament, boreholes in this rock type show more weathering and fracturing at greater depths (30-40 m). The majority of the boreholes done along this lineament seem to be giving a good amount of water.

The yield of the best boreholes is more than 1500 l/min.

In this area, the quality of groundwater is very good. Normally, in this rock type, ferro-magnesium is present. In weathered zones, these ferro-magnesium minerals may give rise to a high iron content in the groundwater.

2. Pink feldspar granite gneiss

Pink feldspar granitic gneiss occurs in thin bands forming discontinuous ridges. Many of the higher ridges are underlain by this rock type.

This rock type is weakly weathered and along the rides the bedrock is cropping out at many places. Hydrogeologically, these rock types are important because well developed joints and fractures can be found in these rocks.

The contacts between the other rock types are especially important. The yield os some of the boreholes in these rock types is 100 - 150 l/min. The quality of groundwater is rather good but varies in different boreholes.

3. Quartzite

The quartzites of the area exist as a few discontinuous bands. These quartzites are mainly inter-layered with charnockites and charnockites gneisses. Some of these quartzite bands consist of feldspars.

Hydrogeologically, all the quartzite bands play a major role in the groundwater exploration because quartzites are intensively fractured aquifers. Well developed joints, fractures, and cleavages are prominent in the quartzites because of the high brittleness of the quartzites. The feldspatic quartzines may give rise to highly weathered zones, and these weathered zones may cause problems in deep drilling on the quartzites.

In the Owissa area, the quarzitic bands are associated with a major lineament trendline - the Pinja Oya fault zone. Drilling results show the deep weathering and fracturing. The yield of some of the boreholes is rather good - 100 - 350 l/min.

The quality of ground water in this rock type is rather good. Only in some boreholes is the iron content too high.

4. Hornblende biotite gneiss

Hornblende biotite gneiss is also one of the widely distributed rock types in the Harispattuwa area. This rock type can be divided into two groups on the basis of mineralogy and appearance. Generally, this rock type exists inter-layered with granitic gneiss The joint and fracture intensity is slight, and the joints are tight. Hydrogeologically, this rock type is not very favourable in supplying water.

The yield of the drilled boreholes is 50 - 100 l/min. Generally, the quality of water in this rock type is good.

Structures and Tectonics

Geological structures play a major role in groundwater exploration in hard rocks. The deep groundwater resources consist of all the fractured aquifers. The majority of the fractured aquifers are associated with lineaments and fracture zones. When the fractures and lineaments are considered in groundwater exploration, the orientations of the fractures and lineaments are important. In Sri Lanka NNW-SSE, NW-SE, and WNW-ESE lineaments are open fractures whereas NNE-SSW, NE-SW, ENE-WSW and N-S fractures and lineaments seem to be closed and tight. The open fractures are favourable for potential deep groundwater paths and aquifers (for example the Pinja Oya lineament) whereas the closed and tight fractures and lineaments are not. The major disadvantages of these linear structures (lineament and fractures) in groundwater exploration is the steepness of the linear structures and secondary mineralization along some of the linear structures (see Fig. 3).

Results of the Deep Groundwater Surveys

One of the main objectives of the water supply project was to identify deep groudwater resources which could be used to serve 11 high population density areas where piped groundwater schemes were recommended.

According to the hydrogeological, geophysical and test drillings, there was potential to get deep groundwater for these 11 piped schemes. Generally, the groundwater resources were found very close to the piped scheme areas and the yield of the drilled production wells is adequate to meet water demands. The pilot scheme was the Akurana scheme - one of the largest schemes. It was completed in the summer of 1983.

In the connection with the deep groundwater investigations, small yield boreholes were also drilled. For many of these boreholes, it was useful to equip them with handpumps. In addition to these wells, there was also a special drilling programme to drill boreholes to be provided with handpumps. The so-called handpumped wells were drilled during the wet seasons when the low level paddy areas were out of reach. These handpumped wells will be drilled continuously once the drilling of production wells is completed. These handpumped wells were drilled in those areas where it was not possible to construct shallow wells, usually on high mountain areas in the northern, middle and western parts of the Harispattuwa area and in those areas which were outside the scheme areas.

Totally, by the end of the year 1985, there will be 350 wells with submerged pumps and 650 wells with handpumps. There will also be 11 groundwater intakes completed with 35 deep wells.

In addition to the above described systems, there will be some small gravity schemes in the high mountain areas. The first gravity scheme will be the Yatihalagala gravity scheme.

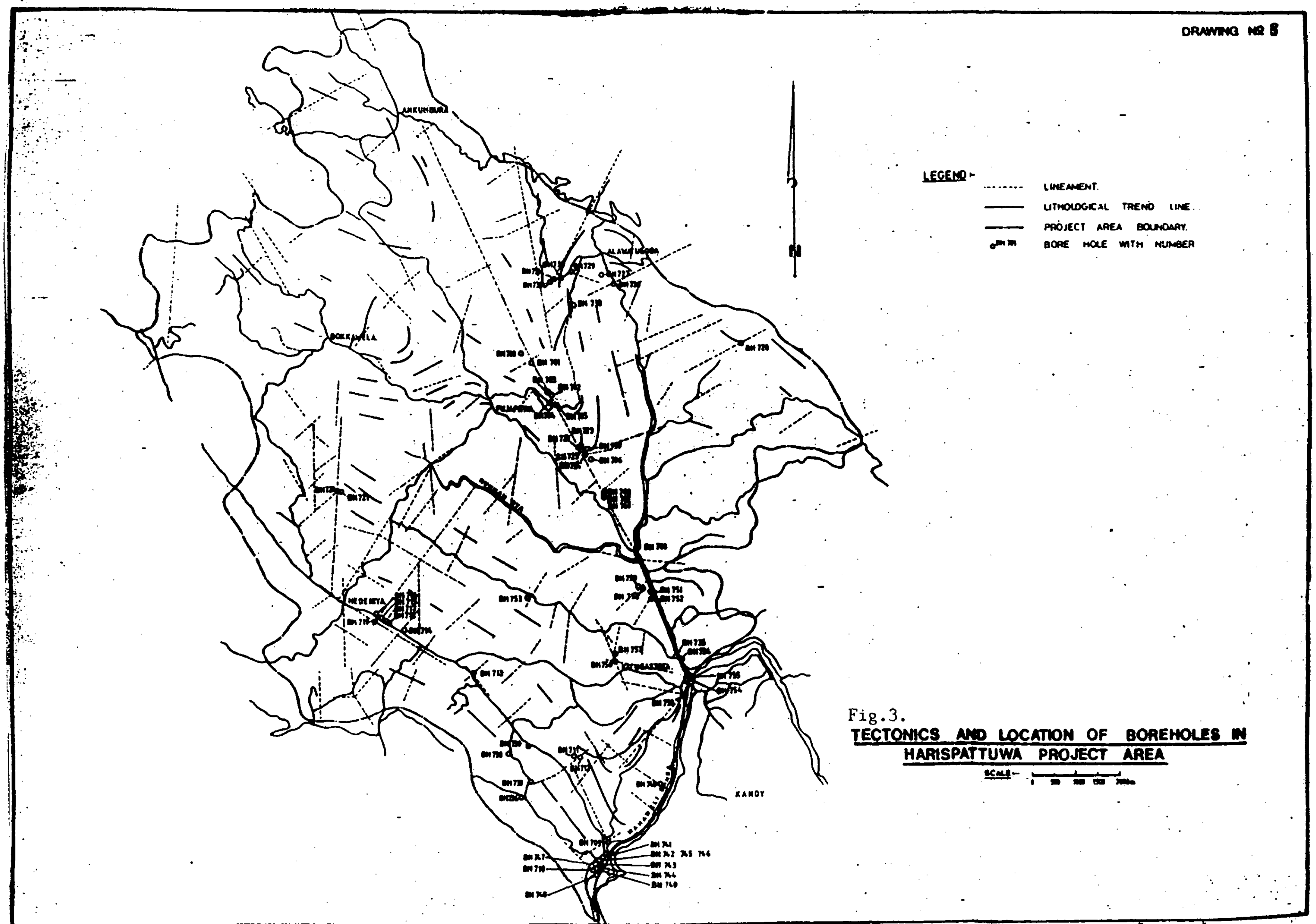


Fig.3.

TECTONICS AND LOCATION OF BOREHOLES IN HARISPATTUWA PROJECT AREA

DISCUSSION

The chairman reminded that according to this paper the basic level and the question of ground water investigations are more or less the same anywhere in the world.

To Mr. Odira's question on green areas on the slides presented the speaker said that the average rainfall in the area is as high as 2400 mm/a.

The chairman noticed that in a very densely populated area like this surface waters are more or less polluted. Mr. Arölä said from his personal experience that in the area hand pumps are appropriate in rural areas. However, in densely populated areas piped systems with deep boreholes must be used. Of all the shallow wells constructed by the project two thirds are ring wells and the last third comprises drilled wells.

Mr. Ayele asked what were the costs of geophysical investigations in Harispattuwa water supply project. Mr. Ärölä replied that the geophysical expatriate cost of the total expatriate staff costs were about 5 % but the portion of materials and spareparts of all the construction materials was far less. Mr. Jalkanen suggested that in a ground water project the portion of geophysical costs should not be less than 10 %.

Dr. Esa Rönkä
National Board of Waters
Water Research Institute

HYDROGEOLOGICAL INVESTIGATIONS AND DATA COLLECTION FOR INVESTIGATOR

Hydrogeological Investivations

Traditionally aquifers have been determined by field geological mapping techniques and drilling. Aerial photographic interpretation has formed a significant part of such work and as well as other remote sensing methodsof today. Based on the earth resources technology satellite programme a whole range of imagery is now available. Remote sensing imagery has also become popular for hydrogeological purposes. Infrared imagery has long been in use especially to detect ground water discharge in coastal waters. However, results are not always encouraging; line scan surveys are expensive and ground control is essential.

Data-gathering techniques are now giving geophysical results of better quality and resolution at lower cost. Seismic and resistivity surveys are providing valuable information on aquifers in consolidated sediments.

Surface geophysical interpretations require borehole control and the laboratory or borehole measurement of physical properties. Surface and borehole geophysical techniques are thus increasing, particularly in resistivity studies. Interest in borehole logging techniques has increased over the past few years, due to the need to assess the effective thickness of an aquifer as opposed to its stratigraphic thickness. The use of highly sensitive electrical conductivity and temperature logging together with flow logging can reveal aquifers of very limited effective thickness. Conductivity logging provides good control of saline interfaces and together with surface resistivity surveys very good technique for practical means of mapping fresh-saline water zones.

Borehole geophysics has been limited to a certain extent in hydrogeology due to the lack of systematic borehole schedules. In engineering geology use is being made of borehole acoustic measurements to define fracture zones between boreholes. This technique may well assist in determining high permeability zones in fissure systems.

Hydrochemical Studies

Hydrochemistry has always played an important role in assessing the suitability of ground water for a different use. The application of ground water chemistry, however, is expanding considerably and emphasis is now being placed increasingly upon its relationship with flow mechanisms. Hydrochemistry is intimately related to flow distribution and can provide collaborative information on flow net studies or the only positive information where disturbed aquifer conditions exist. Advances in isotope chemistry interpretations and in regional studies of environmental isotopes have assisted in the interpretation of ground water resources assessment and are likely to extend knowledge of ground water residence in aquifers and of the boundary conditions operating between differing water types.

Data Bank - Reference Center

The investigator needs a data bank containing all the material on his research area, old material as well as data collected in the course of the projects. This data bank should not be confused with the permanent system of data keeping that requires a different approach approach. It is possible to classify the material into five categories:

1) The Card Index and the Basic Location Maps are the base of the data bank. A simple card index without references will usually suffice. Each location should be identifiable by one name and by two grid coordinates.

2) Data and Information comprise borehole section, the results of pumping tests, complete chemical analyses, etc., in short items that are collected only once or at rare intervals. This material is kept in folders.

3) Records comprise the results of observations carried out on a routine basis. This material that continually accumulates and is frequently taken out for updating and copying is best kept on filing cards. For example, monthly observations for period of one year in borehole, including water levels, ground water abstraction and water quality (not complete chemical analyses), can easily be accommodated on a small filing card. The graphic representation of records is a waste of time and storage space. The user who requires them should draw them for himself on the scale he finds most appropriate.

   It should be noted that distinction between data and records is a matter of convenience not of principle. Water level records are better kept separate from borehole sections because otherwise very bulky files result that eventually disintegrate by frequent use.

4) Reports comprise old reports, reprints of published papers, internal reports, geologic maps and sections together their explanatory notes, various yearbooks, field notes and typewritten or handwritten material from archives. However, books of general character and administrative documents are excluded. The former find their place in a hand library; the latter belong to the files of the investigator in charge.

5) Borehole Samples consist of the boxed collection of samples. In percussion drilling, samples are taken from the material bailed from the bottom of the hole. In rotary drilling the cuttings (powder) are continually brought to the surface by the drilling mud. The samples are taken to be representative of the simultaneously recorded depth of drilling, although this is not quite correct, because it takes some time for the sample to travel from the bottom of the hole to the surface. Well siter, who should always be present at a site of rotary drilling, collects samples at depth intervals of about 5 m, prepares their preliminary description, and puts them into small boxes for future detailed analysis.

The storage of the large number of samples has to be organized using cardboard boxes, each one containing quite large number of cells (for example 25 cells, each 4 x 4 cm). The designation of the well and the depth interval of the samples are marked on a flap attached to each cell.

Each box is used for keeping samples from one well only. The code number and location of the borehole as well as the total depth interval of samples in the box are clearly marked on its side. It is a good system to tidily arrange the boxes on shelves so that their content can be read off without handling.

The complete collection of samples should be kept at least until the project (project produced these samples) of investigations is terminated. The samples will be needed for correlation and re-examination, even though it may seem that they have already been described in all possible detail. The question of what to do with the samples arises when the project is terminated. It is the best way to transfer the whole collection to an appropriate permanent organization, such as a geologic survey or some research department. If this cannot be done, at least a few of the most characteristic items of the collection should be kept by the investigator or the client.

Ground Water Observation Network

One result of a ground water project should be recommendations for systematic, continuous monitoring of the resource.

In the course of the investigations, water levels should be measured at monthly intervals in all wells. Exploration boreholes drilled for the purpose of hydrogeological prospection should be equipped with a small-diameter casing and screen, so that they can be used for routine water level observations. The density of the final, permanent network depends on aquifer characteristics and on the purpose of the observations. Records obtained by monthly water level measurements are sufficiently detailed for most purposes.

Monitoring of water quality is always carried out by water samples taken from exploited wells. Yearly or twice yearly measurements of electrical conductivity are required for the purpose of general supervision. Closely spaced observations and more detailed analyses are necessary when electrical conductivity changes significantly or where significant changes of water quality are anticipated.

Water level and quality data can be interpreted only if reliable information on ground water abstraction is available.

The motivation of personal operating the network (investigation) is an important factor in the reliability of the data. It is true that field observers carry their duties well as long as they feel that their data are being used. Data sent to a distant filing system, without evidence of being used, stands a poor chance of being reliable.

DISCUSSION

The speaker stressed the need for gathering all data available.

Mr. Rantala reminded that the reliability of data is of utmost importance. It has been noted in Finland a couple of times that there are footmarks in the snow but there are still records made! Therefore, the motivation of the field staff must be stressed.

Dr. Mälkki's opinion was that it is not useful to gather all data, the most important parts are normally enough.

The chairman suggested that in a specified project you should gather all data available but in general data banks you could concentrate on the most important ones.

The speaker pointed out the importance of communication between the surveyor and the data collector.

Mr. Lucas informed that the water master plans common in different regions in Tanzania serve as data banks.
Mr. Rantala reminded that in spite of possible unreliabilities it is better to have some data than none at all.

Mr. Pentti Rantala
Tampere University of Technology (TUT)

GROUND WATER PROTECTION

Introduction

Ground water is virtually an ubiguitious natural resource with areal distribution, as opposed to linear distribution of surface water, under varied conditions of depth, yield and quality. As such, it is the most important source of water for community supply, and especially rural water supply in all regions. Large-scale ground water development schemes are to be implemented if the objectives of the International Drinking Water Supply and Sanitation Decade are to be attained.

In the course of the last 20 years (1962-82) the United Nations has carried out some 120 projects (including on-going projects) for groundwater exploration and development in developing countries throughout the world. An overview of this extensive programme, especially as regards the origins, the objectives and the geographical location of the projects, clearly demonstrates the importance of ground water in developing countries (Dijon 1983).

In arid regions and in deserts - and also in some semi-arid and Mediterranean areas - ground water is the only source of water and its occurrence at reasonable depths and under acceptable quality standards has, for a long time, been a prerequisite for the existence of human settlements and livestock. Modern technologies for groundwater prospection, well construction, deep drilling, and pumping have facilitated both an assessment of groundwater potential over vast areas and the development of additional resources.

It is very obvious that important resources must be well protected. The quality of the ground water is normally good for drinking in its natural form. In some occasions ground water must be treated to reach drinking water quality. Human activity posesses the most dangerous risk for ground water resources. With proper precautions it is possible and even fairly cheap to protect ground water properly.

Ground Water Pollution

Pollutants can be divided into

- organic compounds
  - hydrocarbons
  - bacteria, viruses etc.

- inorganic compounds
  - heavy metals

Under organic and inorganic compounds are mentioned only a few examples.

From the point of view of drinking water, the most important pollutants in rural areas are (Lewis et al 1980).

- bacteria
- viruses
- nitrates

Reasons for pollution are mainly due to different human activities. Some natural phenomena may detoriate the ground water quality as well. Reasons for pollution can be classified as follows

a) Human activities

- solid wastes
- disposal sites
- uncontrolled disposal

Wastewater

- disposal on land
- disposal into soil
- leaky sewage system

Industries

- careless handling of materials
- disposal of wastes
- careless storage

Accidents

Agriculture and forestry

- seed dressing
- fertilizers
- herbicides
- plant protectants

Diffuse pollution

- street pollution and traffic
- other street pollution
- air traffic
- gardening activities
- car washing
- airborne pollution

b) Natural phenomena

- evaporation may increase the salt concentration in the soil
- seepage of salty waters
- decomposition of organic matter
- high fluoride or iron or manganese concentrations

Protection of Ground Water Resources

Figure 1 illustrates the survival of different types of micro-organisms in ground water. Fig. 2 gives the effect of sand on the survival organisms.

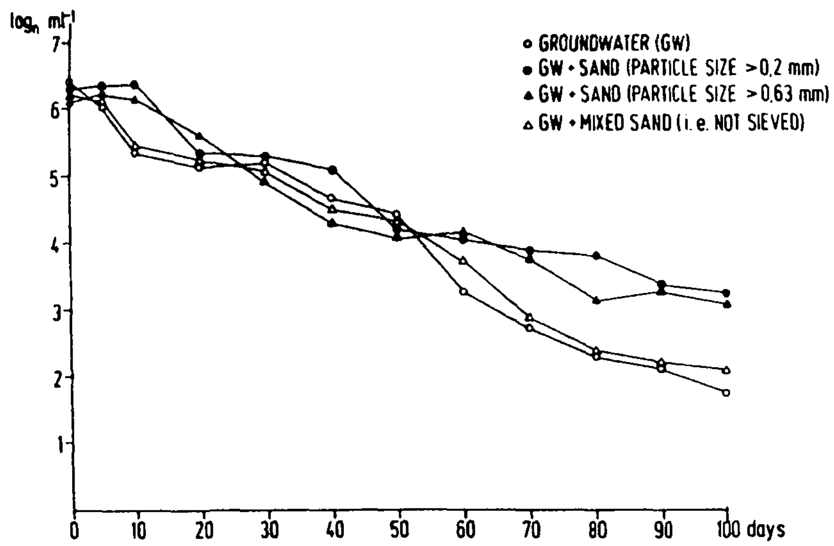


Fig 1. Survival of S. typhimurium in groundwater with and without addition of salt. (Drkuddu-Mulindwa et al 1983)

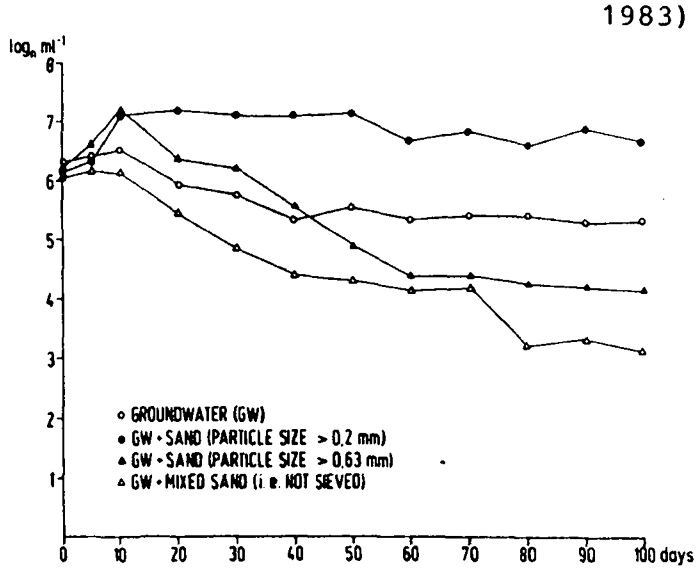


Fig 2. Survival of pseudomonas aeruginosa in groundwater with and without addition of sand. (Drkuddu-Mulindwa et al 1983)

Fig 3. shows an example on how the spreading of pollutants may occur. Figure 4. presents a schematic hydrological cycle of water diposal site.

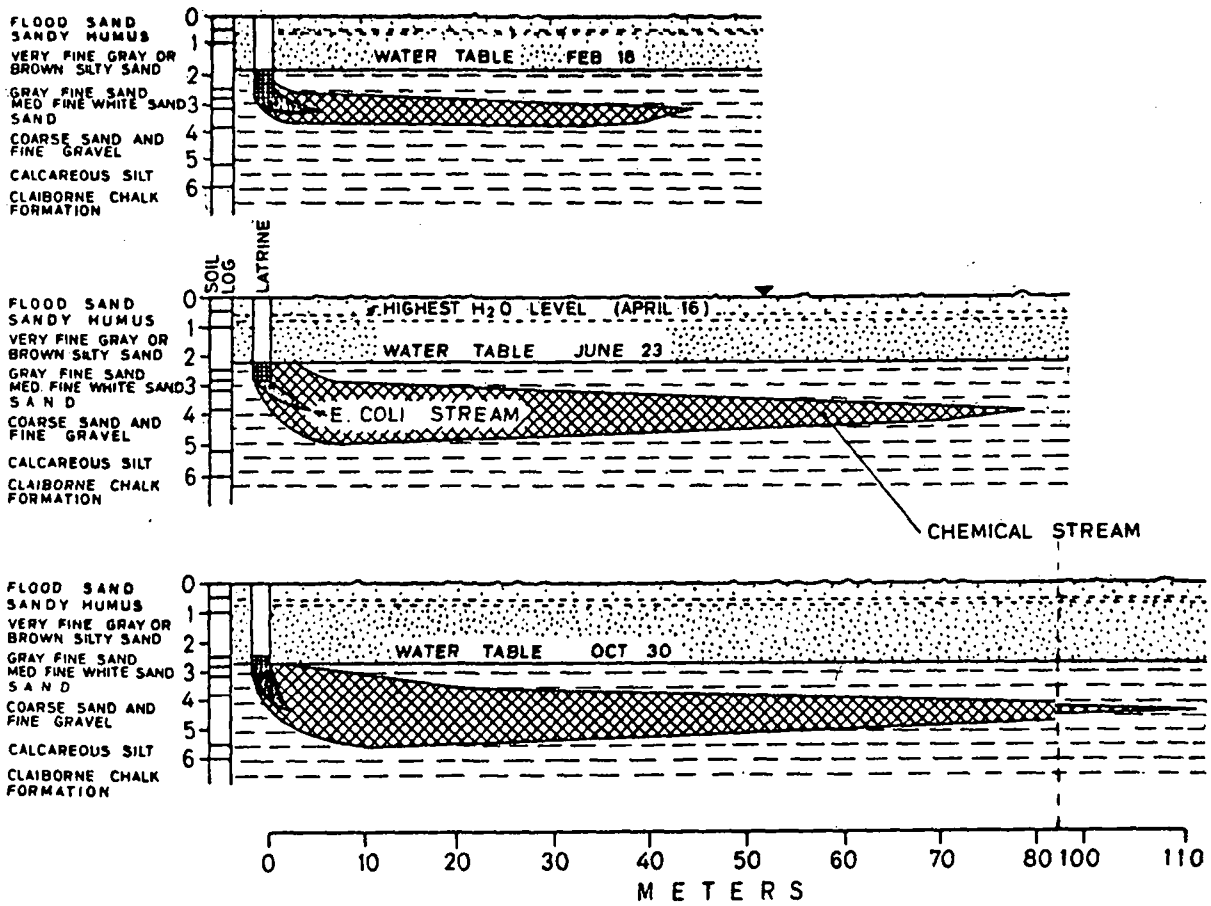


Fig 3. Pollution travel from a pit latrine penetrating the water table in a medium-fine sand (Caldwell 1938)

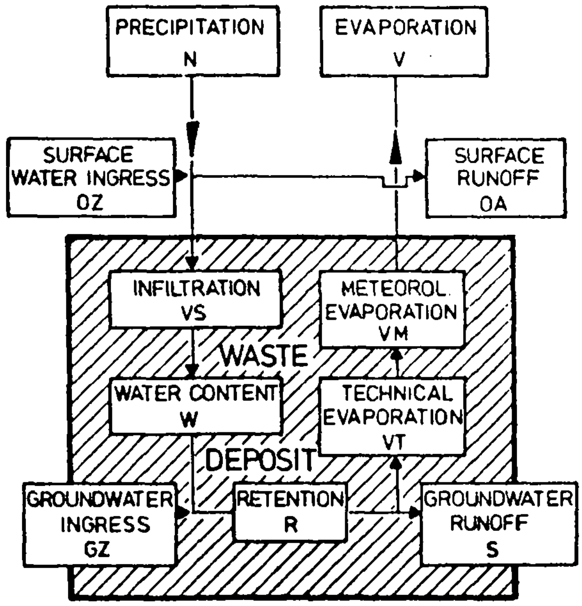


Fig 4. Schematic hydrologic cycle of a waste deposit (Franzius 1977)

The protection of ground water resources can be divided into active and passive methods as follows

Active

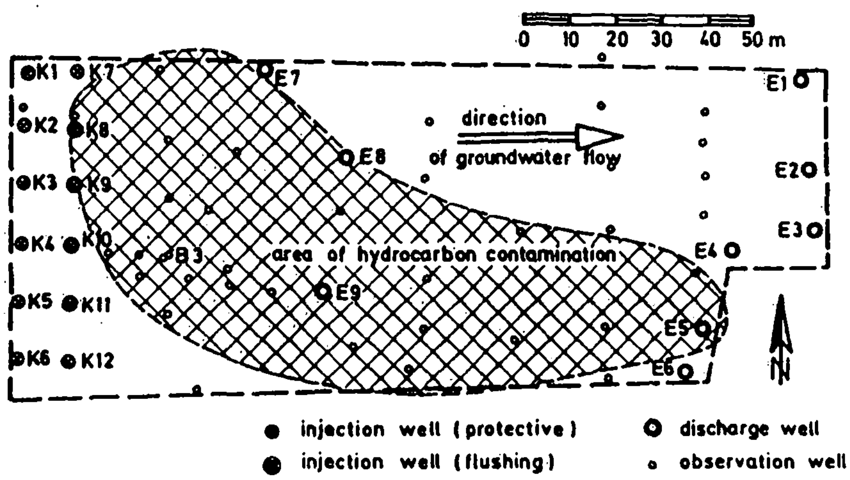
- education/community participation
- establishment of protection zones
- restrictions
- planning in advance for different situations occuring in the catchment area
- monitoring of quality

Passive

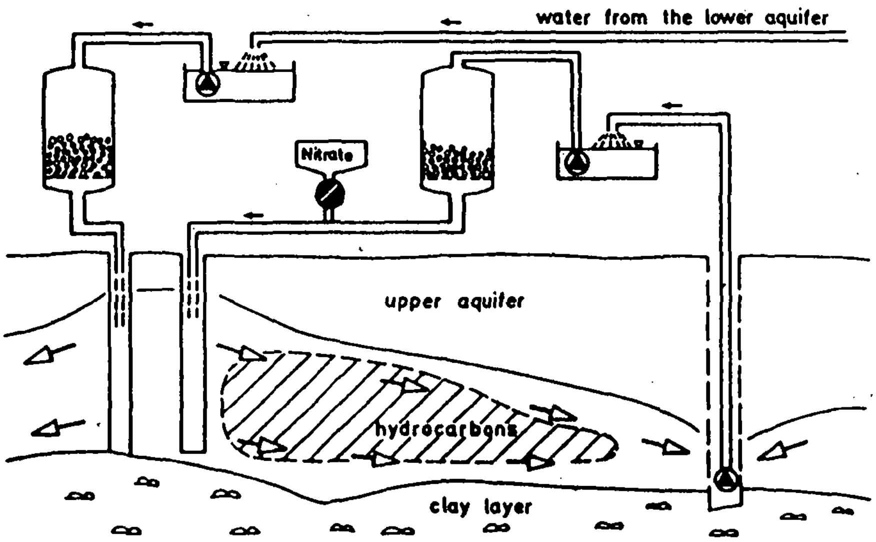
- corrective measures
- prevent spreading of pollutants

Fig 5. gives an example of ground water pollution and remedities made to improve the water quality back to normal level. In this case hydrocarbons entered the ground water due to an accident. Most of the carbons were removed by pumping over a period of 3 years. There was still a residual saturation of specific hydrocarbon compounds which could have a serious effect on a water supply system near by.

There were two possible ways to stop transport of hydrocarbons. One was to surround the area with an impermeable wall which would intersect the aquifer. This would not have been a final solution because the hydrocarbons would have stayed in the soil. The other possibility was to flush the aquifer and to activate the biodegradation to remove the hydrocarbons completely. This was also far cheaper than the construction of the wall. This system is illustrated in Fig 5.



Study area



Operation scheme

Fig 5. Removal of hydrocarbons from the soil
(G. Battermann 1983)

Figure 6 gives an algorithm for siting the pit latrines in connection to ground water resources (Lewis et al 1977). The distances mentioned should be critically studied for each case before the final decisions.

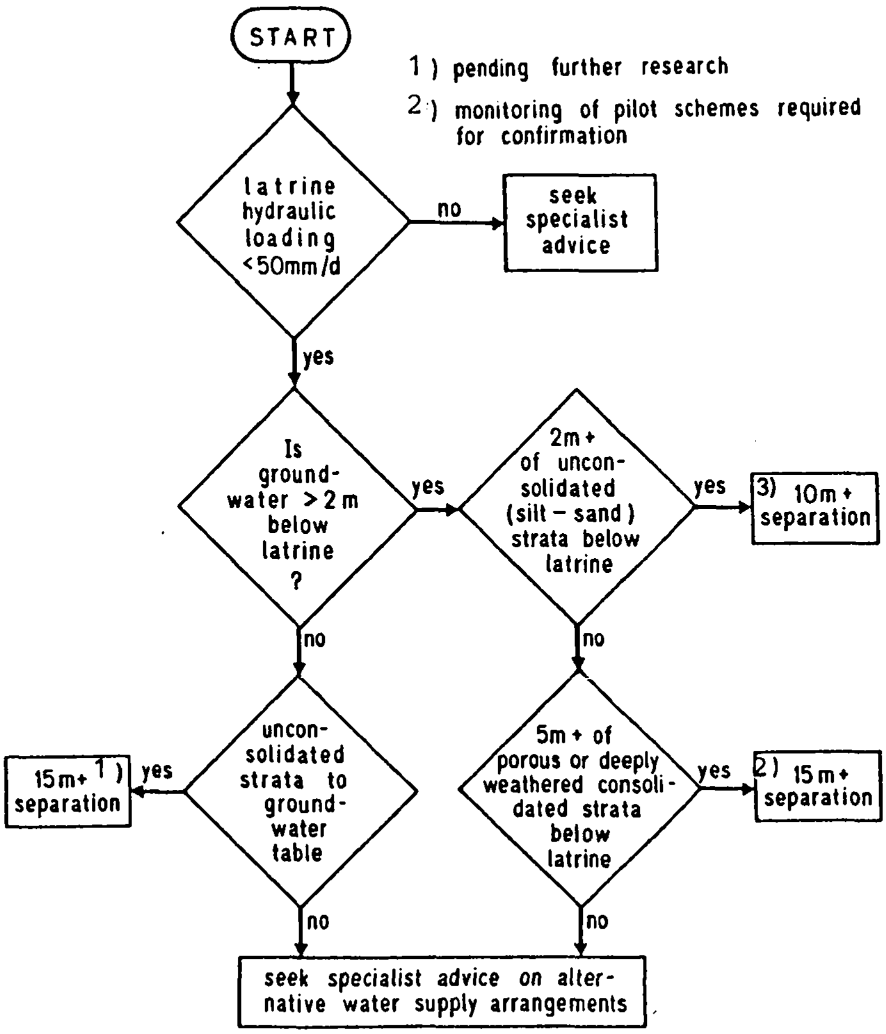


Fig. 6 Preliminary algorithm for selecting separation between on-site excreta disposal units and water supply installations in a range of geohydrological environments (Lewis et al 1980)

Conclusions

Ground water is one of the most precious resources of mankind. This resource must be protected against human activities to maintain the good, natural quality of ground water. To cope with this difficult task, one must understand the behaviour of water in the soil, characteristics of different types of pollutants and how these behave under many different conditions prevailing in the ground.

Active methods are much more effective and even cheaper than passive ones in ground water protection. In rural areas making people understand through education why and how ground water resources should be protected is one of the most important tasks.

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DISCUSSION

The chairman commented upon the presentation by saying that in surface water the pollution as well as natural purification happens faster than in ground water. In many countries the legislation for ground water pollution is quite strict. In Finland not even the Water Court is allowed to give any permit for ground water pollution. However, pollution of surface water rivers can be accepted if the benefits are higher than disadvantages.

Mr. Hatva asked what are practical possibilities for ground water protection zones in the course participants' home countries. Mr. Laike said that in Ethiopia wells and springs are protected but protection zones for large areas are not applicable in practice in the very near future. Mr. Thuku said that possibly the MOWD has some power in the matter. Mr. Boro verified that in Kenya the policy does exist but the enforcement does not. People are not aware what ground water really is. Mr. Zimba from Zambia said that so far not full emphasis has been given to ground water protection. Mr. Ngainayo noted that drillers have to indicate the methods for borehole protection. However, in a few cases when flushing a borehole it has been found that people have laid human excreta to the borehole.

The chairman reminded that there must always be a continuous battel against ignorance. In highly cultivated valleys it might be difficult to protect ground water even if the land is owned by the government. In places where boreholes are situated far from villages the protection is easier.

The speaker pointed out that in Finland it is perhaps easier to know where ground water is formed at least in eskar areas.

Mr. Laike reminded that the temperature and depth of ground water has its effect on bacteria movement and thereby on ground water flow.

The chairman told that e.g. poliovirus can live for two years underground. Viruses can be killed but some of them can change themselves into partly inactive form and later change back to active form. The higher the temperature the faster the growth and the death of bacteria.

The speaker mentioned that the decrease of pH in ground water caused by acid rain will not be so risky because the acids can be deposited on the top layers. In the long run this might affect ground water as well.

Dr. Mälkki reminded that the climate is cold in Finland but in tropical climate decomposing is more effective and that is why it is not necessary to restrict too much human activity in the tropics.

Mr. Odira said that water supply and sanitation should go hand in hand and asked what impact can latrines have on ground water. The speaker replied that if wells and latrines are properly sited and constructed, pollution of ground water should not be a problem.

Mr. T. Ärölä
Plancenter Ltd.

ECONOMIC SELECTION OF A WATER SOURCE

Alternative sources

When we are talking about selection of a water source for a piped water supply system, we must have two or more alternative sources from which to select. Very often we are in a situation that we have practically only one source because the alternative sources are too far away, water quality is not acceptable or the treatment cost or pumping cost is too high.

The most typical water sources which we may have are

- borehole well
- spring
- stream or river
- pond or lake

The water sources differ from each other in following aspects

- water quality and possibility to improve the quality and treatment
- distance from the town and altitude
- reliability of the source during draughts
- safety against pollution

Selection criteria

I have divided the selection criteria into three categories.

A. Economic criteria

- construction costs
- operation and maintenance costs

B. Social criteria

- water quality after treatment
- reliability of the source during draughts
- protection against pollution

C. Technical criteria

- availability of construction methods and materials
- availability of qualified staff

In most cases we have to consider all the three criteria. In other words, we have to consider how much the community is willing to pay for better water quality and reliability.

As for the technical criteria, they are actually partly of economic and partly of social nature. For instance, technically complicated constructions can be solved by increased construction costs, but technically complicated operation often has a result of poor water quality.

There is also one more criteria which can be called competitive use. It means that the same source can be used for different purposes such as

- domestic use
- industrial use
- irrigation
- power supply
- recreation, fisheries, navigation etc.

Here we do not emphasize competitive use because domestic use always has the highest priority.

Economic criteria

For the economic evaluation of the alternative we have to assume

a) Construction cost

- water intake
- pumping station
- treatment plant
- main pipe to the town
- power supply

b) Operation and maintenance costs

- salaries of the operational staff
- pumping energy
- chemicals
- maintenance of the structures

The most common methods for the economic evaluation are the annual cost method and the present worth method.

I will show here the annual cost method because by using annual cost method it is easy to get the idea about the cost of water.

The annual cost method can be presented briefly as follows

- the construction costs are depreciated in 20...30 years by assuming a certain interest rate, say 6 %...10 %, in order to get annual capital costs
- the operation and maintenance costs are calculated for one year
- the maintenance costs are often assumed as a certain percentage of the construction costs
- the annual costs are the sum of annual capital costs and the annual operation and maintenance cost
- the cost of water is the annual costs divided by the amount of water supplied.

If a loan is used for the financing of the water supply system, the interest rate of the loan may be used in calculations.

Sometimes, when the water supply system is financed by a foreign donor, the construction costs may be completely left out, or only the future replacements may be considered.

Selection of the source

There seems to be quite a few aspects when the final decision of the water source is made. The engineer always carries out the economic calculations but he should study thoroughly even the social aspects so that he is fully aware of them, and he should explain them clearly to decision makers.

Case study: Udunuwara Water Supply System in Sri Lanka

Population = 30 000
Max. daily demand = 1,2 x 0,135 x 30 000 = 5 700 m^3/d.

Alt 1. 6...8 boreholes
- close to the town
- simple treatment
- pumping head 80 metres
- yield during draught not verified
- distance 2 km

Alt 2. Big river
- close to the town
- existing rising main
- existing intake needs rehabilitation
- chemical treatment required
- affluent availability of water
- pumping head 80 metres
- water pollution from communities

Alt 3. Stream
- far from the town
- simple slow sand filtration needed
- high altitude, no pumping costs
- pollution not severe

Constr. costs in USD	Alt. 1	Alt. 2	Alt 3.
- intake	37 000	33 000	10 000
- treatment plant	-	1 100 000	630 000
- pumping station	-	83 000	-
- rising main	100 000	-	300 000
- power supply	20 000	10 000	2 000
Constr. costs	157 000	1 226 000	942 000
Operat. & maint.			
- salaries	5 000	6 000	5 000
- energy	73 000	73 000	-
- chemicals	4 000	14 000	6 000
- maintenance	-	-	-
Op. & maint.	82 000	93 000	11 000
Annual costs			
- capital cost (6%, 25yrs)	12 000	96 000	74 000
- Op. & maint.	82 000	93 000	11 000
Total	94 000	189 000	85 000
Cost of water c/m^3	5,5	11,0	5,0

The final solution seems to be the gravity system. But because the yield during extreme draughts is not confirmed, borehole sources to be used temporatily may also be required.

DISCUSSION

The chairman pointed out that the economic aspects are extremely important for any project. Mr. Boro from Kenya reminded that the constraints connected with operation and maintenance are more critical than other aspects and therefore they should be taken into account via special way. Mr. Rantala asked if we should analyse the values as well instead of poor cost analysis.

Mr. Musyoka was worried about desertification and asked how much forestration can affect ground water occurence and vise versa. The chairman said that in the long run forestration has the tendency to change the climate towards more humid conditions. However, forestration and ground water utilization are not competitive with each other. Naturally we should choose the type of trees that are not causing too much evaporation.

Mr. Alemayehu asked how we take into account the life time of projects in economic selection. Mr. Ärölä admitted that there can be difficulties e.g. in estimating the remaining value.

Mr. Mashauri pointed out that the financial situation at the starting moment of the project is very important in developing countries. The speaker noted that naturally a developing country easily prefers an alternative with minimum operation and maintenance costs in case the donor is financing the construction costs.

Mr. Lucas raised the question of community participation. Mr. Odira said that the question is quite sensitive one and that in one report the Kenyan government wanted to limit the self-help work because of too high costs.

Mr. Boro stressed the importance of training of operators which is an actual question in Kenya.

TAMPEREEN TEKNILLINEN KORKEAKOULU
VESITEKNIIKKA
JULKAISUSARJA B

TAMPERE UNIVERSITY OF TECHNOLOGY
WATER SUPPLY AND SANITATION
PUBLICATION SERIES B

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