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Sustainable Groundwater Development: the Challenge for the Hydrogeologist in the 1990's

JAC A. M. VAN DER GUN & GIDEON P. KRUSEMAN*)

Groundwater, water resources, water harnessing, water consumption, water supply, water management, protection, pollution, case studies

Yemen, Netherlands, Java, Tanzania

Abstract: Not long ago the main challenge for hydrogeologists was the exploration for groundwater, but over the last decades serious concern has been raised about the sustainability of groundwater development. A fundamental cause of the problem is the rapid growth of the population. The main threats are: (1) depletion of groundwater resources; (2) deterioration of groundwater quality; (3) negative environmental impacts of groundwater abstraction; and (4) insufficient capacity for adequate operation and maintenance of the technical infrastructure for groundwater abstraction and distribution. Four case histories are presented to illustrate the role the hydrogeologist may play. Today's challenge for the hydrogeologist lies in the broadening of his profession towards water resources and environmental management planning; and in contributing to the development and strengthening of institutes in charge of groundwater resources management.

[Dauerhafte Erschließung von Grundwasser: Die Herausforderung an den Hydrogeologen der 90er Jahre]

Kurzfassung: Noch vor kurzem war die Grundwassererkundung die wichtigste Beschäftigung des Hydrogeologen, aber während der letzten Jahre haben sich die Fragen bezüglich der Nachhaltigkeit der Grundwassererschließung in den Vordergrund geschoben. Diese Fragen sind grundsätzlich an die schnelle Bevölkerungszunahme gekoppelt. Die wichtigsten Probleme in dieser Beziehung sind: (1) Erschöpfung des Grundwassers durch Überbeanspruchung, (2) Verschlechterung der Qualität des Grundwassers, (3) durch Grundwassererschließung hervorgerufene Umweltschäden und (4) das Unvermögen zu angemessenen Betrieb und zur Wartung von Anlagen zur Grundwasserentnahme und zu dessen Verteilung. Vier Beispiele aus der Praxis sollen zeigen, welche Rolle der Hydrogeologe dabei spielen kann. Heute ist der Hydrogeologe herausgefordert, im Rahmen seiner beruflichen Arbeit stärker als bisher wasserwirtschaftliche Themen und Umweltaspekte zu berücksichtigen und außerdem zur Entwicklung und Unterstützung von Institutionen zur Bewirtschaftung und zum Schutz des Grundwassers beizutragen.

*) Address of the authors: Ir. J. A. M. VAN DER GUN & Prof. Dr. G. P. KRUSEMAN, TNO Institute of Applied Geoscience, P. O. Box 6012, 2600 JA Delft, The Netherlands.

Introduction

International cooperation in groundwater-related studies in developing countries is a fascination to many groundwater specialists, both from developing and industrialized countries. Working in different regions exposes them intensely to the charms of the hydrogeological profession, and the pronounced development aspects give it a very special additional dimension.

An issue in this respect that currently attracts world-wide attention is that of 'sustainable development'. The Brundtland report — 'Our Common Future' (1987) — defines sustainable development as follows:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Managing our water resources is only one of its many prerequisites, but it is of vital interest. Hence, contributing to sustainable development of the world's groundwater resources certainly is one of the main challenges for the hydrogeologist in the 1990's.

Below, attention will be paid to different aspects of this challenge. This will be done with the theme of this symposium in mind: 'technical-scientific cooperation with developing countries'. First of all, the concept of 'sustainable development of groundwater' is characterized by listing the perceived main threats to sustainability. Next, the problems and practical implications are viewed from two different perspectives: a global one and a regional one. From a global viewpoint a few trends are reviewed that may explain some of the important changes observed in the water sector. How the hydrogeologist may contribute to sustainable development is explored on the basis of a number of regional cases. This allows some conclusions to be drawn on the role of the hydrogeologist in this respect, and statements to be made regarding priorities.

Sustainable development of groundwater

Not very long ago the main challenge for hydrogeologists in relation to groundwater development was the exploration for groundwater. More than others, the hydrogeologist was capable to discover reservoirs from which this hidden resource can be exploited. The hydrogeologist certainly has been one of the main actors causing the observed world-wide boom in groundwater development during our century. There is no doubt that the increased use of groundwater has been and still is of great benefit to many regions in the world.

However, developments over the last tens of years have raised serious concerns about the sustainability of groundwater development. It appears that observed and predicted threats to sustainable groundwater development belong particularly to the following categories:

(a) depletion or partial depletion of the resources, as a result of overexploitation;

(b) deterioration of the groundwater quality by salination or pollution;

(c) negative environmental impacts of groundwater abstraction;

(d) insufficient technical, financial or organizational capacity for adequate operation and maintenance of groundwater abstraction works.

The problems experienced all over the world as a result of these factors have triggered the need for corrective action and — above all — the need for careful planning of groundwater development, and for management of the groundwater resources. This is not the exclusive domain of the hydrogeologist, but hydrogeologists have an essential role to play in it.

Many hydrogeologists nowadays are engaged in research and studies intended to contribute to sustainable groundwater development. Like in the past, the hydrogeologist is still handicapped by the invisibility of groundwater and still has to be aware of the particular time scales of the processes related to groundwater. But as a result of changing focus of applied hydrogeological work, he will need to be open for new fields of knowledge and skills that do not belong to the 'traditional' hydrogeological discipline.

Global Changes affecting the Water Sector

Population growth

A fundamental cause of observed world-wide changes in the water sector in our times is the unprecedented population growth, especially during the second part of this century (see Figure 1 and Table 1). It is believed that two thousand years ago there were approximately 300 million people in the world; it took more than 1500 years before this number was doubled. But afterwards the rates of growth increased explosively; already in the year 1800 there were more than 1 billion people, around 1930 the number of 2 billion was exceeded, and at present the world is populated by some 5.5 billions of people. The rate of growth seems to slow down in recent years; nevertheless, demographers expect that the world population will be some 8 billion people in the year 2020.

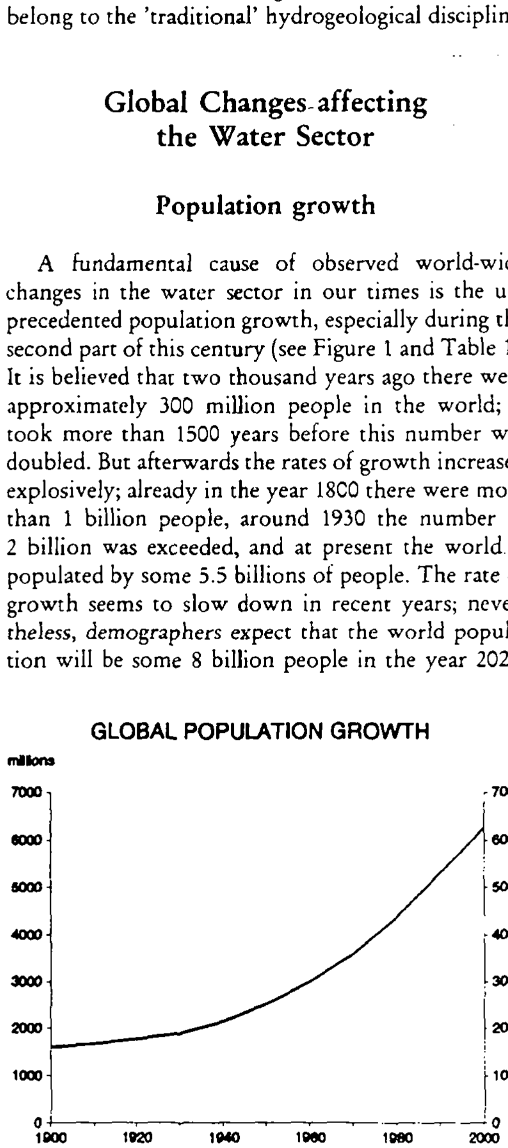

Fig. 1: Population growth during the 20th century.

Abb. 1: Bevölkerungszunahme während des 20. Jahrhunderts.

Over 60% of the world's population lives in Asia. In decreasing order of magnitude follow the populations of Europe, Africa, Latin America, North America and Oceania. The spatial distribution of the population, however, is changing as well. As a result

Table 1: Some global statistics and projections

Tab. 1: Einige weltweite Statistiken und Prognosen

	1900		2000		Relative increase
Population	**millions**	**%**	**millions**	**%**	**factor**
Rural	—	—	3334	53.3	—
Urban	—	—	2917	46.7	—
Total	1608	100	6250	100	3.9
Africa	120	7.5	906	14.5	7.6
North America	81	5.0	321	5.1	4.0
Latin America	63	3.9	543	8.7	8.6
Asia	937	58.3	3720	59.5	4.0
Europe	401	24.9	742	11.9	1.9
Oceania	6	0.4	18	0.3	3.0
Water Consumption	**billions m^3/a**	**%**	**billions m^3/a**	**%**	**factor**
Agriculture	525	90.6	3250	62.6	6.2
Industry	37	6.4	1280	24.7	34.4
Municipal	16	2.8	441	8.5	27.4
Reservoirs	0	0.1	220	4.2	733.3
Total	579	100	5191	100	9.0
Africa	42	7.2	317	6.1	7.6
North America	69	12.0	796	15.3	11.5
Latin America	15	2.6	216	4.2	14.3
Asia	414	71.5	3140	60.5	7.6
Europe	38	6.5	673	13.0	17.9
Oceania	2	0.3	47	0.9	29.3
Miscellaneous	**value**	**unit**	**value**	**unit**	**factor**
Irrigated lands	47	Mha	347	Mha	7.3
Applied irrigation water	1110	mm/a	937	mm/a	0.8
Per capita municipal water use	27	l/s	193	l/s	7.0

Sources: SHIKLOMANOV 1991; OKUN 1991; Atlas of the World (1983).

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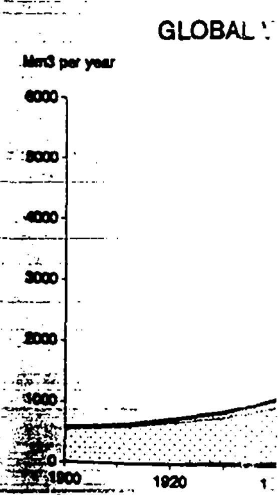


	Relative increase
%	factor
3.3	—
6.7	—
0	3.9
4.5	7.6
5.1	4.0
8.7	8.6
9.5	4.0
1.9	1.9
0.3	3.0
%	factor
62.6	6.2
24.7	34.4
8.5	27.4
4.2	733.3
00	9.0
6.1	7.6
15.3	11.5
4.2	14.3
60.5	7.6
13.0	17.9
0.9	29.3
unit	factor
Mha	7.3
mm/a	0.8
l/s	7.0

of high annual rates of growth in Africa (3%), Latin America (1.9%) and South-East Asia (1.8%) and much lower ones elsewhere (e. g. only 0.2% in Western Europe), the share of the so-called 'Third World' countries in the world population is increasing from 68% in 1960 to expectedly some 77% in the year 2000.

Furthermore, people tend to concentrate more and more in urban centres. In 1950 only 29% of the world's population was urban, at present it is more than 43% (OKUN & LAURIA 1991).

Trends towards urbanisation culminate in the increasing number of large and very large cities ('megacities'). From 1950 to 1990, the number of cities of more than one million inhabitants increased from 78 to 290; during the same period those of over 10 million rose from 3 to 12. (OKUN 1991).

Water use and water demands

Table 1 and Figures 2 and 3 give an impression of the evolution of water use rates during the present century. The data were extrapolated until the year 2000, in order to span the entire 20th century.

At first glance, it is evident that on a global scale water use has increased — and is still increasing — even more than population. Agriculture is still the largest water user, but the shares of industrial and municipal water use have increased significantly.

Per capita agricultural water use has increased more than 1.5 times, although the average depth of irrigation water applied has decreased slightly; this is because irrigated lands now have a larger share in the total food production than at the beginning of the century. This tendency will certainly persist in the near future.

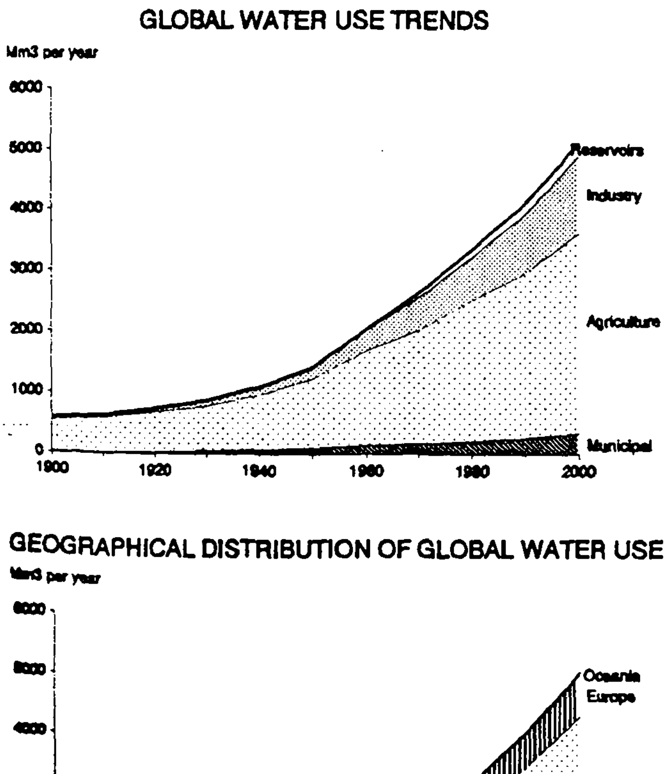


Fig. 2: Trends of water use by subsector.

Abb. 2: Entwicklung des Wasserverbrauchs in den verschiedenen wirtschaftlichen Sektoren.

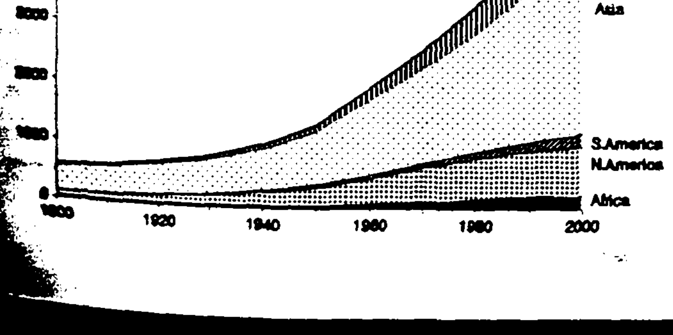


Fig. 3: Trends of water use by geographical region.

Abb. 3: Entwicklung des Wasserverbrauchs in den verschiedenen Regionen der Welt.

Numerous programmes in the drinking water sector all over the world have been carried out to create the infrastructure for an adequate domestic water supply. This is reflected in the evolution of the per capita municipal water use figures. "Safe water and sanitation for all" – the goal of the International Water Decade launched by the Mar del Plata Conference of 1977 – has not yet been reached, as was assessed at the Global Consultation on Safe Water Supply and Sanitation, held in 1990 at New Delhi. Efforts to pursue this goal will continue.

Regarding the geographical distribution of water use, it is noteworthy that water use in most continents has developed far in excess of population growth, except in Africa and Latin America. Per capita water use in Africa has remained approximately constant over the century, and in Latin America it increased only modestly. A plausible explanation is that in these continents of maximum population growth the financial and technical means have been lacking to create a technical water development infrastructure at the pace required.

In spite of possible effects of demand management activities, it may be expected that the total and per capita water demands will continue to expand in next decades, probably most markedly in Africa and in Latin America, where per capita water use currently is comparatively low.

Water availability and the role of groundwater

Table 2 presents aggregated data on annual runoff and annual groundwater runoff into rivers for the different continents, along with the water use estimates for the year 2000 as presented before. On these scales of space and time, no deficits are observed, which is at least an indication that sustainable development of water resources in principle is not inconsistent with the present size of the world population. Note that the estimated water use for the year 2000 even does not exceed the groundwater runoff figures given.

Apart from this general statement, the figures give only a very general impression on likely differences in availability of water; e. g., that in Oceania and in Latin America much more water is available per person than in Asia, Europe or Africa.

In spite of the figures shown above, problems of water scarcity and unsustainable development are occurring in many regions all over the world. The runoff figures give an upper limit to water availability rather than the real availability. This is because of other factors, such as variations of water availability in space and in time, environmental aspects, water quality problems, economic aspects and the human factor. We need a more local or regional point of view to assess the real availability of water properly.

Table 2: Surface water and groundwater runoff versus water use in the year 2000

Tab. 2: Oberflächen- und Grundwasserabflußmengen gegen den Wasserverbrauch im Jahre 2000

Continent	Annual volume of river runoff (billions m^3/a)	Groundwater runoff as % of river runoff	Groundwater runoff into rivers (billions m^3/a)	Water use estimate for year 2000 (billions m^3/a)
Africa	4570	35	1600	317
N. America	7450	29	2160	796
Latin America	11760	35	4120	216
Asia	14410	26	3750	3140
Europe	3210	35	1120	673
Oceania	2390	24	575	47
Total	43790	30	13320	5191

Sources: UNESCO 1978 (cited by AYIBOTELE 1992) and table 1.

It is clear that along with the growth of the world population the water demands will steadily increase as well, whereas the water resources will not become larger. On the contrary, pollution and environmental problems rather tend to reduce these resources. Thus can be expected that water scarcity problems will aggravate in areas where they are already present, and will tend to emerge elsewhere where thus far no problems of that kind were observed. It is a challenge to the hydrogeological profession to help eliminate these problems by studying, documenting and understanding the groundwater systems concerned.

Regional cases of threatened sustainability

Groundwater depletion in the Yemen Highlands

Like in many other countries in the Middle East, groundwater depletion is becoming a problem in the Republic of Yemen. This problem is in particular pronounced in the Yemen Highlands (see Figure 4).

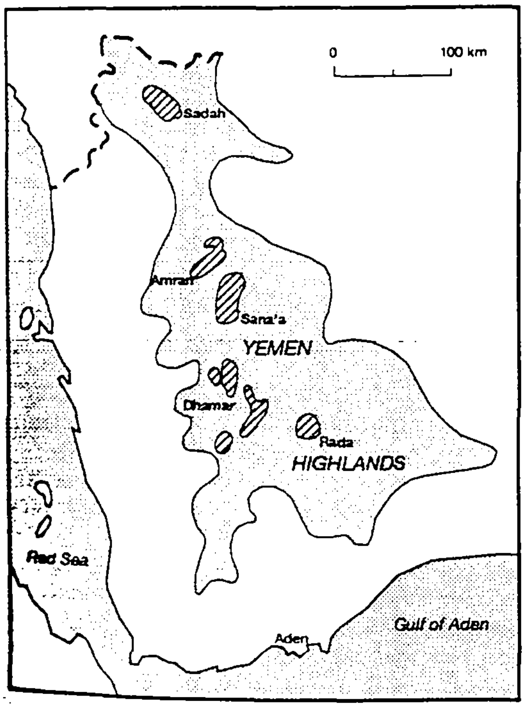


Fig. 4: The Highland Plains of Yemen (after VAN DER GUN 1987).

Abb. 4: Die Hochlandebenen Yemens (nach VAN DER GUN 1987).

Within this Highland region there are intermontane plains that constitute relatively favourable groundwater zones. Population densities are high and most of the groundwater abstraction in the Highland region takes place in these plains. Surface water systems in the plains are only weakly developed: the groundwater zones of the plains have largely the characteristics of isolated groundwater basins.

From ancient times wells have been dug on the Highland Plains. They mainly tapped shallow alluvial or weathered consolidated aquifer horizons, and traditionally water was lifted to the surface by hand or by animal traction. Until recently the lack of modern technology restricted groundwater development and kept the total groundwater abstraction small.

However, starting in the 1960's, conditions have changed. Drilling rigs appeared to drill deep wells, and diesel-powered pumps were introduced. Large zones of uncultivated lands were converted to groundwater-irrigated fields in order to satisfy the steadily increasing demands for food and income. Moreover, groundwater was tapped for new drinking water supply systems to quench the thirst of towns and villages. Currently, between 10 000 and 15 000 wells are present in the Highland Plains, pumping several hundred million cubic metres annually, which is far in excess of natural recharge.

These developments have raised substantially the standard of living, but at the same time they are changing the hydrological regimes of the zones concerned. Widespread declines of the groundwater level — a few metres a year in most of the zones — are resulting. In the beginning these declines were not generally understood and tended to be interpreted as temporal responses to meteorological variations. Gradually, however, more and more people become aware that the aquifers are being over-exploited. But ready answers are not available on how to respond to this situation that has no precedents in the past.

What can be the role of the hydrogeologist in such cases?

Firstly, it is important that a valid and convincing diagnosis of the problems is made as early as possible. This should be done long before the time series of observed groundwater levels are sufficiently long to provide statistical evidence of a trend. Water resources assessment programmes are an excellent tool to do this systematically.

Secondly, the authorities and the public need to know how the groundwater conditions are likely to develop, what will be the practical consequences of changing conditions, and what options exist for managing groundwater storage. This will require reliable model simulations, thus contributions from the side of the hydrogeologist, both to conduct field observations and to carry out the model study.

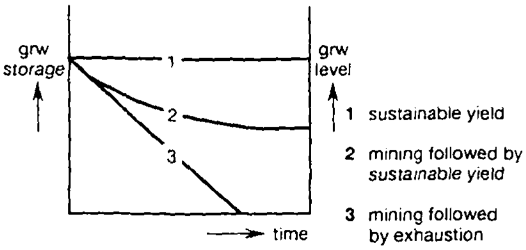


Fig. 5: Groundwater storage management options.

Abb. 5: Alternative Verfahren zur Nutzung von Grundwasserspeichern.

To design and evaluate practical measures to control groundwater pumping, to prepare decision-making and to implement measures opted for, teams of many professionals of different disciplines are needed. Hydrogeologists should be able to function in such teams and to contribute within their field of competence.

Developing and implementing effective management of the groundwater resources requires a long period of time, especially because the decision process and the many people involved make it extremely complex. Its success will be enhanced by consistency and continuity among the main actors, which include the hydrogeologist. It is evident that local hydrogeologists will be on the long term more effective in this respect than expatriates who stay only a few years in the country.

The development of national institutions staffed by capable Yemeni hydrogeologists that conduct systematic investigation programmes and related studies is a 'conditio sine qua non'. Hydrogeologists from overseas may play a valuable role in providing initial support.

Groundwater pollution in The Netherlands

Until the 1960's and even beyond, fresh groundwater in The Netherlands was almost by axiom considered as being of excellent quality and thus a reliable source for drinking water.

The hydrogeologists had to explore and study the occurrence of fresh, saline and brackish groundwater, but most of their work was related to problems of groundwater flow. E. g. in the framework of the selection of favourable aquifer zones and sites for well fields, or to predict possible declines of the phreatic levels that are of vital importance for agriculture in nearly the total national territory.

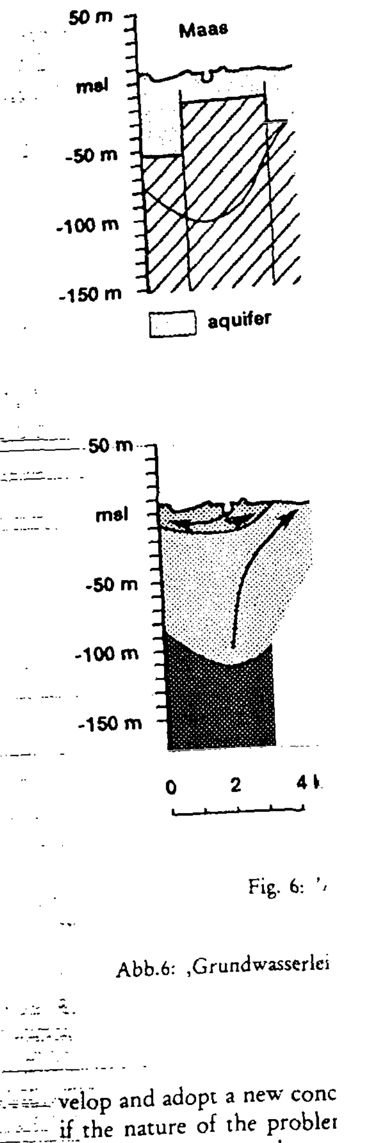
The nature of these problems and the prevailing situation in The Netherlands of Pleistocene sandy aquifer beds alternating vertically with clayey aquitards stimulated under groundwater specialists the so-called 'aquifer approach' (see figure 6). Within aquifer beds, attention was paid to lateral variations, while vertical variations were assumed to be negligible; for computations and simulations, 2D- or quasi 3D-models were considered satisfactory.

Under steadily improving detection limits of water quality analysis in the laboratories, and under strongly increasing pollution loads produced by modern agricultural practices and traditional inadequate waste disposal methods, the views on groundwater quality have quickly changed during the last two decades. Groundwater pollution cases were discovered one after another, groundwater quality monitoring networks were installed, vulnerability studies were carried out, and mapping of groundwater quality became less geochemically- and more pollution-oriented.

Explaining the groundwater pollution patterns, and especially predicting how the bodies of polluted groundwater will move through the aquifer system, met with considerable problems. One of the factors that has caused stagnation in this respect is the traditional fixation of the groundwater specialists on the aquifer approach mentioned above. Thinking in lithologically defined units was a barrier to proper understanding of the migration of solutes.

Adopting the 'groundwater flow systems approach' (see figure 6) — originally developed and promoted by TÓTH (1963) and complementary to the traditional approaches — has caused a breakthrough and provides a useful key to understanding and evaluating groundwater pollution processes. The occurrence and movement of polluted zones is better understood than before, and this allows to predict how and to what extent control of aquifer contamination is feasible. Of particular practical interest are the options to promote that polluted shallow groundwater will be intercepted by the surface water systems.

This example demonstrates that in the strife for the protection of groundwater resources a critical attitude towards the conceptual basis of interpreting and analysing data is continuously of vital importance. The hydrogeologist should be prepared to de-



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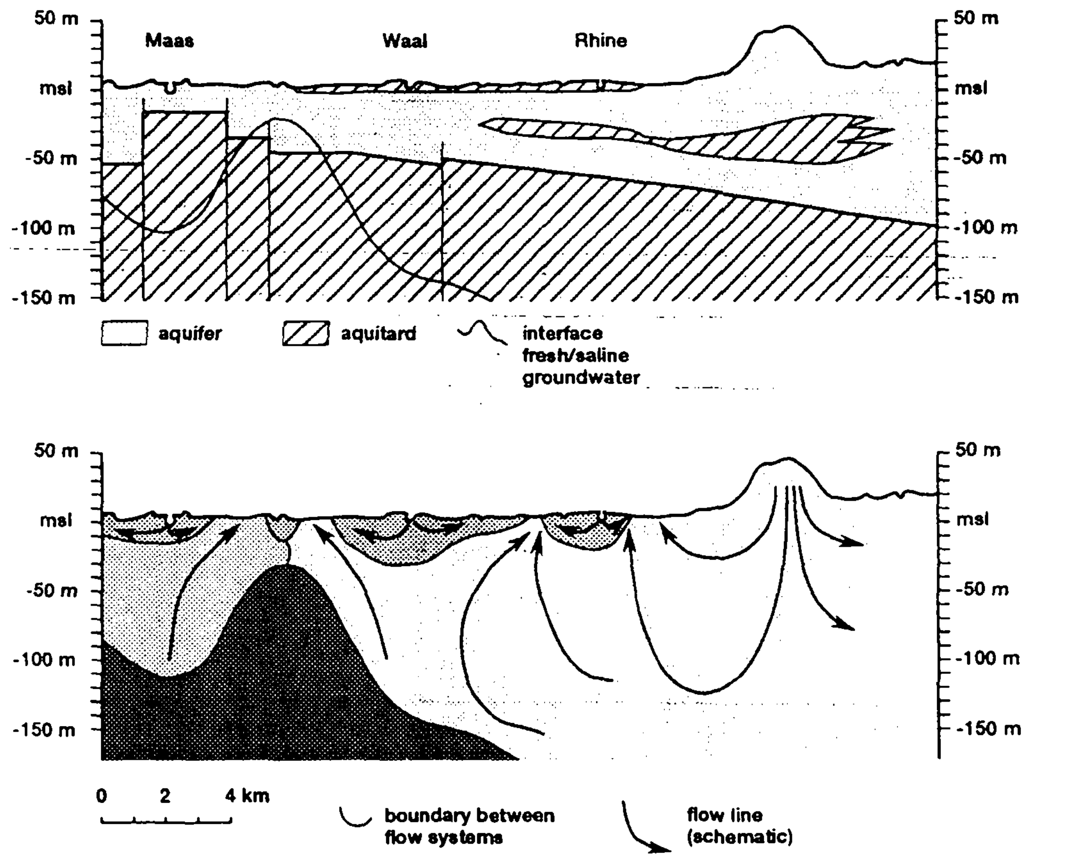


Fig. 6: 'Aquifer approach' (top) and 'groundwater flow approach' (bottom) (Source: TNO Institute of Applied Geoscience).

Abb.6: ‚Grundwasserleiter-orientierte' (oben) und ‚Grundwasserströmungsorientierte Darstellung' (unten) (Quelle: TNO Institute of Applied Geoscience).

velop and adopt a new conceptual basis for his work if the nature of the problems faced is changing and calls for new approaches.

Although in many developing countries groundwater pollution is not yet considered as a first-order problem, it may become so in the near future. The conceptual approach for groundwater pollution studies as developed in The Netherlands may prove to be equally valuable in those countries.

Water resources management planning in the Jabotabek area

The Jabotabek area consists of the city of Jakarta, Indonesia, and the neighbouring urbanized districts (*kabupaten*) Bogor, Tangerang and Bekasi. The area encompasses some 6400 km^2 and had in 1990 approximately 17 million inhabitants, of which 8 millions within the city boundaries of Jakarta.

A pictural impression of the geology of the area is shown in figure 7. Jakarta is situated near the sea on top of a 200 m thick sequence of Quaternary sediments (Jakarta basin). This sequence is in general poorly permeable, with modest layers or pockets of fine sands and silts between thick clayey layers. At the beginning of the 20th century the recharge of this groundwater system took place mainly in the upper part of the Jakarta basin, in the zone adjoining the volcanic rocks of kabupaten Bogor. Downflow from there, towards the sea, the groundwater at medium and greater depths becomes confined; this resulted in those days in pronounced artesian conditions under the city.

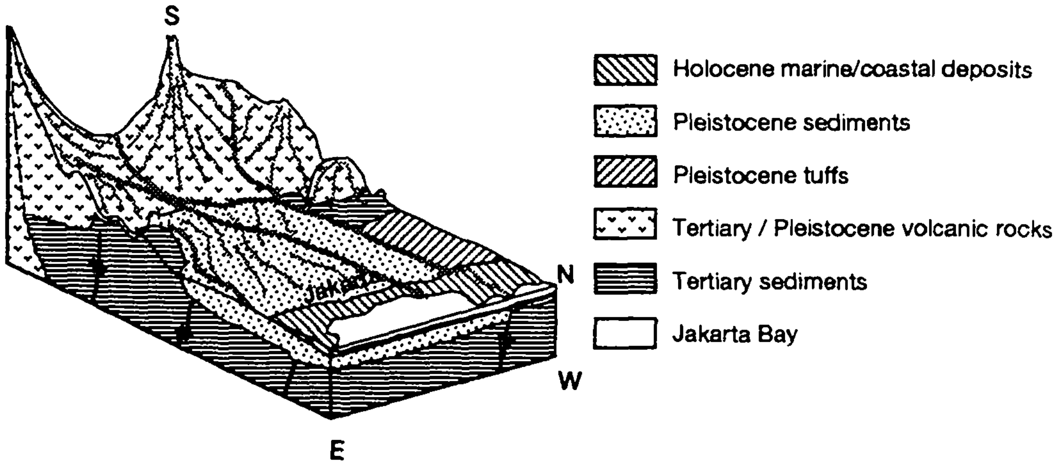


Fig. 7: Geologic impression of the Jabotabek area.
(Source: unpublished information of the JWRMS project)

Abb. 7: Geologischer Überblick des Jabotabek-Gebiets.
(Quelle: unveröffentlichte Information des JWRMS Projektes)

As a result of heavy pumping during the second part of this century, the artesian conditions have disappeared, and piezometric levels have declined locally as much as 50 m (see figure 8).

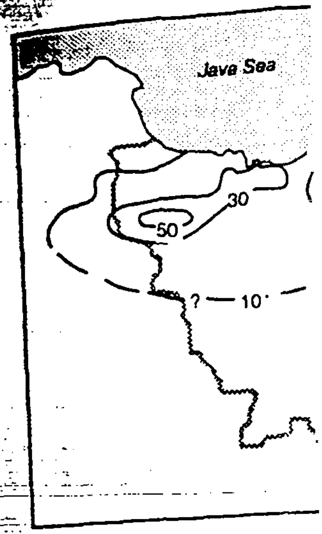
The occurrence of saline groundwater near Jakarta Bay and the considerable declines of the groundwater level have inspired hydrogeologists to make model predictions of possible saline water intrusion. The conclusions developed were that this process would be effectively reduced if groundwater abstractions near the coast will be restricted. This has resulted in the development and adoption of a groundwater conservation plan, of which the most recent version is illustrated in figure 9. In spite of problems in effectively implementing the strategy, it may seem at first glance that in this way an important step forward has been made to conserve the groundwater resources of the Jakarta area. But it can be criticized because of two main reasons: it neglects other import groundwater management issues and it is based on a questionable interpretation of the groundwater salinization processes.

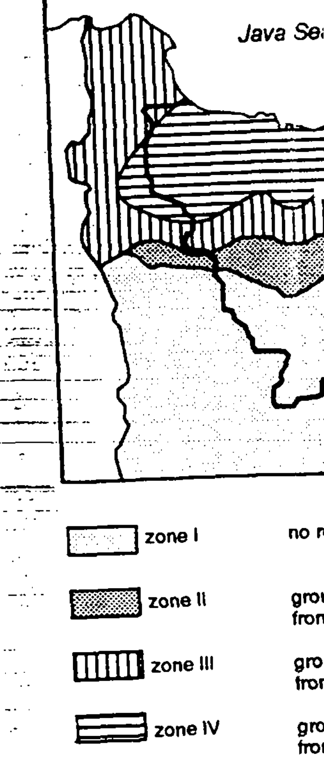
In the Jabotabek Water Resources Management project (JWRMS) that started in 1991, an attempt to a broader approach was made, with the objective to establish an integrated water resources management plan for the area. Regarding groundwater the following main issues were identified: groundwater salinity, land subsidence due to pumping and groundwater pollution. The project did not yet complete its studies but a few remarks on groundwater salinity and on land subsidence hazards will be made.

Investigating groundwater on the basis of hydrochemistry and in the context of geological history resulted in the conclusion that the bodies of saline groundwater occurring under the northern parts of Jakarta are not related to active sea water intrusion, but rather are connate waters that are mobilized by hydraulic gradients due to recent pumping. This throws a different light on the dominant salination mechanism and will certainly lead to other groundwater resources management approaches.

Regarding land subsidence very interesting information was collected by the same JWRMS project. Land subsidence in recent years appears to be considerable (see Figure 10) and its similarity with the pattern of groundwater level declines (Figure 8) yields evidence for the hypothesis that this land subsidence is mainly caused by groundwater pumping from middle-deep and deep parts of the aquifer system. To what extent this process is still continuing and whether it can be effectively influenced by control of groundwater pumping still needs to be studied.

Some provisional conclusions, however, can be made. The example shows how important the judgment of the hydrogeologist can be: it is crucial for the strategies to be developed. Also, it shows that more than one issue can play a role at the same time (this is the more common situation); they should be ad-





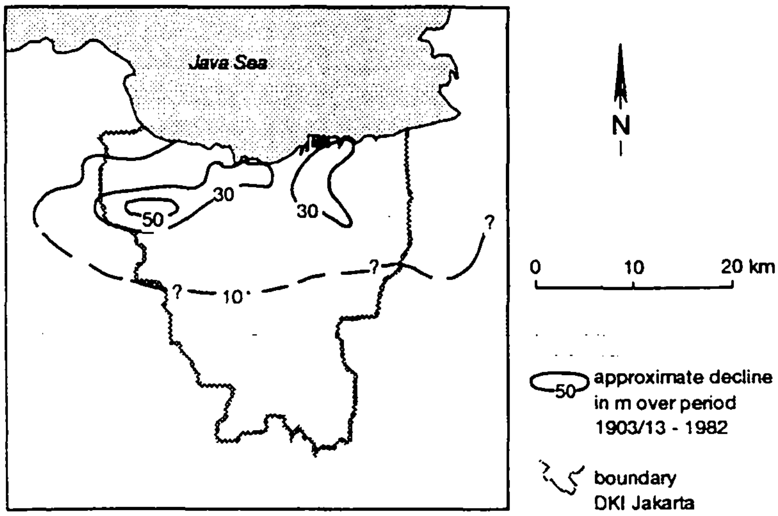


Fig. 8: Groundwater level declines Jakarta area. (Source: DEG, Ministry of Energy and Mines, Indonesia).

Abb. 8: Grundwasserspiegelabsenkungen im Gebiet von Jakarta. (Quelle: DEG, Ministry of Energy and Mines, Indonesia).

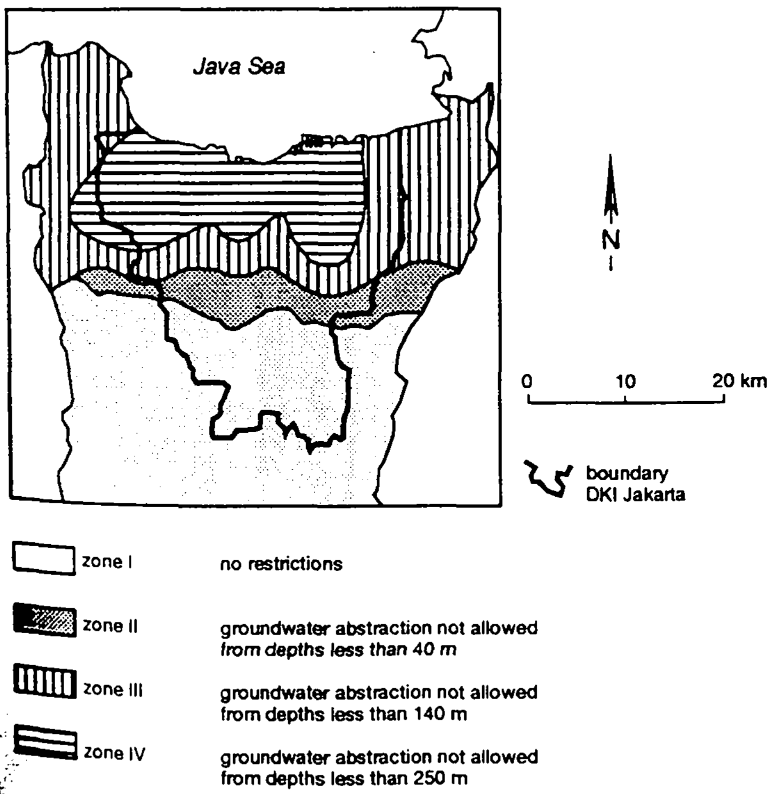


Fig. 9: Groundwater conservation strategy. (Source: DEG, Ministry of Energy and Mines, Indonesia).

Abb. 9: Grundwasser-Konservierungsstrategie. (Quelle: DEG, Ministry of Energy and Mines, Indonesia).

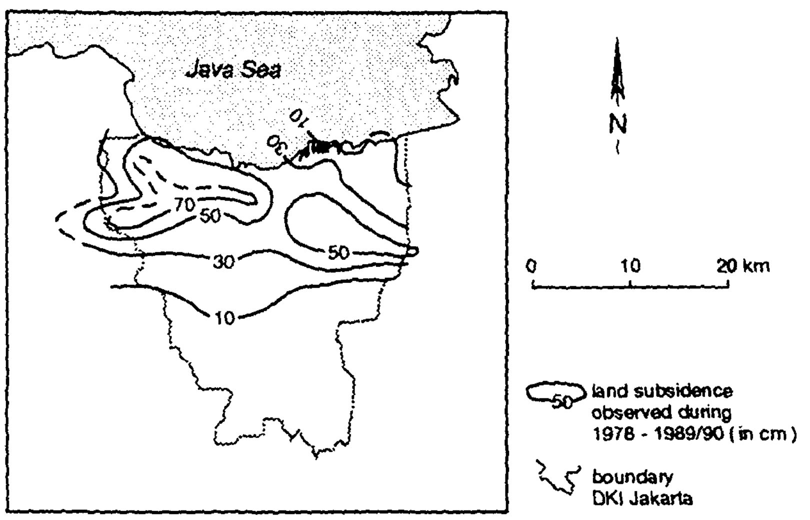


Fig. 10: Land subsidence in the Jakarta area. (Source: unpublished data JWRMS).

Abb. 10: Geländeabsenkung im Gebiet von Jakarta. (Quelle: unveröffentliche Daten des JWRMS Projektes).

dressed simultaneously. What will not be shown in this paper is how the groundwater component is integrated within an overall water resources planning. Integration leads to a different — and supposedly better — management strategy than when groundwater were considered in isolation.

Groundwater development for rural water supply in Iringa region, Tanzania

Finally, a completely different example. Rural water supply systems in countries like Tanzania often suffer from unsustainable infrastructure to produce and distribute the water.

General conditions are that national and regional governmental organizations lack the capacity and finances to operate and maintain the technical systems. Technocratic engineering solutions have been applied in earlier days, but the short life-time of the constructed systems have nourished inspiration to entirely different approaches. Such approaches emphasize the role of the rural communities in the operation and maintenance of the system.

In a Danida-supported project in the Iringa region in Tanzania this principle has been applied, apparently with success. Noteworthy is the role of the hydrogeologist. In order to enhance the feeling of responsibility for the technical infrastructure among the local communities, the project aimed at engaging the population in all phases of the project, including well construction. For that reason, drilling wells — which was justifiable from a technical point of view — was rejected, and hydrogeologists have concentrated on mapping zones where the local population could construct wells themselves, with the help of simple augers and under supervision of the project (NIELSEN 1985). If this approach leads to self-sufficiency of the community as regards maintenance of theirs wells, it will be thanks to — among others — creative ideas of the hydrogeologists involved.

Conclusions and recommendations

1. Although figures show that on global and continental scales the annual flow and renewal of water resources is exceeding by far the present water requirements, it is common experience of all hydrogeologists that the sustainability of groundwater development is widely threatened. Problems are especially occurring in urbanized areas and in densely populated areas within the arid and semi-arid zones.
2. In many regions sustainable groundwater development is certainly not an utopia, but it becomes increasingly more difficult due to steadily growing population, higher aspirations on the quality of life, and cases of irreversible degradation of groundwater quality.
3. Sustainable groundwater development presumes that the groundwater resources are managed. This is a continuous, never-ending activity, with boundary conditions that are likely to change over time.
4. Early diagnosis of threats to sustainability of groundwater development is of vital importance. Once the diagnosis has been made, planners and

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the general public should be made aware of it, in view of strategies to be developed and measures to be implemented. Hydrogeologists can play an important role in this respect.

5. The fact that groundwater-related issues are gradually changing requires the hydrogeologist to have an open mind regarding the conceptualization of the problems and the groundwater systems considered. Combining his professional knowledge and skills with perceived characteristics of the society's demands and problems is a real challenge.
6. The analysis of options for sustainable groundwater development tends to take place more and more in integration with other planning endeavours, e. g. in the context of integrated water resources management planning or environmental planning. This requires that today's hydrogeologist is capable and prepared to work in interdisciplinary teams, and is able to link his discipline with planning.
7. Developing and strengthening specialized national and regional institutes in charge of systematic water resources assessment and monitoring programmes and policy-underpinning studies are a prerequisite for permanent and flexible groundwater resources management.
8. In many 'Third World' countries such institutes do not exist or are not yet strong enough to enable a planned sustainable use of the national groundwater resources. Programmes for related institutional development and capacity-building seem of paramount importance and are expected to bring more structural improvement than any other programme of international cooperation in the water sector. It is a rewarding task for the hydrogeologist of industrialized countries to contribute to such programmes.

References

Atlas of the World (1983): Amsterdam, (Elsevier).

AYIBOTELE, N. B. (1992): The World's Water: Assessing the Resource. — International Conference on Water and the Environment, 26—31 January 1992, Dublin, Ireland; Keynote Papers; 1.1—1.26; Dublin, Ireland.

BRUNDTLAND, G. H. (1987): Our Common Future. — Report of the World Commission on Environment and Development: 400 p., Oxford, U. K., Oxford University Press.

NIELSEN, K. A. (1985): Groundwater Occurences in Weathered Basement Complex Areas. — Vth World Congress on Water Resources, 9—15 June 1985, Brussels, Belgium: 189—198; Brussels.

OKUN, D. A. (1991): An Initiative for Capacity Building for Water Resources Management. Unpublished Paper prepared for UNDP: 35 pages, New York, [Unpubl.]

— & LAURIA, D. T. (1991): Capacity Building for Water Sector Management: An International Initiative for the 1990s. — Proceedings of the UNDP Symposium 'A Strategy for Water Sector Capacity Building', 3—5 June 1991, Delft: 39—69; Delft.

SHIKLOMANOV, I. A. (1991): The World's Water Resources. — In: International Symposium to Commemorate the 25 years of IHD/IHP Unesco, Paris: 93—105; Paris.

TÓTH, J. (1963): A Theoretical Analysis of Groundwater Flow in Small Drainage Basins. — *Journal of Geoph. Research*, 68: 4795—4812; Washington.

VAN DER GUN, J. A. M. (1987): High Rates of Groundwater Abstraction in the Yemen Highlands. — Proc. of the 19th Congress of the IAH, 8—15 September 1986, Karlovy Vary, Czechoslovakia, Part 1: 243—251; Karlovy Vary.

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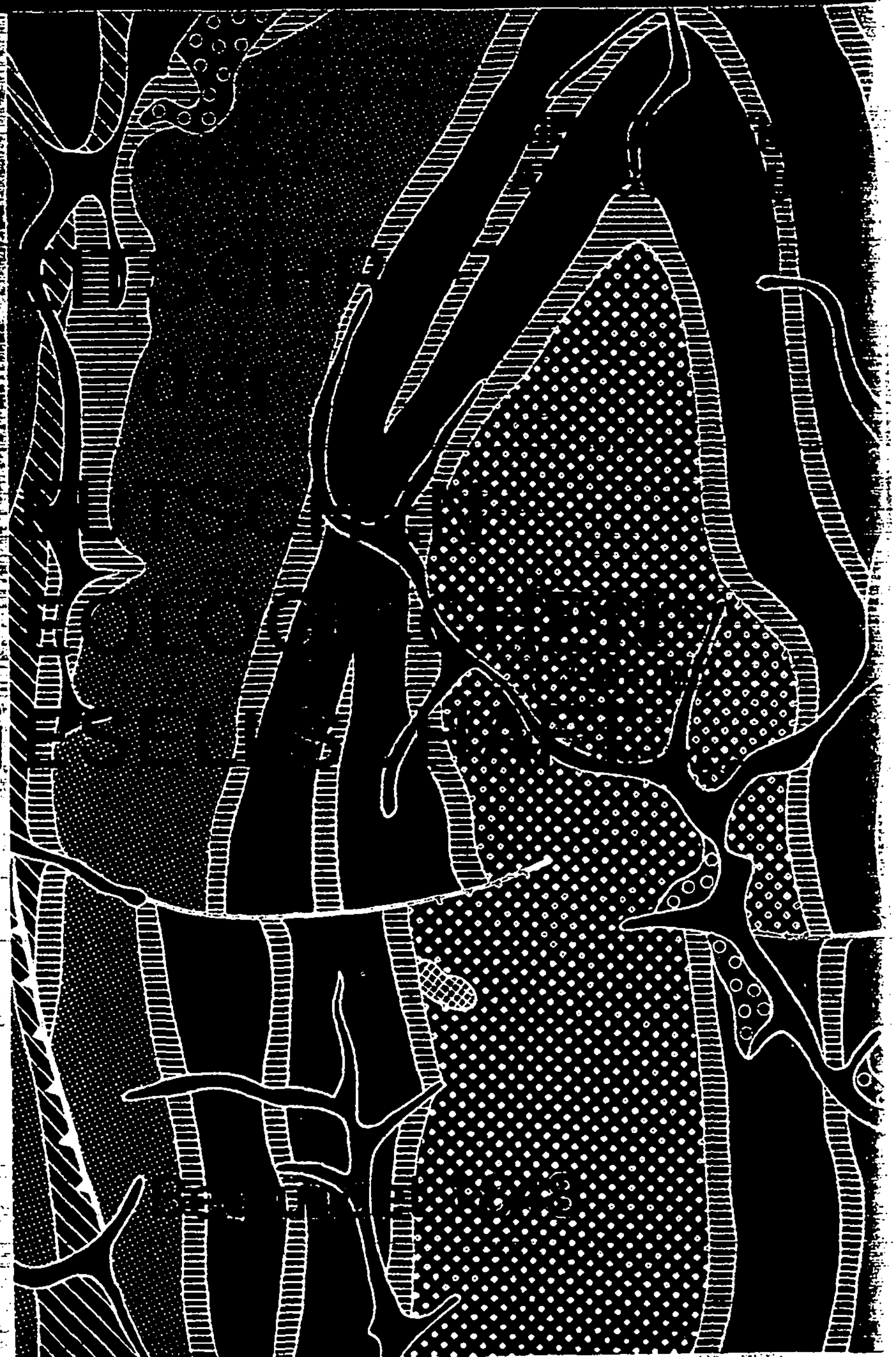

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