DEVELOPMENT OF A STRATEGY FOR GROUND WATER INFORMATION TRANSFER & EDUCATION AWARENESS TO LOCAL AUTHORITIES

WHICH EMANATED FROM A PROJECT ENTITLED

"DEVELOPMENT OF A STRATEGY FOR
DISSEMINATING INFORMATION FROM
THE HYDROGEOLOGICAL MAPPING PROGRAMME
TO VILLAGE WATER COMMITTEES"

PREPARED FOR THE
WATER RESEARCH COMMISSION

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EXECUTIVE SUMMARY

Groundwater is an important water source. Incorrect understanding has resulted in incorrect development, poor management and operation of groundwater schemes.

This has led to poor confidence in groundwater as a water source. Because of the scarcity of water it is of utmost importance that communities gain confidence in this resource and use it wisely. Groundwater is a reliable water source if understood, developed, managed and operated correctly.

Attitudes therefore need to be changed. To achieve this a groundwater education and awareness campaign needs to be initiated. Adequate knowledge on groundwater resources are available for public use. The real problem is not the unavailability of knowledge on groundwater, but the appropriate strategies to transfer this knowledge.

This "transfer gap" is identified as the real problem to disseminate groundwater information.

This project has therefore concentrated on developing strategies for knowledge transfer to specifically local councilors.

It further identifies the contents of information required to be transferred, the different methodologies to transfer this information. The need for a broader groundwater awareness strategy is also highlighted.

The project also draws on experience from other countries especially Australia through the direct involvement on the project of W R Evans from the Australian Geological Survey Organization transferring their lesson from the Land Care Programme

1 INTRODUCTION

One of the major challenges facing the new South Africa within the changing political climate, is the provision of basic services & capacity building in previously disadvantaged communities. Within this context, the provision of sustainable water supplies to rural communities has become a priority.

More than 12 million people, most of whom live in rural areas, do not have access to sufficient clean water. Water resources in South Africa are limited and the ever growing population is placing an increasing burden on these crucial, but limited resources.

Groundwater is an important water source in most rural communities. Incorrect understanding results in incorrect development, poor management & operation of groundwater schemes. This has led to poor confidence in many communities of this valuable resource. Because of the scarcity of water, it is of utmost importance that communities gain confidence in this resource and use it wisely. Groundwater is a reliable source if understood, developed, managed and operated correctly. Community's attitudes therefore need to be changed.

The "White Paper" on Water Supply and Sanitation, released by the Department of Water Affairs & Forestry, clearly states that communities will be given the responsibility of operating and managing their own water supplies. This policy necessitates that communities need to be well informed.

2. BACKGROUND

This project builds on a range of previous initiatives within the South African water arena. Specifically, it combines the information on the published General Hydrogeology Map, Pietersburg, at 1:500 000 scale, and a general philosophy of empowering the village water Committees to undertake water management.

The project addresses the issue that communities will be given the responsibility to operate and manage their own water supplies. Further it is recognized that communities will ultimately make better decisions, regarding their resource usage, if they are included in the decision making process from the inception of the project. It is vital that community level decisions regarding community resources be driven by the community itself.

For this decision-making mechanism to operate effectively, communities need a basic understanding of water sources as well as a high level of technical support. Technical support is usually in the form of a range of future options regarding management directions, as well as detailed data and information regarding resource performance and capability. Specifically, when communities are faced with decisions about managing their groundwater resources, they require not only basic information on groundwater occurrence and behaviour, but also detailed information on zones of influence and aquifer sustainable yields. They also require this data at a strategic level - this being the best place to develop their water supplies as well as instruction of the strategic limits on development.

A key outcome of this project will be an expectation that communities will start to plan their groundwater resource development more strategically.

3. PROJECT OBJECTIVES

The primary objective of the research project was the development of educational packages for the transfer of hydrogeological knowledge, arising from the regional hydrogeological mapping programme to communities, so that they can understand and manage their own groundwater sources on a sustainable basis.

However, as the research progressed, it became apparent that the above objectives could not be achieved without a proper strategy being put in place, and that this strategy needed to form part of a broader longer term National Groundwater Awareness Strategy.

It further became apparent from interviews and workshops with target groups, that the information to be relayed is more than just the knowledge arising from the mapping, but that a translation of fundamental groundwater issues was required first.

For this reason, it was decided, together with the Steering Committee, to de-emphasize the development of detailed educational packages, and place more emphasis on the development of a strategy.

4. METHODOLOGY

In order to achieve the project objectives, the following methodology was adopted :

- Understand the institutional arrangements and Policies set up by Government
- Identify decision makers and managers at lowest level - Target groups
- Interview selected members of the Target groups in terms of their role in water supply as well as their understanding of water supply issues, specifically groundwater, and ascertain their knowledge of basic groundwater concepts in their area.
- Based on information obtained from the above steps, develop a matrix of the range of basic

information on groundwater.

- Conduct workshops with Target group, presenting basic information developed to ascertain what information they require and how to transfer this information.

- Formulate a strategy to develop and transfer relevant information.

- Develop the contents of educational material.

5. AUSTRALIAN EXPERIENCE

The Australian National Landcare Programme (NLP) provides a useful model to illustrate how these processes are being driven. Water resource management (indeed all natural resource management) is undergoing massive change in the Australian context, and reflects a worldwide trend towards empowering the resource users to manage the resource base. In Australia, the Government has recognized that previous Government management of natural resources led to confusion amongst users what their role and the role of government should have been.

In most cases, an application of "the beneficiary pays" principle has resulted in the supply arm of resource agencies applying charges to users to recoup the real cost of delivery. Further, Governments have seen these charges as an opportunity to develop a water business, with a reduction in funding from central treasuries.

This has understandably brought conflict amongst resource agencies when eg the same agencies who have been applying charges to water users, have been called upon to frame resource management policy. The main outcome of this process has been to separate these functions by privatizing or Corporatising the water business arms of Government into two areas - bulk water supply and water delivery.

This move to Corporatisation has led Governments to question who the main clients for these water businesses would be. In irrigation areas the answers to these questions were obvious - a water delivery business (a local water board) would sell water to individual farmers within the irrigation area. What then, would an appropriate role for Government be, on the a local scale?

One such role was to facilitate a move towards sustainability within these farming areas. This was best done under a philosophy of allowing the local community to make their own resource management decisions, on the understanding, that Governments would enter into a partnership with the community, to fund it's share of works needed to ensure a sustainable future for the region. Government also stipulated that before funds would be made available, each region will be required to formulate a Land and Water Management Plan. The aim was to achieve this by making use of representatives of the region's community, supported by technical expertise where it was required (usually funded by Government).

At the same time, a philosophy that built on the knowledge that the land and water systems are interconnected, was developed and took shape in the form of a commitment to Integrated Catchment Management. Simply, this philosophy embodied the concept that each component of a natural system is inextricably linked to other components - for example, a management decision related to land management could have an impact on water quality.

This led to the formation of a number of catchment areas, based on major surface water catchment boundaries - each area being administered by representatives from the catchment community. Using the irrigation experience with Land and Water Management Plans, Government undertook to fund its share of the cost of moving toward economic and environmental sustainability, based on a Catchment Plan. Likewise, Government also saw the Catchment Committee as being responsible for the decisions made in the catchment, in return for receiving funds.

The outcome of this process was twofold. Firstly, Government had clearly identified communities organized around catchments as being the drivers of sustainability and resource management. Government was willing to provide funds on a shared basis to allow this to take place. It became government's role to support this process. Secondly, communities were given the power and prospect of funds to undertake the process, but were immediately faced with a knowledge gap. How were they to formulate a strategic plan for the long-term sustainability of all the resources in their Catchment?

It is clear that the process of knowledge transfer and community education/awareness becomes a necessity.

This process of knowledge transfer and community education/awareness is now taking place. Governments are funding a range of projects directly as well as through the Catchment Committees.

These projects usually take the form of a partnership, between the knowledge providers (the researchers/investigators) and the trainers/educators, and are driven by the community.

6. SOUTH AFRICAN SITUATION

The following extract from the White Paper on Water Supply and Sanitation (November 1994) provides a good introduction to sketch the South African situation.

"South Africa's entire framework of Government is undergoing massive transformation at central, provincial & local levels. In this process, it is essential to ensure that existing institutional capability for water supply and sanitation provision is maintained in the short term. It is equally important, if the objectives of Reconstruction and Development are to be met, that the foundations of a sound institutional structure are laid for the long term, consistent with the provisions of the Constitution and the principles outlined above.

The policy of the Department of Water Affairs and Forestry, is to ensure that all communities in the country have access to basic services, as well as to the support that they need to achieve them. This does not imply that the provision of these is necessarily the direct responsibility of the Department. What is required is a framework, within which responsibilities and lines of support for water supply and sanitation activities are clear. This institutional framework will necessarily involve a range of other agencies, notably Provincial and Local Governments as well as other interested parties, such as the private sector and non-governmental Organizations. The Department of Water Affairs and Forestry will support the work of the other agencies; as important, it will assume the responsibility to fill the gaps in the interim.

In this context, the institutional goals of the Government with regard to water supply and sanitation services can be stated as follows :

***In the short term**, the immediate goal is to maintain service delivery, to rationalize the central Government Department and ensure the smooth integration of all the previous homeland, staff, functions and budgets into a new National Department with appropriate Regional structures; to transform and democratize the Water Boards and to "gear up" to achieve medium term goals.*

***In the medium term**, the objective of Government is to support institutional development at local level as well as to provide financial and technical assistance for the physical development of water supply and sanitation services. This will be achieved through the restructured Department of Water Affairs and Forestry at Regional level, and through second tier water Institutions, such as the Water Boards, with the full involvement of the private and NGO sectors.*

***In the long term**, the goal is that the provision of services to consumers should be the function of competent, democratic local Government, supported by Provincial Governments. Where necessary and appropriate, second tier Institutions (such as Water Boards) will provide bulk or Regional water supplies or wastewater disposal services to local authorities, under the supervision of the Central Department of Water Affairs and Forestry.*

This Department will be responsible for water resource management, for monitoring and regulating functions and specifically to ensure that an enabling environment for community based water *supply and sanitation development is maintained. Public Agencies should be served by a strong private and NGO sector".*

On the premises of the Reconstruction and Development Programme, Government has adopted the following principles viz :

- **DEVELOPMENT SHOULD BE DEMAND DRIVEN AND COMMUNITY BASED**

  Decision making and control will be devolved as far as possible to accountable local structures. There is a reciprocal obligation on communities to accept responsibility for their own development and governance, with the assistance of the State.

- **BASIC SERVICES ARE A HUMAN RIGHT**

  This will be interpreted, in terms of the Constitution, as a right to a level of services, adequate to provide a healthy environment. They do not imply the right of an individual person or community to demand services at the expense of others.

- **"SOME FOR ALL" RATHER THAN "ALL FOR SOME"**

  To give expression to the constitutional requirements, priority in planning and allocation of public funds will be given to those who are presently inadequately served.

- **EQUITABLE REGIONAL ALLOCATION OF DEVELOPMENT RESOURCES**

  The limited national resources available to support the provision of basic services, should be equitably distributed among Regions, taking population and level of development into account.

- **WATER HAS ECONOMIC VALUE**

  The way in which water and sanitation services are provided must reflect the growing scarcity of good quality water in South Africa, in a manner which reflects their value and does not undermine long term sustainability and economic growth.

- **THE USER PAYS**

  This is a central principle to ensure sustainable and equitable development, as well as efficient and effective management.

- **INTEGRATED DEVELOPMENT**

  Water and sanitation development is not possible in isolation from development in other sectors. Co-ordination is necessary with all tiers of Government and other involved parties, and maximum direct and indirect benefit must be derived from development in, for instance, education and training, job creation and the promotion of local democracy.

- **ENVIRONMENTAL INTEGRITY**

  It is necessary to ensure that the environment is considered and protected in all development activities.

Government is presently trying to achieve the medium term objectives[1]. In this respect, the restructuring of the Department of Water Affairs and Forestry (DWAF) has progressed well, one of the results being the development of a new Directorate : The Community Water Supply and Sanitation Directorate[2], which takes overall responsibility for Water Supply in rural areas.

This Directorate is, at present, supporting institutional development at local level as well as financial and technical assistance for the physical development of water supply and sanitation services.

As functional, competent Local Government were not yet in place, Local Water Committees (LWC's) were established to undertake local water and sanitation service provision, together with Government, NGOs and the private sector.

The first democratically elected local Councils have recently be inaugurated. The Transitional Local Councils (TLC's[3]) and the process of interaction into the institutional goals needs to commence. However, at this stage, the TLCs lack the capacity to implement the responsibilities given to them, in terms of water supply. This has resulted in conflict between some Local Water Committees and the TLCs.

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[1] Since the development of this document Government has moved from the medium term to the long term objectives.

[2] Since the development of this document, The Community Water Supply and Sanitation Directorate has changed its name to the Water Services Directorate.

[3] Since the development of this document the 2nd democractically elected local elections have taken place electing councilors for the newly demarcated municipalities (a consolidation of the previous Transitional Local Councils). These municipalities are expected to be operational by end April 2001.

In order to co-ordinate ongoing water development and stimulate TLC involvement, area planning forums have been set up by the DWAF Directorate consisting of all the role players.

A framework is now required, within which responsibilities and lines of support are clarified, to resolve the conflict between LWC's and TLC's.

7. TARGET GROUPS

The following possible target groups[4] were identified, viz. :

- **TRANSITIONAL LOCAL COUNCILS (TLCs)**

  This group holds the main legal responsibility for water supply development in their area of jurisdiction. However at this stage, they do not have the capacity to convey the responsibilities given to them. They would require an overview strategic understanding of the groundwater resources in their area, their main task being management.

- **LOCAL WATER COMMITTEES**

  These Committees were seen as the group most likely to hold the operational role of water supply. They would need to understand issues around groundwater supply, operation and maintenance.

- **COMMUNITY**

  This group was not seen as a target group for this project. They were rather identified as needing education via a broader awareness programme.

[4] Since the development of this document, target groups, in addition to the ones mentioned above have been identified viz :- Water Users Associations (WUA's), Catchment Management Agencies (CMA's), Project Steering Committees (PSC's) and Community Development Officers (CDOs). Transitional Local Councils (TLC's) have been replaced by Municipalities and District Municipalities.

- **GOVERNMENT DEPARTMENTS**

  These groups were seen as critical stakeholders in the broader awareness programme. Their involvement in this project is seen as one of ownership of the process. Though they would not be targets for information generated by this project, an awareness raising programme would be needed.

In order to restrict this project to a manageable programme, it was agreed that this project would focus on the TLCs as the major target group.

This project intends addressing the deficiencies in capacity at TLC level, in terms of understanding groundwater.

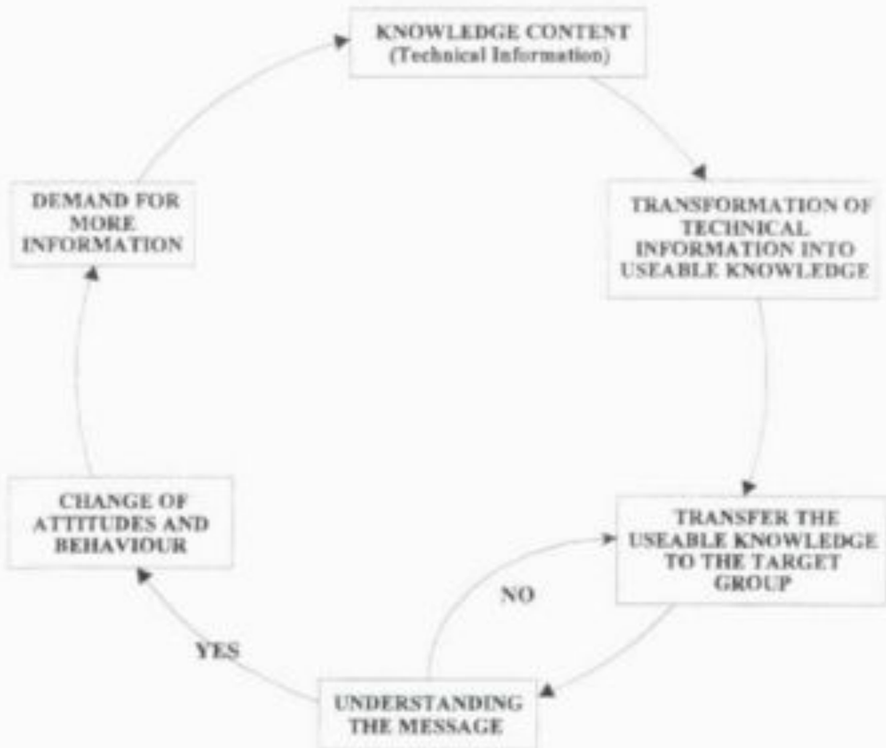
8. STRATEGY

In recent years, it has generally been assumed, at least implicity, that adequate knowledge on groundwater resources are available for public use. The real problem is not the unavailability of knowledge on groundwater, but the appropriate strategies to transfer this knowledge (some too technical for a layman to understand) to communities. This "transfer gap" has often been considered to be the real problem confronting the present day South Africa in its bid to disseminate groundwater information. This section, therefore, presents strategies that will help reduce, if not eliminate, this transfer gap.

From discussions and workshops held with the various TLC's it was found that most councilors had a negative attitude towards ground water in terms of solving their water supply problems. In most cases this attitude was based on the fact that ground water was seen to be an unreliable source. In simplistic terms, ground water was associated with a broken handpump. A reliable water source was perceived to be from a dam, and consisted of a pipeline, a reservoir and taps.

In order for these councilors to make well informed wise decisions on water supply options, their attitudes towards ground water needs to change.

Below is a simplistic model of the process involved for behaviour change.



- **KNOWLEDGE CONTENT** (Technical Information)

  A range of technical information needs to be collected that is accurate and relevant to the basic information requirements of the TLC's. This information is in the form of ideas, conceptual models, reports, databases and maps and needs to be collated by a technically competent person as this information needs to be transferred to the target group and will form a factual base upon which further interpreted or specialist materials are developed.

- **TRANSFORMATION OF TECHNICAL INFORMATION INTO USEABLE KNOWLEDGE**

  Before information can be transferred, two things need to happen :

  - The style in which the information is to be presented to the target group has to be decided on, so that maximum impact is gained, thus curriculum developers are required.

  - It is important to ensure that the key questions within the target group are explicit so that the correct information can be transferred to address these questions, thus social scientists are required.

- **TRANSFORM THE USEABLE KNOWLEDGE TO THE TARGET GROUP**

  Here the messenger plays a major role. Often the messenger is more important than the message if successful transfer is to take place.

- **UNDERSTANDING THE MESSAGE**

  After the message is transferred it is important that interaction with the target group take place to ensure that the message is understood correctly. Here again social scientists are needed to evaluate this.

- **CHANGE OF ATTITUDES AND BEHAVIOUR**

  The best that can be expected from education and awareness raising is a change of attitude with a corresponding change of behaviour. This leads to longer term changes that are sustained by ownership of the process.

- **DEMAND FOR MORE INFORMATION**

  The model acknowledges that a desire/need for more information (probably both more specific and specialized) may well be generated by the initial information transfer process. This results from the recipients ability to better frame questions and issues within the technical field of interest. This process of question/knowledge building/question may well become an ongoing process.

This process will provide the TLC's with a mechanism to enable them to identify resource management problems and to devise solutions to address causes rather then symptoms.

The above simplistic model should form part of the broader national education and awareness strategy. For the specific target groups identified in this project ie the TLC's, the following more detailed strategies are given below :

8.1 <u>Knowledge Content</u>

From the workshops held, the following issues were highlighted which needs to be addressed (See Appendix A), viz :-

- what is groundwater?
- where and how does it occur?

- how much is there?
- what is the quality?
- how do you exploit it?

From these issues the following modules are recommended :

8.1.1 *The Water Cycle*

This module should address the issue of "What is groundwater?", by describing all the components of the water cycle with specific reference to the role groundwater plays. A full understanding and the interaction of all it's components should suffice.

8.1.2 *The occurrence of Groundwater*

The module should address the issue of "Where and how does groundwater occur?", by describing intergranular, fractured, karst and weathered and fractured occurrences.

Here Vegters explanation booklet (Vegter, 1995) and map as well as the 1:500 000 Hydrogeological maps can be used to assist.

8.1.3 *Quantification of Groundwater Resources*

This module should address the issue of "How much Groundwater is there?" Here basic groundwater concepts need to be discussed and understood such as :

- aquifer
- recharge
- storage
- hydraulic conductivity or transmissivity
- the difference between aquifer yield and borehole yield

Here the Harvest Potential Map can be used to illustrate how a combination of the above concepts can be used to quantify the groundwater resources.

8.1.4 *Groundwater Quality*

This module should address the issue of "What is the groundwater quality?", by describing the chemical and bacteriological characteristics of groundwater. Here the document produced by DWAF and the Department of Health "Quality of Domestic Water Supplies" Volume 1 :

Assessment Guide, can be used.

Potential groundwater pollution sources such as waste sites, fertilizers, pesticides and pit latrines should also be discussed.

The National Groundwater Quality maps of Vegter, 1995 can also be used.

8.1.5 *Groundwater Exploration and Development*

This module should address the issue of "How do you exploit groundwater?, by describing, but not going into detail, groundwater exploration methods, such as field mapping, geophysics and possibly also diviners, drilling techniques, test pumping, and different types of borehole equipment.

8.2 Transfer Mechanisms

The transfer mechanisms proposed for the dissemination of groundwater information to the TLC's is categorized into three main headings which will each be discussed below. They are:

- strategy methodologies
- strategy means; and
- the way forward

8.2.1 *Strategy Methodologies*

Two methodologies of information transfer is proposed for the information transfer of groundwater :

- participatory orientated training
- social mobilization and marketing

These methodologies are internationally accepted approaches used to disseminate information and are suggested to be adopted within the South African context. In personal interactions these two methodologies are applicable.

- **Participatory Orientated Training**

This section dwells on the works of Srinivasan (1990) and Choi and Hannafin (1995).

Unlike traditional teaching methods which have emphasized the transfer of knowledge through messages or knowledge content which have been pre-selected by outside specialists, participatory training (proposed in this study) focuses more on the development of human capacities to assess, choose, plan, create, organize and take initiatives. With this learner-centred approach, the trainer merely facilitates a process of competency-building and self-discovery for the learners whose needs, experience and goals are the focus of the training. These skills can then spill over to other aspects of the person's life and community. It is also evident that this approach will serve as a means to further advance the Social Mobilization model, which is the other proposed intervention strategy.

The overriding goal of this participatory training is not simply to ensure sustainability of borehole systems by teaching trainees how to make boreholes function or how to fix a borehole pump. Rather, it is to assist trainees in developing the outlook, the competence, the self-confidence and the commitment which will ensure a sustained and responsible community effort in the sector and beyond. The participatory training has been oriented to promote independent trainee's ability to identify, analyze and solve problems and to participate in the formulation of decisions concerning groundwater issues. The participative training combines learning about issues on groundwater (such as the hydrological cycle or myths about groundwater) with capacity building that will initiate and sustain processes of change and empowerment in developing communities that rely on groundwater.

Learning sessions are therefore structured in the form of problem-solving activities or tasks requiring teamwork and open peer discussion. Whilst the trainer provides the simple structure of the problem-solving activity or task, the content is contributed mainly from the learners, drawn from their own rich experience of life and their understanding of groundwater. To achieve the principles envisaged by any participatory training programme, the learning methods and the structure of the modules have been designed to bring the best out of the learner.

A. **Learning Methods**

(i) Activity Methods

Methods used are based on the SARAR approach (S – self-esteem, A – Associative strengths, R – resourcefulness, A – action planning, R – responsibility). Firstly, trainees are involved in using their creativity and at looking at issues concerning groundwater in new ways. This will give them tools to investigate and analyze the reality. Invariably, this helps trainees to develop skills in accessing information on groundwater, and planning groundwater projects.

The cluster of method used includes the following :

- Creative methods

  Major transformation in groundwater will depend not only on how many good ideas we generate for the trainees, but on how open trainees themselves are to innovation, how imaginatively they look at their resources and how ingeniously they go about solving their problems.

- Investigative methods

  These methods refer to those activities in the training that enable trainees to do their own assessment of problems and situations in their locale. This will help to reduce the marginalisation of local people by the "supreme all knowing" academics and/or technical experts. It enables trainees to gain a fuller understanding of their problems and to contribute their insights on causes and alternative solutions to groundwater issues.

- Analytic Methods

  A series of analytical exercises are incorporated in the materials to assist trainees in developing critical as well as lateral thinking skills during the training. The programme has been structured in a way that will allow creative methods to precede analytic methods. If analysis takes place too early, every new idea could be shot down by premature judgment and trainees would hesitate to make suggestions.

- Planning Methods

  The involvement of local communities in the development of groundwater projects requires a certain minimum ability to plan. Various types of educational exercises have been incorporated in the materials to provide practice in the use of basic planning skills in groundwater projects.

- Informative Methods

  For the trainees to feel self-confident about his/her knowledge on groundwater issues, the need for information is essential. Over and above the participative training methods, the training package should contain didactic teaching (traditional teaching approach) materials. These materials have been designed to facilitate faster adsorption of the contents and the ability to retain information. To diverge a little from the didactic approach, some kinds of activities that will help the trainees to acquire knowledge in a participatory way are included. Among these include :

  - Demonstrations
  - Contests
  - Needs assessment brainstorming
  - Information-sharing exercises
  - Evaluation exercises
  - Informative games
  - Case studies

(ii) The Role of Facilitation

Since learning is assumed to be indexed by personal constructions of reality, experience is fundamental to understanding and using knowledge and skills. In this training programme, trainees are to be provided the support to facilitate personal constructions of meaning about the world they experience. Ongoing, interactive, and continuous facilitation is to be provided. Facilitation provides learners with opportunities for internalizing information, thereby promoting the higher-order, meta-cognitive skill-development (self-monitoring and correction skills) as well as self-regulation and self-assessing abilities. In situated learning environments, facilitation has assumed several forms.

The following forms of facilitation have been incorporated into this project:

- Modeling

  The trainee observes, then mimics, the facilitator/lecturer in the performance of a task. Through modeling, trainees would be able to observe normally invisible processes and begin to integrate incidences that occur with the reasons for its occurrence.

- Coaching, Guiding and Advising

  This method involves observing and helping trainees whilst they attempt to learn or perform a task. It includes several techniques including directing learners' attention, reminding them of overlooked steps, providing hints and feedback, challenging, structuring ways to do things, and providing additional tasks, problems, or problematic situations. The coaching explains activities in terms of learners' understanding and background knowledge, and provides additional directions about how, when, and why to proceed. Advice and guidance help students to make maximum use of their own cognitive resources and knowledge.

- Collaborating

  Trainees attempt to solve problems by interacting with other people using socially provided schemata and contextual cues. Trainees learn to negotiate meaning with others and experience shared responsibility for learning. Trainees clarify, elaborate, describe, compare, negotiate and reach consensus on the meaning of various experiences.

(iii) Assessment Methods

Three assessment methods are addressed :

- portfolios
- performance assessment, and
- concept maps

- Portfolios

  These are the purposeful collection of the work-in-progress of a trainee as well as the final product produced by the trainee, through which external aides can facilitate individual growth and trainees can become active in their own assessment. Portfolios can include various learning materials, such as videotapes, written papers, drawings, to name a few. They provide concrete referents with which facilitators can guide and support the trainee in attaining this or her own goals.

- Performance Assessment

  This refers to the process of asking a trainee to produce things or to perform tasks that require a given skill. Performance assessment requires a collection of complementary sources such as the observation of student performance, exhibits, presentations, interviews, student-generated projects, as well as role playing.

- Concept Maps

  These help trainees to represent concepts in concrete, meaningful ways. Concept maps are diagrams that indicate the organization of lesson, units, or domain knowledge. After identifying concepts relevant to a particular topic, trainees create mental models by organizing along dimensions such as hierarchies and chronologies. The relationships are then identified and labeled. Through mapping, trainees connect concepts to represent the personal meaning they hold for those concepts.

B. **Structure of the Modules**

Research has shown that the relevance of instructional materials to a particular target group of learners should be considered when designing instructions. Types of relevant enhancing strategies incorporated in the modules are goal orientation strategies and familiarity strategies. Table 1 and 2 list all the goal orientation and familiarity strategies applied respectively as well as a brief rationale explaining their inclusion.

TABLE 1 : GOAL ORIENTATION STRATEGIES

Strategy	Rationale
Add titles	Titles can be effective in creating learner-focused goals for the next section and provide a suggestion of what comes next in the instruction
Statements of the utility of content	This statement should emphasize the importance of the content by stating its worth
Present the objectives	Goals are being created for the learners
Statement of the utility of instruction	These are straightforward explanations of the utility instruction, helping the learners to see why they should learn the information
Future usefulness	This statement ties the instruction to the greater whole and points to the importance of the learning. The learner needs to know the way forward after this learning

TABLE 2 : FAMILIARITY STRATEGIES

Strategy	Rationale
Use concrete language	All learners know, the difference between their right hand and left hand, what a mirror is and have used one, the definition of parallel.
Portray a familiar type of situation	This provides a meaningful scenario for taking a closer look at the instruction
Use imagery and analogies	This associates the unfamiliar with familiar.
Use human interest graphics and stories	This is a cartoon that makes the point that the instruction is worthy. This is a story of interest that makes a point.
Use concrete examples	This gives the abstract concepts a meaningful example the learners can understand.

- **Social Mobilization and Marketing**

This section dwells on the work of KcKee (1992).

Social mobilization is the process of bringing together all feasible and practical intersectoral allies to raise people's awareness of and demand for a particular development programme, to assist in the delivery of resources and services and to strengthen community participation for sustainability and self-reliance.

The aims of social mobilization as a strategy for the transfer of groundwater information to local authorities are :

- To increase people's awareness, knowledge and ability to organize for self-reliance;
- To help disadvantaged communities to be motivated and to know about their rights and duties, and to begin to explore the groundwater resources in their localities
- To understand and modify people's ideas and beliefs about groundwater; and
- To mobilize all available resources.

Social mobilization aims at mustering national and local support for the acceptance of groundwater as a reliable source of water. The process will involve the mobilization of human and financial resources through five main approaches :

- Political mobilization

  This method aims at winning political and policy communities for a major goal and the necessary resource allocation to realize the goal of maximizing the use of groundwater in areas where other sources of water are scarce. The targets are national policy and decision makers and the methods of communication include advocacy, lobbying, using goodwill personalities and the use of mass media.

- Government mobilization

  This aims at informing and enlisting the co-operation and assistance of service providers and other government organizations which can provide direct or indirect support. Methods of communication include training programmes, study tours and coverage of the subject by the mass media.

- Community mobilization

  This method aims at informing and gaining the commitment of local political, religious, social and traditional leaders as well as local government agencies, non-governmental organizations (NGOs), women's groups and co-operatives. The communication methods include training, participation in planning, and coverage of their activities by the mass media.

- Corporate mobilization

  This method aims at securing the support of national or international companies in promoting appropriate goals, either through the contribution of resources or carrying of appropriate messages as part of their advertising or product labeling.

- Beneficiary mobilization

  The aim is to inform and motivate the programme beneficiaries through training programmes, the establishment of community groups, and communication through traditional and mass media.

In ensuring an affective social mobilization in the dissemination of groundwater information to the TLCs, Water Committees, and rural communities at large, a synthesis model of advocacy, social mobilization and programme communication is suggested.

Advocacy consists of the organization of information into argument to be communicated through various interpersonal and media channels with the view to gaining political and social leadership acceptance and preparing a society for a particular development.

Social mobilization is the process of bringing together all feasible and practical intersected allies to raise peoples awareness of and demand for a particular development programme to assist in the delivery of resources and services and to strengthen community participation for sustainability and self-reliance.

Programme communication is the process of identifying, segmenting and targeting specific groups/audiences with particular strategies, messages or training programmes through various mass media and inter-personal channels, traditional and non-traditional.

The goal of advocacy is to make the innovation a political or national priority that cannot be swept aside with a change in government. It consists of a large number of what are traditionally known as information and public affairs activities. Lobbying should be done with decision-makers through personal contacts and direct mail, holding seminars, rallies and news-making events, ensuring regular newspaper, magazine, television and radio coverage and obtaining endorsement from popular people.

Advocacy leads directly to social mobilization, a process which involves the addition of more partners for advocacy and programme communication activities, resource mobilization and service delivery. Social mobilization is the glue that binds advocacy activities to more planned and research programme communication activities. As the process of social mobilization gathers momentum, advocacy is taken by a whole range of partners so that early advocacy is magnified many fold. A host of allies at the national, regional and community level will join in influencing a wide spectrum of society. Some of the same allies may join directly in service delivery, mobilizing resources from international, national or community sources, providing training and logistical support for field workers who will implement the programme, and in some cases managing field workers directly. Social mobilization, therefore, magnifies advocacy activities and strengthens programme communication. Many more societal partners participate in the programme, such as NGO's and grass-roots organizations which often have the motivation and skill for involving local communities in programmes.

FIGURE 8.2 : DEVELOPMENT COMMUNICATION MODEL

8.2.2 *Strategy Means*

For the information transfer models suggested to be effective, accurate information must be presented in an understandable form. Very often, many different presentations of the same facts and ideas are needed. The important thing to remember is that effective communication is seldom achieved through the use of one method alone, or even two or three methods. The messages to be develop should address the needs and concern of the intended audience and should be appropriate to their level of knowledge and awareness. They should be :

- simple and easily understandable
- culturally and socially appropriate
- technically correct
- brief
- practical
- positive, and
- relevant

Success will depend on the ability to combine a variety of methods to accomplish the intended educational purpose. The following strategy means channels are therefore proposed for the transfer of groundwater information to the target groups envisaged in the project.

- Groundwater Seminars and workshops

  Talks on groundwater can be made more educational by combining the lecture with other methods especially visual aids, such as posters, slides and flannelgraphs. In addition, talks on groundwater it must be tied into the local setting through the use of eg proverbs and fables. The interaction and the interest of the audience should be roused by using discussion, song and possibly role-plays and demonstrations.

- Posters

  Posters can be used effectively for three reasons :

  - To give information and advice;
  - To give directions and instructions, and
  - To announce important events and programmes

- Exhibitions

  Exhibitions are displays of real objects, models, pictures, posters and other items which people can look at and learn from. They are most successful if a variety of materials are used to attract people.

- Films or movies

  Audiences are attracted to films because of the multi-media effects of action, colour and sound they capture and as such they are a useful medium of communication. Many kinds of films can be made for educational purposes. Some films provide mainly information (they look like lectures that use sound and visual aids); others demonstrate skills.

- Interaction Computer Modeling

Through computer modeling, trainees would be able to observe normally invisible processes and begin to integrate incidences that occur with the reasons for its occurrence.

- Art

Certain shapes, signs, animals, plants and colors have meaning for people. These symbols represent certain characteristics eg purity, evil, courage, laziness, honesty, cowardice, bravery etc. Local painters or weavers or traditional leaders could be consulted on appropriate symbols to use in the case of groundwater education. Experience has shown that the use of traditional art forms and symbols make educational messages clearer and therefore more effective.

- Songs and plays

Songs and plays portraying groundwater information could also be used. If the tune of a song is attractive, people will remember the song and the information it contains. Just like stories, plays make us look at our own behaviour, attitudes, beliefs and values in the light of what we are told or shown. Plays are especially interesting because you can both see and hear them.

- Dance

People communicate ideas through movement of their bodies. This happens, for example, when you wave your hands or wink your eyes. In some cultures, traditional dancing is used to tell issues at stake. This type of channel could be used in combination with channels to disseminate groundwater information to the targeted audience.

8.2.3 *The Way Forward*

The task of implementation and disseminating groundwater knowledge to the TLCs should not rest on the Department of Water and Forestry alone. Other departments that are concerned with water, education and training must also play a very active role in the disseminating awareness programme. However, the lead should be taken by the Department of Water Affairs & Forestry. Local government structures have a special role to play as a driving forces in this knowledge disseminating programme. Organizations such as the National Community Water and Sanitation training institute, which is well vested in the types of methodology suggested above should be capacitated and provided with all the necessary resources to carry the programme forward. For the programme to succeed, an integrated, holistic implementation approach has to be adopted. All relevant stakeholders in the water sector must be co-opted to collaborate. This will ensure that limited available resources are harnessed, in addition to the avoidance of duplications and contradictory programmes.

Avenues to be achieved include the following :

- developing appropriate educational materials
- harnessing the enormous human resource potential of disadvantaged communities and the nation at large
- linking educational programmes to infrastructure groundwater projects
- providing in-service training and support to service providers
- lobbying for effective groundwater policy
- promoting inter-sectoral collaboration around groundwater programmes/projects and
- promoting mass media involvement

These avenues will lead to a comprehensive, co-coordinated and coherent groundwater program and education strategy.

All said and done, it is proposed that a steering committee headed by the Department of Water Affairs and Forestry should be formed. Preferably it should be an inter-departmental/NGO structure, and should have a national, provincial and regional structures.

9 CONCLUSIONS AND RECOMMENDATIONS

There is need for a broader National ground water awareness strategy.

This project only addresses a strategy for information transfer to local authorities (TLC's).

There is an urgent need to train local authorities in terms of basic ground water concepts.

There is a need for a ground water awareness campaign within Government Departments, specifically within DWAF.

The process will build confidence of TLC's own abilities, & will eventually influence issues outside the ground water sector.

Once information is disseminated & understood, the demand for more information will increase.

APPENDICES

APPENDIX A

ISSUES EMANATING FROM THE INAUGURAL MEETING/WORKSHOP HELD AT THE NATIONAL COMMUNITY AND SANITATION TRAINING INSTITUTE, UNIVERSITY OF THE NORTH, 1 AUGUST 1996

ISSUES EMANATING FROM INAUGURAL MEETING/WORKSHOP HELD AT THE NATIONAL COMMUNITY WATER AND SANITATION TRAINING INSTITUTE, UNIVERSITY OF THE NORTH ON 1 AUGUST 1996.

1. PROJECT OBJECTIVES

The broader issue of a national strategy was discussed and it was agreed that this project should be restricted to a manageable programme, recognising that a national ground water awareness strategy was needed.

This programme should also de-emphasis the development of detailed module materials and place more emphasis on the development of a strategy to reach TLC's and water committees.

The development of basic module materials is however still required.

2. TARGET GROUPS

A great deal of discussion occurred about the main target group for the project. The meeting agreed that the main target group was the TLC's and the village water committees.

- **TLC**

  This group would hold the main legal responsibility for resource development within their area. However, at the moment they have no technical capacity in order to carry out the responsibilities given to them. There was also some concern that their political focus may not provide the best environment for full disclosure of information. There was broad agreement though, that TLC's were one of the main target groups, having a planning/management interest in ground water resources.

- **WATER COMMITTEE**

  These committees were seen as the group most likely to hold the operational management role in the water resource arena. As well, they would be the originators of future scheme proposals. They however see the TLC's as a threat in terms of dominating their aspirations.

- **COMMUNITY**

  This group was not seen as a target group for this project, rather they were identified as needing education via a broader awareness program.

- **GOVERNMENT DEPARTMENTS**

  These groups were seen as critical stakeholders in the project. However, the issues related to their involvement in the project were ones of ownership of the process. Though they would not be targets for information generated by the project, an awareness raising program of the need for a ground water education strategy was critical. The meeting agreed that if this group, and in particular the provincial offices of DWAF, did not own the strategy, the project would not succeed.

3 INFORMATION TO BE TRANSFERRED

It was agreed that information to be transferred should concentrate on basic ground water principles.

It was also agreed that information should relate to questions such as :-

- what is groundwater?
- where and how does it occur?
- how much is there?
- what is the quality
- how do you exploit it?

4 RESPONSIBILITY OF IMPLEMENTING TRAINING

The meeting discussed the issue of who the trainers should be. Some suggestions were members of the TLC`s, members of the Water Committees, Development Officers from Regional DWAF offices and people hired by DWAF regional offices. There was no consensus on any of these suggestions but the most likely trainers would be the development officers from DWAF regional offices. However, it was pointed out that these officers were already over committed and did not have the capacity. They further showed reluctance to get involved.

It was mentioned that once the National Water Supply and Sanitation Training institute was properly established and staffed, that they could take over the responsibility of implementing the training.

APPENDIX B

ISSUES ARISING FROM INTERVIEWS AND WORKSHOPS WITH TLC'S

All TLC's in the Northern Province were invited to attend workshops which were held in each district, viz:-

- Lowveld district workshop held at the Tzaneen Council Boardroom (4 of the 9 TLC's attended)
- Southern district workshop held at the Department of Agriculture Land and Environmental Affairs regional offices in Lebowakgomo (5 of the 9 TLC's attended)
- Northern district workshop held at Thohoyandou Fire Station (2 of the 5 TLC''s attended)
- Central district workshop held at Col-Johns in Pietersburg (4 of the 6 TLC's attended)
- Western and Bushveld districts workshop held at the office of the Premier in Potgietersrus (no-one arrived)

These workshops commenced with an introductory talk on ground water followed by a short video entitled "What is ground water?" produced by the Water & Rivers Commission of Western Australia.

After the talk and video an open discussion was held. The following main points eminated from these discussion, viz :-

- The information required by the TLC's appears to be demand driven (we need so much water), rather than resource driven (what can we do with the available water resource).
- Management requirements appears to focus on scheme the borehole (pumps and pipes) rather than resource.
- Main focus of communities is still on bulk schemes as proposed to local schemes. An underlying factor could be the perceived low reliability of Ground water resources.
- All persons questioned were keen to learn more about ground water admitting that their knowledge was virtually non existent.
- Information required revolved around ground water supply as apposed to ground water per say. Typical questions asked were :
    - How is a borehole constructed?
    - How water is extracted (pump)?
    - How much water can a borehole yield?

APPENDIX C

AN EXAMPLE OF AWARENESS MODULES DEVELOPED BY THE NATIONAL COMMUNITY WATER AND SANITATION TRAINING INSTITUTE FOR THE LOCAL GOVERNMENT TRAINING PROGRAMME

MODULE A1 : THE HYDROLOGICAL CYCLE

MODULE A2 : WHAT IS GROUNDWATER : AQUIFERS AND THE GROUNDWATER ZONE

MODULE A3 : THE DISTRIBUTION, USE AND POTENTIAL FOR THE EXPLOITATION OF GROUNDWATER IN SOUTH AFRICA

MODULE A4 : QUANTIFICATION OF GROUNDWATER RESOURCES

MODULE A1: THE HYDROLOGICAL CYCLE

1. DEFINITION

Terrestrial moisture is in constant motion, and all near-surface water participates in what is called the hydrologic cycle. The term "cycle" suggests that water originates from a single source and ultimately returns to that source. Oceans serve as the primary reservoir for water participating in the hydrologic cycle. Water in the hydrologic cycle not only undergoes changes in its geographical location, but it also continually changes state. Water can exist as solid, liquid, or gas (vapour). During changes in physical state, huge amounts of energy are absorbed or released, and this energy drives all weather systems.

The first stage in the hydrologic cycle is the evaporation of water from the oceans. This vapour is carried over the continents by moving air masses. If the vapour is cooled to its dew point, it condenses into visible water droplets which form cloud or fog. Under favourable meteorological conditions the tiny droplets grow large enough to fall to earth as precipitation.

Cooling of large masses of air is brought about by lifting. The resulting decrease in pressure is accompanied by a temperature decrease in accordance with the gas laws. Orographic lifting occurs when air is forced to rise over a mountain barrier. For this reason the windward slopes of mountains are usually regions of high precipitation. Air may also rise over a cooler air mass. The boundary between these air masses is called a frontal surface, and the lifting process is called frontal lifting. Finally, air heated from below may rise by convection through cooler air (convective lifting) to cause the isolated convective thunderstorm characteristic of summer climate in much of the world.

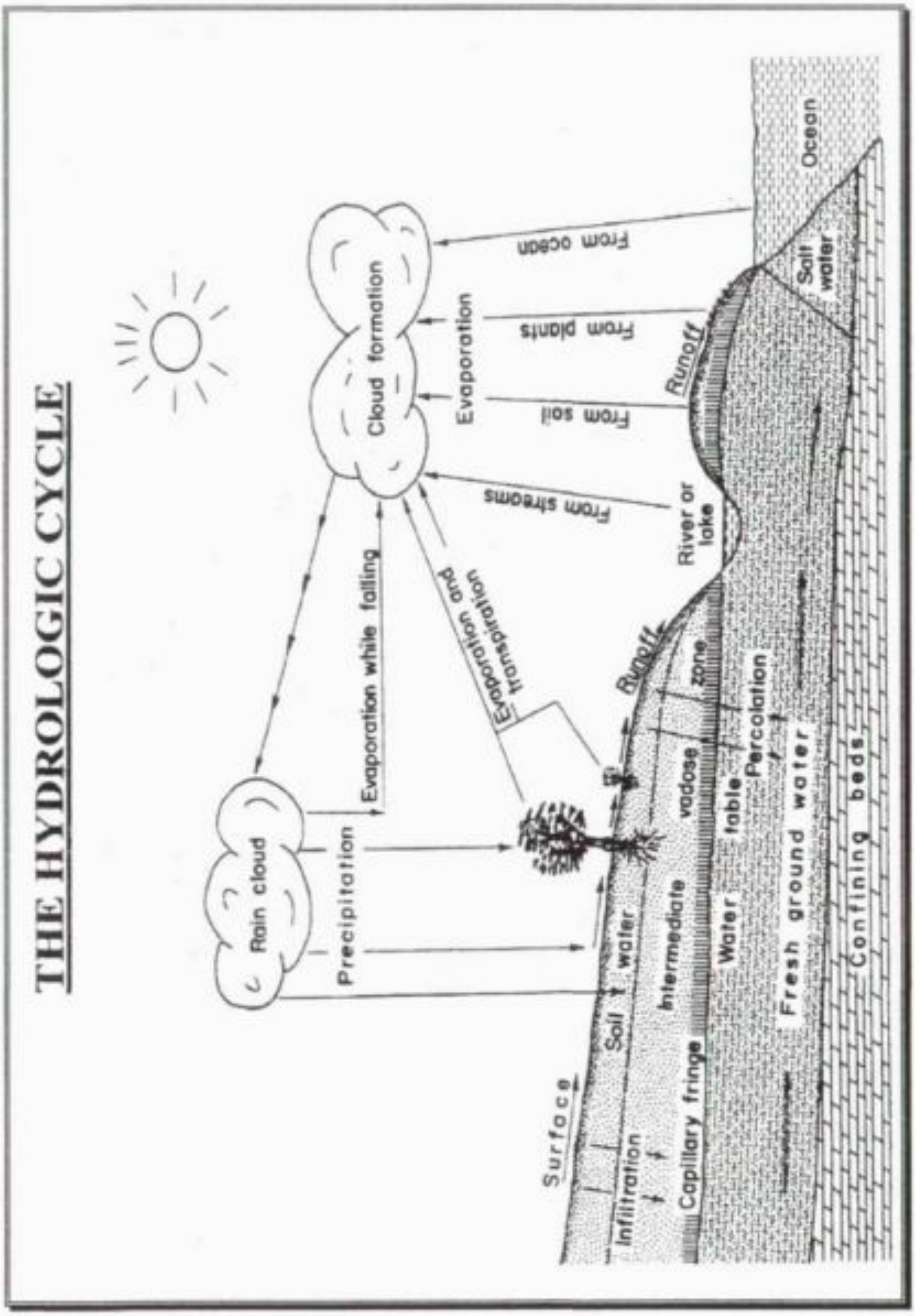
About two-thirds of the precipitation which reaches the land surface is returned to the atmosphere by evaporation from water surfaces, soil, and vegetation and through transpiration by plants. The remainder of the precipitation returns ultimately to the ocean through surface or underground channels. The large percentage of precipitation which is evaporated has often led to the belief that increasing this evaporation by construction of reservoirs or planting of trees will increase the moisture available in the atmosphere for precipitation. Actually only a small portion of the moisture (usually much less than 10 percent) which passes over any given point on the earth's surface is precipitated. Hence, moisture evaporated from the land surfaces is a minor part of the total atmospheric moisture.

No simple figure can do justice to the complexities of the cycle as it occurs in nature. The science of hydrology is devoted to a study of the rate of exchange of water between phases of the cycle and in particular to the variations in this rate with time and place. This information provides the data necessary for the hydraulic design of physical works to control and utilise natural water.

Hydrology is the science of distribution and behaviour of water in nature and is a part of climatology. The cycle of water or the hydrological cycle is without beginning or end and consists of the following:

* *Precipitation:*	All water from the atmosphere deposited on the surface of the earth as either rain, snow, hail or dew.
* *Surface run-off:*	The water which is derived directly from precipitation and passes over-ground into water-courses is known as surface run off. The surface run off then consists of the precipitation less the losses from infiltration and evaporation.
* *Evaporation/ Transpiration*	Combined loss of water from land and water-surfaces by evaporation and plant transpiration.
* *Percolation:*	The term percolation describes the passage of water into, through and into the ground. The term infiltration is frequently used to describe the entrance of water into the ground and its vertical movement down to the ground water table, while percolation or ground water flow is applied to the movement of water after it has reached the water table.

Figure 1: The Hydrological Cycle



2. CONSTITUENTS OF THE HYDROLOGICAL CYCLE

2.1 EVAPORATION / EVAPOTRANSPIRATION

Evaporation is the transfer of water from the liquid to the vapour state. *Transpiration* is the process by which plants remove moisture from the soil and release it to the air as vapour. More than half of the precipitation which reaches the land surfaces of the earth is returned to the atmosphere by the combined process of *evapotranspiration*. In arid regions evaporation may consume a large portion of the water stored in reservoirs.

2.1.1 Factors affecting evaporation

During evaporation, water molecules near a water surface acquire sufficient energy from solar radiation to vaporise. The added heat gives the molecules enough kinetic energy to overcome the surface tension of the liquid and change to a gaseous state. The rate of evaporation depends on (a) the difference between the volume of water vapour in the overlying air mass and the volume of vapour in the thin layer of air lying just above the water body and (b) the rate of incoming solar radiation. Winds are also an important factor in evaporation since they continually cause unsaturated air to flow over the water surface, thereby increasing the evaporation rate.

Two other processes contribute to total evaporation: transpiration and sublimation. In transpiration, moisture given off by plants is returned to the atmosphere. In most parts of the world, transpiration and ordinary evaporation cannot be differentiated; thus, the loss of water from a land surface is called evapotranspiration. Sublimation occurs when ice and snow pass directly into the gaseous state without first becoming a liquid.

In summary, the rate of evaporation from a water surface is proportional to the difference between the vapour pressure at the surface and the vapour pressure in the overlying air (Dalton's law). In still air, the vapour-pressure difference soon becomes small, and evaporation is limited by the rate of diffusion of vapour away from the water surface.

Turbulence caused by wind and thermal convection transports the vapour from the surface layer and permits evaporation to continue.

2.1.2 *Evaporation: the South African situation*

As a consequence of the low frequency of cloud over much of South Africa, the high proportion of solar radiation that reaches the earth's surface provides an abundance of energy to evaporate water from land and water surfaces and cause its loss to the atmosphere. The rate of evaporation also depends on the temperature and humidity of the adjacent air. 'Potential evaporation' is the term used to define the depth of water that could be evaporated in this manner.

There are only a few isolated areas in South Africa where the average annual potential evaporation is less than the average annual rainfall. These are in high rainfall areas where the annual rainfall is generally in excess of 1 500 mm. Over the rest of the country the average annual potential evaporation varies from less than 1 100 mm to more than 3 000 mm per annum. In parts of the Northern Cape evaporation exceeds rainfall by a factor of 25: 1. See Figures 2 and 3 below for the mean annual surface temperature and mean annual evaporation from open water surfaces in South Africa.

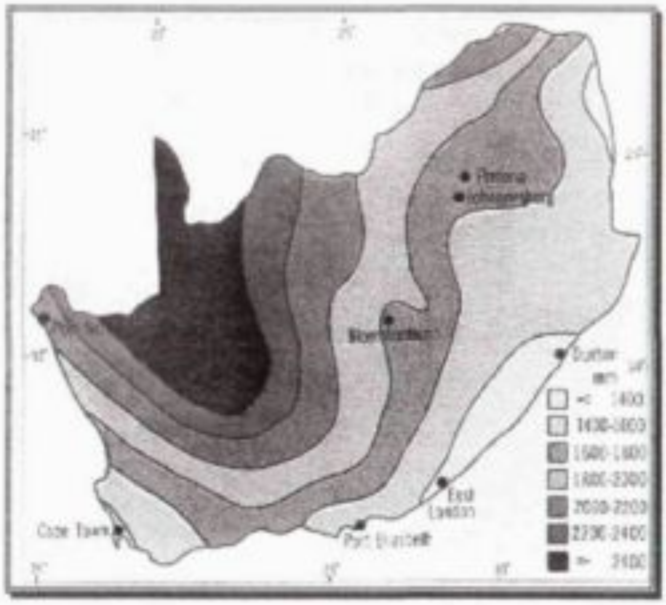
The difficulties of water resource development resulting from a generally decreasing rainfall from east to west are thus intensified by the progressively greater potential evaporation losses. The loss of water from dams in areas of high potential evaporation is of great consequence.

2.1.3 *Efficient storage of water*

Attempts to raise the net assured yields of our storage works may be approached from three angles: first, the possibility of rendering a greater percentage of river flow available for use by means of suitable storage; secondly, the efficient management of available supplies and, thirdly, the elimination of water works that are not beneficial.

The first approach aims at raising the yields from dams by planned siting of dams. A purposeful programme should be launched for the investigation of all possible sites where dams can be built so that it may be possible to determine with confidence the maximum utilisation of the runoff of our rivers. In the selection of dam sites, special attention should be given to the reduction of evaporation losses.

Figure 2:
Mean annual evaporation from an open water surface



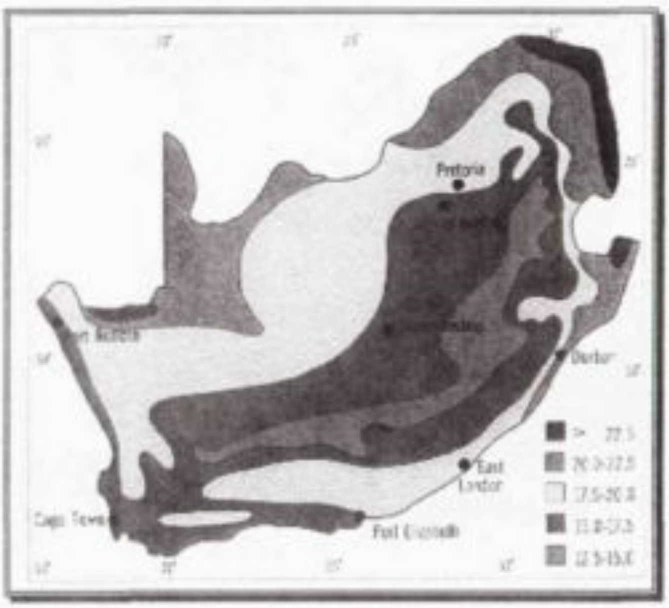


Figure 3:
Mean annual surface temperature

The second approach involves the application of advanced control systems for the management of dams to ensure improved yields. In managing a multi-purpose scheme that has to meet competing needs within a region, the aim must be the optimum yield and utilisation of the available water supplies.

The final approach attempts to limit the numerous small farm dams that lead to unnecessary evaporation losses; construction of these should be permitted only where the advantages fully compensate for the concomitant evaporation losses and runoff reduction.
The implication is that in principle there should be some control over all dam-building to ensure that in future, storage of water will be beneficial to the country as a whole. Such control must, of course, be exercised in such a way that it will not be a hindrance to sound, desirable agricultural development.

A comprehensive site investigation programme which considers all factors and includes intensive geological studies is now undertaken for all dams. For the past decade the Department of Water Affairs (DWA) has been striving to apply improvements in the analytical techniques developed for the operation of dams. Research is being undertaken by the DWA to determine the usefulness and the influence on water resources of small farm dams and legislation aimed at controlling the number of farm dams in critical catchments is being considered.

2.1.4 Reduction of evaporation losses

Although the percentage diminishes from west to east and varies considerably from place to place, on the average about 27% of the water that our existing dams can deliver is lost by evaporation. Reduction of this loss will raise the assured yield of our storage dams. Methods that have already enjoyed attention include the application of protective layers to water surfaces, the construction of larger and deeper reservoirs, the siting of dams in regions of low net evaporation, and the storage of water underground. As evaporation loss is much greater from full than from part-full reservoirs, it follows that losses will be lessened by operating reservoirs according to the variable draft procedure. The application of correct management procedures, especially where there are multiple dams in a single basin or in separate interlinked catchments where evaporation loss rates differ, can help considerably to keep losses as low as possible.

In the planning of storage, account is taken of the advantage of deep basins with a small water surface area. As the most favourable dam sites have already been exploited, implementation of this principle is becoming more difficult. However, some notable successes have been achieved, for example with the Sterkfontein Dam, which augments the Vaal River system. Its high altitude and deep basin favour low evaporation.

Evaporation suppressants, normally films of chemicals sprayed onto the water surface, have proved disappointing in experiments. Variable draft procedures used to reduce evaporation have been implemented where applicable and improved techniques are being developed.

2.2 CONDENSATION AND CLOUD FORMATION

2.2.1 Condensation

Water may be present in the air as a solid, a liquid or a gas and may change phase into a gaseous state by the process of *evaporation* (liquid to gas) or *sublimation* (solid to gas directly) at temperatures commonly observed in the atmosphere. Conversely it may change from gas to liquid *by condensation* and from gas to solid, or liquid to solid by *crystallisation*. Water vapour plays a fundamental role in regulating atmospheric processes, not only in the formation of precipitation, but also in heat exchange by affecting the transmission of radiation and through heat released or taken up in phase changes. Water is supplied to the atmosphere from the surface through evaporation and returns to the surface as precipitation. In general, for an entire continent precipitation exceeds evaporation, whereas over the ocean the reverse is true. The amount of water present in the atmosphere as a gas is enormous and far exceeds that present as a liquid or solid. Over South Africa the water vapour content of the air is significantly greater than the volume of water transported by all rivers combined. Only a small fraction of this water vapour is actually precipitated.

If the vapour is cooled to its dew point, it condenses into visible water droplets which form cloud or fog. Under favourable meteorological conditions the tiny droplets grow large enough to fall to earth as precipitation.

Cooling of large masses of air is brought about by lifting. The resulting decrease in pressure is accompanied by a temperature decrease in accordance with the gas laws. *Orographic lifting* occurs when air is forced to rise over a mountain barrier. For this reason the windward slopes of mountains are usually regions of high precipitation. Air may also rise over a cooler air mass. The boundary between these air masses is called a *frontal surface*, and the lifting process is called *frontal lifting*. Finally, air heated from below may rise by convection through cooler air *(convective lifting)* to cause the isolated convective thunderstorm characteristic of summer climate in much of the world.

2.2.2 Clouds and Cloud formation

The study of clouds provides useful information on both the type of weather that can be expected at the earth's surface and the nature of weather-producing systems themselves. Clouds have long featured in weather lore due to the perceptive observation that shape, structure, texture and patterns of cloud express the kinds of air movements responsible for their development. Recent analyses of cloud characteristics using satellite pictures have also greatly enhanced the understanding of weather systems and concomitant rainfall patterns. In this chapter discussion centres on the manner by which cloud types can be grouped, the processes of cloud droplet and ice crystal formation, cloud droplet growth and precipitation mechanisms.

2.2.2.1 Classification of clouds

A first step in ordering cloud types by their appearance was proposed about 170 years ago by Luke Howard. He recognised three basic types:

* *Cirrus:* fibrous, parallel and flexuous;
* *Stratus:* widely extended, horizontal sheets, continuous; and
* *Cumulus:* convex or conical heaps, increasing upward from a horizontal base.

In addition to these principal kinds of cloud, others were defined by compounding names indicative of transitions or associations. Out of this grew the present international classification of clouds which employs ten cloud genera which fall into four groups. The first three groups are classified according to height and consist of high, middle and low cloud; the fourth group describes clouds of vertical development.

Cloud Height		Cloud Type
High	(> 6000 m)	Cirrus (Ci) Cirrocumulus (Cc) Cirrostratus (Cs)
Medium	(2000 m - 6000 m)	Altocumulus (Ac) Altostratus (As)
Low	(< 2000 m)	Stratus (St) Statocumulus (Sc) Nimbostratus (Ns)
Vertical Development		Cumulus (Cu) Cumulonimbus (Cb)

An important aspect of the classification is that although it was originally based on visual information, it can now be justified on physical grounds. The essential characteristics necessary to distinguish the cloud types as well as the nature of their composition and formation are described below following the International Classification and International Cloud Atlas (1956):

Cirrus (Ci): Detached clouds with a fibrous (hair-like) appearance made up of white, delicate cloud filaments. Since these clouds occur at temperatures less than -25 °C, they are composed of ice crystals (usually of columnar form). Formation is due to widespread, prolonged ascent of air at a rate of 5-10 cm/s.

Cirrocumulus (Cc): Consist of thin and very small white cloud patches, ripples or waves which are delicate in appearance. They are composed of ice crystals with column and prism forms and occur in areas of widespread, slow ascent (5-10 cm/s).

Cirrostratus (Cs): A transparent, white cloud veil of fibrous or smooth appearance through which the sun or moon is visible. This cloud is composed of ice crystals in the form of cubes or thick plates at temperatures less than -25 °C and formed by widespread, slow ascent (5-10 cm/s).

Altocumulus (Ac): White, and sometimes grey, cloud patches composed of flattened globules which may be arranged in groups, rows or waves. These clouds occur at temperatures between 0 °C and -25 °C and consist of water droplets with occasional ice crystals in the form of thick plates. Formation is by widespread slow ascent of air.

Altostratus (As): Greyish or bluish cloud sheets of striated or uniform appearance and usually thin enough to reveal the sun as through ground glass. These clouds are composed of a mixture of ice crystals and water droplets at temperatures between 0 °C and -25 °C and are formed by widespread slow ascent of air.

Stratus (S): Generally grey cloud, amorphous and uniform in shape with a fairly uniform base. This cloud is composed of water droplets at temperatures usually greater than -5 °C and is formed by the lifting of moist near-surface air.

Stratocumulus (Sc): Grey or white cloud globules or ridges with dark parts which may or may not be merged. The composition is similar to stratus but the formation is due to widespread, irregular mixing of air with vertical velocities usually less than 10 cm/s.

Nimbostratus (Ns): Amorphous grey cloud mass with a low, ragged base, with a blurred appearance because of steady precipitation which usually reaches the ground. This cloud is composed of a mixture of water droplets and ice crystals (raindrops or snowflakes) depending on the temperature. It is formed by widespread ascent of air with velocities the order of 5-20 cm/s.

Cumulus (Cu): Dense, detached clouds with sharp outlines which develop vertically in the form of towers or domes. The sunlit portion of the cloud is brilliant white while the base is usually grey. These clouds are composed of water droplets and are formed by the convective ascent of warm air with vertical velocities the order of 1-5 m/s.

Cumulonimbus (Cb): Dense cloud in the form of a huge mountain with towers. The upper part may be smooth or fibrous and is usually flattened. This part spreads out ahead of the cloud mass in the shape of an anvil or large plume. The base of the cloud is usually dark. The cloud is composed of water droplets in the lower part and a mixture of water droplets and ice crystals at temperatures well below 0 °C in the upper part. These clouds are formed currents with updrafts ranging from 3 to 30 m/s.

2.2.2.2 Causes of cloud formation

Clouds form when air is supersaturated with respect to water or ice. The most common manner in which this is achieved involves the ascent of unsaturated air, accompanied by adiabatic expansion and cooling, to the point of saturation. Clouds are formed in this way by buoyant ascent of conditionally unstable air to form *convective clouds* and by the forced ascent of stable air to form *layer clouds*. Forced ascent also occurs over mountains to produce *orographic clouds*. Clouds may also form by diabatic cooling in the absence of lifting. This involves the removal of heat from the air by radiation to cause *radiation fog*. The mixing of warm and cold air can cause *advection fog*

(1) **Convective clouds**

Parcels of air which rise from a warmed surface combine into thermals which condense into cumulus cloud at the lifting condensation level. Visual observation indicates that these clouds grow through the development of individual towers giving the cloud a cauliflower-like appearance. Each individual tower appears to have a short lifespan characterised by rapid growth and decay followed by the appearance of a new tower. In this way the cloud grows vertically from the *cumulus humilis* stage, in which the cloud has limited vertical extent, to the *cumulus congestus* stage where it has grown to considerable heights and has a cauliflower-like appearance. In the presence of a strong wind, the upper portion of the cloud may be displaced causing the cloud to "lean" downwind.

Cumulonimbus clouds are classified separately from other cumulus cloud because of their massive size. The tops of these clouds frequently extend above the tropopause into air temperatures well below -40 °C. As the cloud extends to these heights, the top begins to lose its sharp cauliflower appearance as ice crystals cause the cloud boundary to develop blurred edges.

(2) **Layer clouds**

In contrast to the small-scale circulation of cumulus convection, the nearly horizontal circulation associated with large-scale slope convection produces clouds formed by the slow, prolonged and widespread ascent of air, often at several levels in the atmosphere, and usually in association with mid-latitude cyclonic systems. High cirrus cloud shields often occur on the fringes of these systems at altitudes (heights) as high as 9 000 m. These clouds are composed of relatively large ice crystals with diameters in excess of 1 mm which may precipitate for several kilometres before evaporating. The falling ice crystals are visible as *fall streaks or virga* and in the presence of a vertical wind shear are distorted to give the *uncinus* appearance from the ground of a comma or hook. Cirrostratus is composed of much smaller ice crystals in the form of prisms approximately 100 *gm* in length. These form a nebulous veil across the sky through which the sunlight may be refracted to give a halo.

Cirrocumulus, altocumulus and stratocumulus are characterised by the occurrence of cumulust-ype elements and/or wavelike patterns in the cloud. This is mainly due to the formation of internal convective cells within the cloud layers caused by differential heating as the base of the layer is warmed by radiation from the ground and the top is cooled by radiation to space. If at the same time there exists a vertical shear in the horizontal flow of air, the cells may give way to a wavelike pattern which resembles cloud streets.

(3) Orographic ascent

Air forced to rise over a mountain, or even a small hill, will often cause orographic clouds to form. This is why it often rains on the windward side of the mountain whilst the leeward side remains dry.

* Windward side: the windy side of the mountain i.e. the side from which the wind blows;
* Leeward side: non-windy side of the mountain.

2.3 PRECIPITATION AND WEATHER SYSTEMS

The average annual rainfall of about 497 mm for South Africa as a whole is well below the world average of 860 mm. A comparatively narrow region along the eastern and southern coastlines is moderately well-watered, but the greater part of the interior and the western portion of the country are and or semi-arid. Sixty-five per cent of the country receives less than 500 mm of rain annually, which is usually regarded as the minimum for successful dryland farming. Twenty-one per cent of the country receives less than 200 mm.

A wide variety of rainfall-producing mechanisms occurs across the country, affecting the reliability and variability of river flow. As it gets drier towards the west the variability increases rapidly. Over most of the country the average annual potential evaporation, which ranges from about 1 100 mm to more than 3 000 mm, is well in excess of the annual rainfall. This affects surface runoff from rainfall significantly and causes high evaporation losses from water stored in dams.

The combined average annual runoff of South Africa's rivers is estimated to be 53 500 million m^3. In some areas the highly variable river flow can have periods of up to 10 consecutive years of less than average flow. This must be allowed for in both the planning and the operation of water supply systems. Because of this variability and the high evaporation losses from storage it is estimated that, with the present state of knowledge and technology, only about 62 % or 33 000 million m^3 of the mean annual runoff can be exploited economically. In addition, about 5 400 million m^3/year may be obtainable from underground sources. Further supplies will have to be obtained from the importation of water or from unconventional water sources such as recycled water or desalinated water.

Water availability is distributed poorly in relation to regions of economic growth and the cost of providing water in South Africa will rise in the future owing to the greater distances that water will have to be transported to areas of increasing demand.

2.3.1 The precipitation mechanism

Precipitation can occur in many forms, including sleet, snow and dew as well as rain. Snow and rain are dominant and, therefore, the processes that produce these forms of precipitation are the most important. Moisture-laden air must be lifted and cooled by some mechanism to produce any significant amount of precipitation. Therefore, before discussing precipitation processes, the temperature regime of the lower part of the Earth's atmosphere must be examined because it plays a vital role in triggering these lifting and cooling mechanisms.

There are several concentric atmospheric layers surrounding the Earth. The lowest layer, called the troposphere, influences our activities because all weather phenomena affecting the Earth's surface occur in this layer. The troposphere varies in thickness from about 6,4 km near the poles to about 19,3 km near the equator.

Air cools with increasing height throughout the troposphere. The rate at which it cools is called the lapse rate and equals about 6,5 °C per km i.e. for every km one ascends, the temperature is 6,5 °C cooler. For example, if the temperature is 20 °C at the Earth's surface near lat 45 °N, the air temperature at the top of the troposphere 12.9 km would be about -63,9°C.

A temperature inversion occurs near the top of the troposphere, after which temperatures increase for about 32,2 km. Air naturally cools as it ascends but in a temperature inversion the air warms as it rises. Thus, rising air masses reach an effective ceiling near the top of the troposphere, confining all weather phenomena to this zone. Recognising this fact, commercial airliners fly somewhat above the top of the troposphere to avoid weather problems.

Another temperature mechanism affecting precipitation arises from adiabatic temperature changes. Because air is a relatively poor heat conductor, cooling in rising air masses is independent of the surrounding temperature and pressure conditions surrounding the air masses. Adiabatic temperature changes are produced by changes in pressure and volume that occur within an air mass as it rises or falls; there is no heat transfer between the air parcel and the surrounding air. For example, a decrease in pressure (which happens when air masses rise) causes an increase in volume and a decrease in temperature.

There are two adiabatic cooling rates: dry adiabatic and wet adiabatic. The dry adiabatic lapse rate (when no condensation occurs) is 9,8 °C per km, which is well above the usual tropospheric lapse rate. When condensation occurs in a rising air mass, the latent heat of vaporisation is released, resulting in a wet adiabatic lapse rate which is 6,5 °C per km. The wet adiabatic rate averages about 6 °C per km, somewhat lower than the tropospheric lapse rate. The reason the wet adiabatic rate is much lower than the dry adiabatic rate is because the latent heat contained in the water vapour is released when the vapour condenses as rain, adding heat, and thereby lowering the rate of cooling to 6 °C per km. Recall that each gram of water must receive a certain amount of heat to evaporate which is known as latent heat. This amount of latent heat is retained in the water vapour until it condenses as rain. Thus, the cloud containing the water vapour will continue to cool but at a rate less than the tropospheric lapse rate. Because the cloud cools more slowly than the surrounding air, it will continue to rise until condensation stops or the surrounding air mass becomes warmer. At this point, the cloud becomes denser than the surrounding air and it begins to descend.

All three lapse rates play a part in producing precipitation in rising air masses. In all cases, the air is uplifted and cooled, causing water vapour to condense on salt or clay particles (dust) in the air. The amount and geographical distribution of rainfall depends on the uplift mechanism involved. On a global basis, rainfall patterns generally can be predicted on the basis of physical principles governing air masses and tropospheric temperature conditions.

2.3.2 Causes of precipitation

Convection is one of the three common mechanisms that cause precipitation. Heating of the ground surface causes the overlying air to become warmer and less dense than the surrounding air. (As air rises, pressure and temperature decrease and the volume of the air increases). The warmed air parcel begins to rise and at some point condensation takes place. As long as condensation is occurring, the temperature in the air parcel is determined by the wet adiabatic lapse rate, and the temperature within the air parcel can remain somewhat above that of the surrounding air. So much heat is released during rapid condensation that air parcels can move upward at speeds of 30,5 m/s or more. The cloud formations associated with convection cells are the towering cumulus and cumulonimbus types. Rainfall from convection cells is spotty, often falling in bands parallel to weather fronts. Rainstorms of this type tend to last from 30 to 60 minutes and are occasionally violent.

A second mechanism causing precipitation is cyclonic wedging. When high- and low-pressure air masses collide (come into contact), the warm, moist (lighter) air of the low-pressure system is forced up over the dry, cooler air because warm air tends to rise. See Figure 4. The air which is being forced to rise reaches condensation level and as a result, precipitation occurs along a broad front between the two systems; rain falls over extensive areas and lasts for 6 to 12 hours. This type of rainfall is particularly effective in recharging groundwater aquifers.

Precipitation can also be caused by orographic effects. In many parts of the world, high mountains lie along coastlines and in other places where they intercept moist air. If the predominant wind direction is toward these mountains, air masses saturated with water vapour are constantly being forced to rise over the mountains. When this happens, the inevitable cooling causes condensation as demonstrated in Figure 5 below.

Rainfall on the windward slopes of mountains not only tends to be heavier but also occurs more frequently. Also, convection and cyclonic types of precipitation are more efficient in mountainous regions where moist air is available. Desert conditions may exist on the leeward side of the mountains, if they are high enough, because as the air descends it warms up and can hold more moisture. Not until the air again absorbs sufficient moisture will precipitation occur.

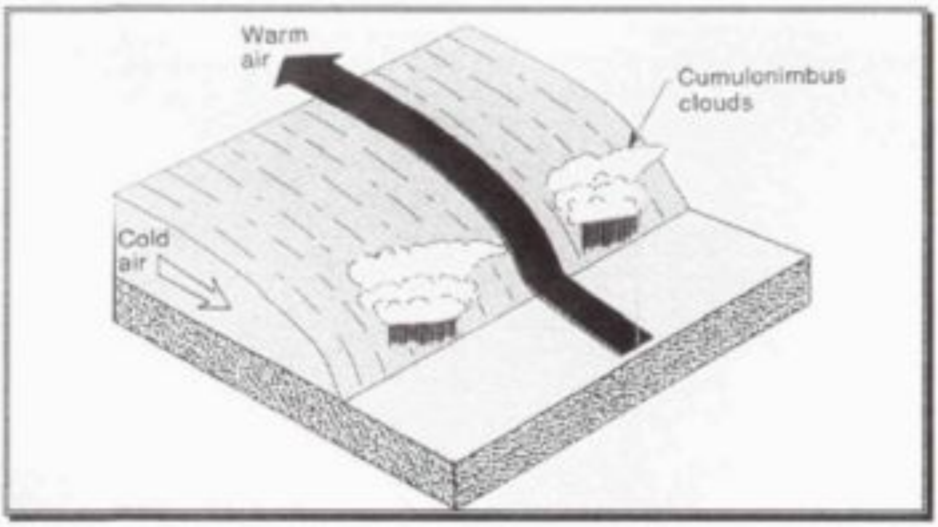


Figure 4: Precipitation occurs along a front created by colliding cold, dry air and warm, moist air

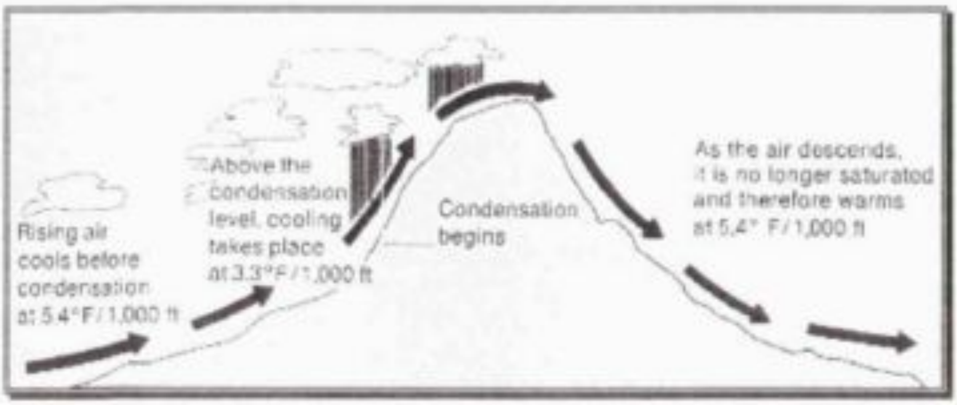


Figure 5: Precipitation caused by orographic effects. As air masses rise on the windward slopes of mountains, the air is cooled and precipitation occurs. Dry conditions prevail on the leeward side of the mountains because the air is warmed as it descends, thereby increasing its ability to hold moisture.

At any given time and place, the atmosphere can contain only about 25,4 mm of water. Heavier precipitation in any area is caused by the movement of air masses containing moisture into that area during storms. A record rainfall of 1 910 mm occurred on Reunion Island, near Madagascar, during a 24-hour period in March 1952.

2.3.3 Types of precipitation

Precipitation includes all water which falls from the atmosphere to the earth's surface. Precipitation occurs in a variety of forms but the hydrologist is interested in distinguishing only between liquid precipitation (rainfall) and frozen precipitation (snow, hail, sleet, and freezing rain). Rainfall runs off to the streams soon after it reaches the ground and is the cause of most floods. Frozen precipitation may remain where it falls for a long time before it melts. Melting snow is rarely the cause of major floods although, in combination with rainfall it may contribute to major floods. Mountain snowpacks are often important sources of water for irrigation and other purposes. The snowfields serve as vast reservoirs which store winter precipitation until spring thaws release it near the time it is required for irrigation.

Fog and Dew

Fog consists of water droplets so small and light that they can not fall as rain. Fog particles which come into contact with vegetation, come into contact with other droplets, and eventually form a drop large enough to fall to the ground. *Fog drip* is an important source of water during the rainless seasons.

Dew is formed on clear nights when the loss of heat by radiation from the soil causes cooling of the ground surface and of the air immediately above it. The water vapour present in the air directly above the soil surface results in a deposit of dew.

The small quantities of dew and fog drip deposited in any day do not contribute to streamflow or groundwater. They do, however, offer a source of water which may be exploited locally. Research in Israel has shown that broad-leaved crops such as cabbage may be efficient dew collectors which can be grown in an arid region, with little or no irrigation.

2.3.4 Rainfall-producing mechanisms

As South Africa is situated within the high pressure belt of the middle latitudes of the Southern Hemisphere, warm dry descending air associated with high pressure systems occurs over the greater part of the country most of the time, which is unfavourable for the formation of rain. This climate is modified by the influence of the warm, southward-flowing Agulhas current along the east coast and the cold northward-flowing Benguela current along the west coast. The warmer east coast air masses tend to be less stable than those in the west and are more likely to give rise to precipitation.

Rainfall is distributed unevenly over the country, with humid subtropical conditions in the east and dry desert conditions in the west. For instance, the mean annual rainfall on the east coast in the vicinity of Durban is 1 070 mm, while that for Port Nolloth at the same latitude on the west coast is a mere 58 mm. The highest rainfall occurs in the mountain ranges of the south-western Cape and in the Drakensberg, where the mean annual rainfall exceeds 3 000 mm in places. See Figure 6 below.

The factors which influence rainfall vary from region to region. At one extreme there is the east-facing Drakensberg escarpment in KwaZulu-Natal where moisture-laden air is often present and where several different rainfall-producing mechanisms exist. At the other extreme is the desert area of the Northern Cape Province where the air is hot and dry and the topography flat and the main rainfall-producing mechanism is the occasional convectional thunderstorms.

During the summer months low-pressure troughs develop periodically over the interior. These troughs are orientated roughly North West-South East and have the effect of drawing in moist air from the north and north-east. This rising moist air cools and produces rain. These convergent systems are the source of most of the runoff-producing general rainfall in the interior of South Africa, although their influence is diminished in the western half of the interior.

Orographic rainfall occurs when winds force moist air up a mountain or escarpment slope. This is an important source of river flow along the southern and eastern escarpments and mountain ranges. Although the rainfall intensity may be lower than that of other rainfall-producing mechanisms, orographic rain occurs more frequently and for longer durations, with the result that river flow in these areas tends to be more reliable and less variable than that in regions which do not have a large orographic rainfall component. See Figure 7 which illustrates the percentage deviation from mean annual rainfall. It is clear that only the yellow areas (i. e. parts of Gauteng, KwaZulu-Natal, the Eastern Cape and the Western Cape) have a reliable annual rainfall.

Although mountains and escarpments create favourable rainfall conditions on their windward slopes, they also create the opposite conditions in the downwind (or leeward) areas, as demonstrated by the sharp difference in rainfall conditions between George and Oudtshoorn. Cold fronts which regularly approach the country from the west and south-west during the winter months are the main source of rain in the Western Cape Province.

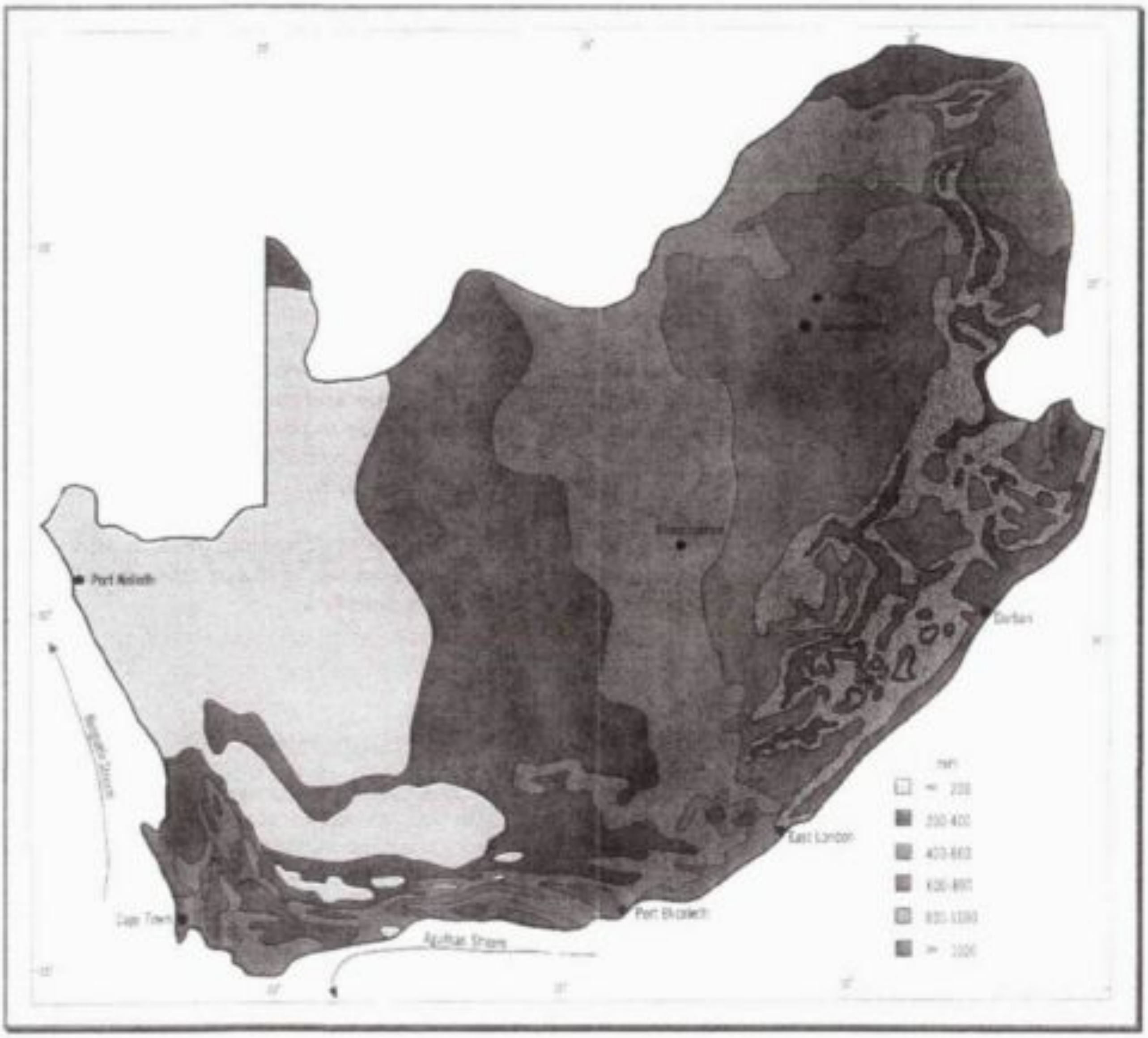
In the drier areas occasional convectional thunderstorms are the main source of rain. These usually occur over a small area and are generally of short duration, although intensities may be sufficiently high to cause short-term flow in local streams.

The most appropriate form of water resource development for a region depends on local hydrological conditions. The winter rainfall region is a relatively narrow area along the western and south-western coasts of the Western Cape. The summer rainfall region covers most of the remainder of the country. Between the winter and summer rainfall regions lies a transitional area where rain occurs during all seasons. See Figure 8 for the seasonal rainfall regions.

In the winter rainfall region precipitation results mainly from cyclonic disturbances. These rains are often of long duration and low intensity except along the mountains, where orographic effects may induce heavy showers. Snow which melts within a few days may occur on the mountains four to six times during the winter but it is not a significant contributor to river flow.

Winter snow in the summer rainfall region is confined mainly to the eastern highlands, especially the Drakensberg and the Maluti Mountains. Over most of the summer rainfall region convectional storms, frequently violent and accompanied by thunder, lightning and often hail, are the source of most of the rainfall.

Figure 6: Mean annual precipitation



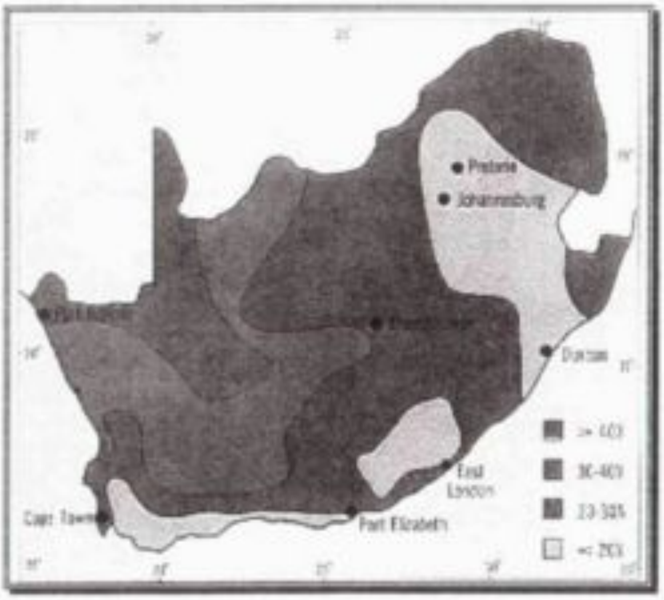
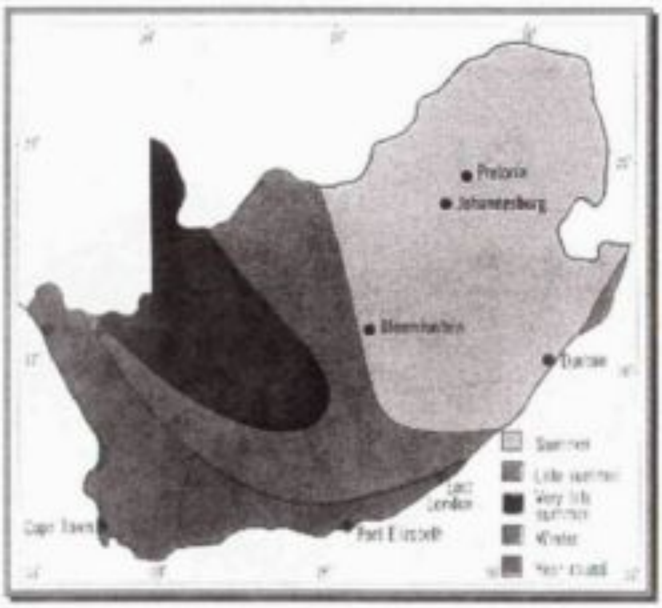


Figure 7: Percentage deviation from mean annual rainfall

Figure 8: Seasonal rainfall regions



2.3.5 Droughts

South Africa is periodically afflicted by severe and prolonged droughts. The greater part of the country was drought-stricken from 1960 to 1966, while the longest drought on record was from 1925 to 1933. The drought that commenced in 1978 introduced new cumulative lows in runoff records in many areas. Droughts are usually associated with prolonged periods of high pressure activity over the inland plateau and consequently are most common in the summer rainfall region, especially towards the west. Droughts are often terminated by severe floods.

2.3.6 Floods

South Africa is regularly subjected to floods. The major flood-producing rainfall mechanisms in the southern part of the Western Cape and the Karoo are the cut-off low-pressure systems such as those which produced the severe flooding in Laingsburg and adjacent areas in January 1981 and which are responsible for frequent flooding over the south-eastern coastal areas and the Karoo.

Heavy floods in the summer rainfall region of the interior normally occur when a low-pressure system over the interior is trapped by high-pressure systems in the Indian and Atlantic Oceans. Warm moist air is drawn into the interior from the north and north-east and moderately heavy rain may last for several days, producing widespread floods such as those in the Vaal River in 1975 and in the Orange River and the Northern Cape Province in 1978. Smaller convectional systems such as cloud mergers can produce very high intensity rainfall of very short duration (less than 30 minutes) over areas of a few square kilometres only. For example, at Nelspruit 102 mm of rain fell in 16 minutes in December 1975.

Tropical cyclones which cause heavy rain to fall over a wide area, such as cyclone Domoina in January 1984, occasionally penetrate as far south as the Lowveld, southern Mozambique, Swaziland and northern KwaZulu-Natal.

2.4 RUN-OFF AND INFILTRATION

2.4.1 Pathways of water after it falls to earth

When precipitation falls to Earth as snow, rain, or hail, some part of it is intercepted by trees, plants, and buildings. This water does not reach the ground during brief or low-intensity storms but is rapidly evaporated. Thus, light rainfall is re-evaporated into the atmosphere within a short time. This portion of the total rainfall is known as the interception loss.

During heavier precipitation, water does reach the ground and can follow several pathways. Almost immediately, some of it evaporates from the soil surface and returns to the atmosphere; another part enters the ground. If precipitation eventually exceeds the infiltration and evaporation rates, water will begin to collect on the surface. Water temporarily stored on the surface in low areas is called depression storage. If rainfall continues, overland flow commences as water in low-lying places begins to run together. Water soon collects into small channels which flow into gullies leading to streams. The overland flow that enters streams is called surface run-off.

Water entering the ground may remain temporarily in the soil zone, it may flow across the surface above the groundwater table until it reaches a stream or other low-lying body of water, or it may continue to infiltrate downward until it reaches the groundwater table. Water remaining in the soil zone may be used by plants or evaporate directly. The maximum volume of water a soil zone can hold is called its field capacity; some fine-grained soils can hold more than 300 mm of water in the soil zone, although the exact amount of water is difficult to determine.

Overland flow does not result from storms of short duration or low intensity. In more severe storms, however, overland flow will occur after some time. Interception, evaporation, and depression storage can account for all of the moisture falling during the early stages of a rainfall. But as interception becomes ineffective, the depressions are filled, and the infiltration capacity of the soil is exceeded, overland flow commences and the local streams begin to rise.

Even though overland flow carries water away from local areas, the water may not totally bypass the groundwater system. Ordinarily, most perennial streams and lakes are supported by the groundwater table. Many sediments near the shores of lakes and the banks of streams are highly permeable, and water can flow easily into the groundwater system once a stream or lake has temporarily risen above the groundwater table.

Figure 9 demonstrates the hydraulic relationship between a stream and the groundwater system before, during, and after a storm of moderate intensity and duration. Inflow to a stream during a storm may consist not only of overland flow but also of direct channel precipitation and interflow. Interflow is the water that moves toward a stream above the groundwater table, but underneath the soilwater zone. The stream recharges the groundwater during and some time after the storm.

The situation shown in Figure 9 suggests that a dynamic relationship exists between the groundwater system and streams. For much of the year the groundwater table may support the level of streams, but during periods of heavy precipitation or the spring melt in cold climates, streams may provide large volumes of surface water to recharge the underground. During dry seasons, some of this water will support the streams.

It might seem that lakes are quite influential in recharging groundwater levels because lakes exist throughout the year at relatively constant elevations. But studies have shown that the bottom sediments of most lakes are nearly impervious to water movement; clay sediments and organic muds produced in lakes effectively seal the lake bottoms. Therefore lake water actively interchanges with the groundwater system only in areas close to the shore or in other areas where sediments are removed by wave action, and at springs which may occur randomly in the lake bottoms. Except for springs, the water depth in these recharge zones are usually only a few feet deep. Thus a lake may not support the local groundwater system during severe drought. See figure 10 below.

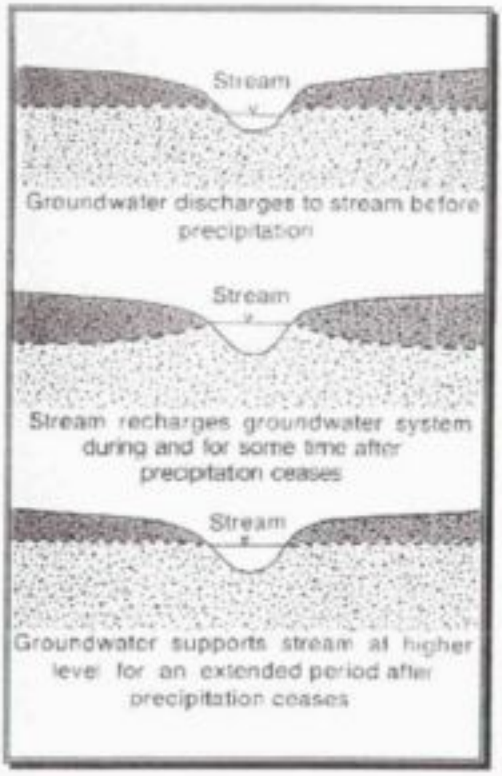


Figure 9:

Between rainstorms, most streams are supported by the local groundwater table. During storms, overland flow raises the stream level above the groundwater table. In time, recharge from the stream raises the water table until a new water level relationship is established with the stream. With no further precipitation , both the stream level and the groundwater table will gradually fall, with the groundwater partially or completely supporting the stream.

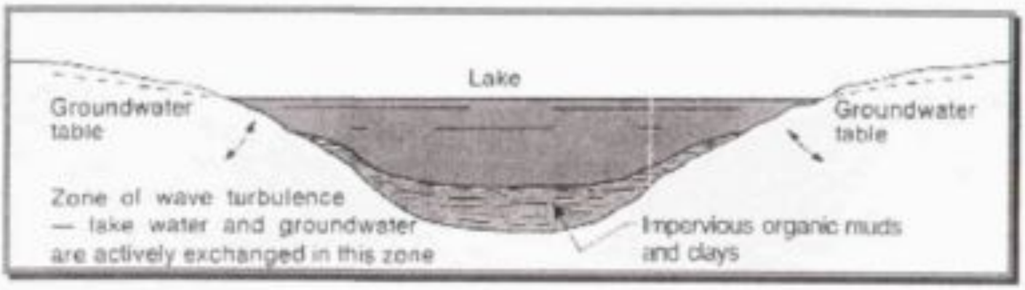


Figure 10:

During periods of drought, the groundwater table and lake level fall. However, if the lake falls more than a few feet, the mud at the bottom of the lake will prevent lake water from entering the local groundwater system, even though the groundwater table continues to fall.

2.4.2 *Run-off*

Factors affecting run-off

Run-off of water after it has precipitated to the surface is affected by the following factors:

1. rainfall intensity
2. rainfall duration
3. topography (gradient)
4. vegetation
5. soil type

2.4.3 *The availability of surface water*

Surface runoff is the dominant source of water in South Africa, although on average only 9 % of the total rainfall is discharged by rivers. The total volume of runoff is estimated at 53 500 million m^3/year, of which it may be practicable for all the states sharing the water to exploit only about 33 000 million m^3/year.

The construction of storage facilities is generally required in order to make the best use of surface runoff. Existing major dams in South Africa have a total capacity equivalent to 50 % of the total mean annual runoff. These dams command virtually the total runoff from the interior plateau while the untapped resources are concentrated mainly along the coast. The maximum practicable exploitation of the conventional water sources of large regions of the interior has therefore already been achieved.

Apart from engineering difficulties associated with the development of the generally short and steep coastal rivers, their exploitation may also be detrimental to sensitive estuaries. The availability of surface runoff for urban, industrial and agricultural use may be further reduced by an increase in the water required for other purposes such as recreation and environmental conservation.

Distribution and variable nature of runoff

The great escarpment divides South African river systems into two groups - the plateau rivers and those of the surrounding areas. Rivers flowing towards the east, such as the Komati, the Crocodile, the Olifants and the Limpopo have broken through the main escarpment and have their headwaters well back on the interior plateau. The Eastern plateau slopes, covering 13 % of the area of South Africa, account for some 43 % of the total surface runoff. This volume is distributed over a large number of small rivers which flow directly to the sea, limiting the possibility of their use. South of the Vaal-Limpopo divide, which runs east-west along the Witwatersrand, almost the entire plateau, or 48,5 % of the area of South Africa, is drained by the Orange River system, which contributes only 22,5 % or 12 057 million m^3 of the total annual runoff. This is partly because of lower precipitation, but especially as a result of a less favourable runoff to precipitation ratio, caused mainly by extensive evaporation losses over the western interior.

From the Mont-aux-Sources area the Orange River traverses 2 250 km from east to west, discharging into the Atlantic Ocean. Its major tributaries are the Caledon River and the Vaal River. The latter is actually longer and drains a much larger area than the main Orange headstream, but it contributes only 37 % of the total runoff in the Orange River system. Downstream of its confluence with the Vaal at Douglas, the Orange flows erratically for the remaining 1 200 km of its course. There is hardly any further addition to its runoff and in living memory no water has reached the river from the large Molopo-Nossob system situated to the north. In the Western and Eastern Cape major rivers are the Gamtoos, Gouritz, Breede, Berg and Olifants, which extend in the order given from a year-round rainfall area to a winter rainfall area.

Perennial rivers occur over only one-quarter of South Africa's surface - mainly in the Western Cape and on the eastern plateau slopes. Rivers that flow only periodically are found over a further quarter of the surface. Over the entire western interior, rivers are episodic and flow only after infrequent storms. An extreme example is provided by the Hartbees River at Kenhardt, where half of the total discharge between 1932 and 1972 was registered in six months during 1961.

In the absence of lakes and permanent snowfields to stabilise flow, even the perennial rivers flow irregularly and are very often strongly seasonal. Before construction of the Orange River Project dams the mean natural flow of the Orange River at the Boegoeberg Dam was 14 times larger in February, the peak month, than in August, the month with the lowest flow.
Variations in the total annual flow can be equally large. 26 700 million m^3 were registered at Boegoeberg in 1943/44, as against 1 490 million m^3 in 1948/49.

2.4.4 Infiltration

Most underground water is constantly in motion - being pulled by gravity from higher aquifers to lower, where it may appear in springs and streams. It is lifted from the ground by plants and by man himself. Gravity attracts water from the skies, pulls it beneath the surface of the ground, distributes it among permeable layers of the earth and influences the direction in which it flows. Rainwater seeps downwards through the soils until it is blocked by rock or non-porous layers such as clay. Simultaneously it spreads out horizontally so that vast volumes of the earth become saturated with water. The water soaks into the soil and moves through the permeable earth from pore to pore.

The proportion of water that sinks into the ground varies with the character of the soil. If the soil is dry and porous, large amounts will seep in. If a sudden downpour falls on a sloping surface of less permeable material, such as clay, most of the rainwater will run off and be lost to the soil. The outermost layers of the earth are composed largely of porous material, sands, gravels, silts and decaying vegetation. Most of this surface is underlain by porous or decomposing rocks. Beneath this everywhere is bedrock, so compact, as a result of its molten origin or of subsequent heat and pressure, it is totally impermeable. All layers are classified by water content - the upper zone of aeration and the lower zone of saturation.

Seeping below the surface, water first enters the zone of aeration, where the soil contains both water and air. Its depth varies widely from a few centimetres, in a vlei with a high water table, to hundreds of metres in areas with a low water table. In this zone of aeration water shows its powers of adhesion by clinging to particles of soil and rock. Some water that enters this region sinks to the layers beneath, some is absorbed by plants and some evaporates into the air again.

The lower moist layer, the zone of saturation, is the earth's main reservoir. Wells and boreholes dip into it and springs, rivers and lakes are its natural outcroppings on the surface. The top of the saturated zone, the boundary between the water layer (known as the water table) and the zone of aeration, is a narrow zone called the capillary fringe where water rises as a result of capillary action into the zone immediately above the water table. The sparkle of water at the bottom of a well is an exposed part of the water table. Around it and continuous with it, the same water table extends in the ground to be exposed again in the next well or in a natural feature like a river or lake.

Groundwater emerges at the earth's surface in the form of springs. These springs feed rivers whose water supply is augmented by run-off. This water eventually finds its way to the ocean thereby closing the continuous "loop" of the hydrological cycle.

MODULE A2: WHAT IS GROUNDWATER: AQUIFERS AND THE GROUNDWATER ZONE

1. INTRODUCTION

Water fit for drinking exists in the ground in some form at some depth nearly everywhere on earth. Even the Sahara desert is underlain by water, an estimated 600,000 cubic kilometres of it, spread over 6.5 million square kilometres of land area. Almost all of the world's stock of fresh water, 8.2 million cubic kilometres, or more than 97 % of the total available, is inside the earth itself and exists as groundwater. The rest exists in lakes, streams and rivers.

Most underground water is constantly in motion - being pulled by gravity from higher aquifers to lower, where it may appear in springs and streams. It is lifted from the ground by plants and by humans themselves. Gravity attracts water from the skies, pulls it beneath the surface of the ground, distributes it among permeable layers of the earth and influences the direction in which it flows. Rainwater seeps downwards through the soils until it is blocked by rock or non-porous layers such as clay. Simultaneously it spreads out horizontally so that vast volumes of the earth become saturated with water. The water soaks into the soil and moves through the permeable earth from pore to pore.

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2. THE GROUNDWATER ZONE

Seeping below the surface, water first enters the zone of aeration, where the soil contains both water and air. Its depth varies widely from a few centimetres, in a vlei with a high water table, to hundreds of metres in areas with a low water table. In this zone of aeration water shows its powers of adhesion by clinging to particles of soil and rock. Some water that enters this region sinks to the layers beneath, some is absorbed by plants and some evaporates into the air again.

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The groundwater itself occurs in pores, voids or fissures in the ground material. Pores are the spaces between the mineral grains in sedimentary ground layers and in decomposing rock formations. The word 'aquifer' is used to denote a layer of water bearing material.

The quantity of water that a given piece of saturated earth can contain depends on the earth's *porosity*, the total measure of the spaces among the grains or in the cracks that can fill with water. If the grains of sand or gravel are all about the same size or 'well sorted', the spaces between them account for a large proportion of the total volume of the aquifer. If the grains however are poorly sorted, the spaces between the grains may be filled with smaller particles instead of water. Poorly sorted rocks, therefore, do not hold as much water as well sorted rocks. If water is to move through rock or other material, the pores must be connected to one another. If the rock has a great many connecting pore spaces big enough to enable water to move freely through them, the rock is said to be permeable. A rock or underground material that is a good source of water must contain many inter-connecting pore spaces or cracks. A compact rock almost without pore spaces, such as granite, may be permeable if it contains enough sizeable cracks or fractures. The *permeability* of the ground is a measure of the freedom with which water moves through it.

Nearly all consolidated rock formations are broken by parallel systems of cracks called joints. At first the joints are like hairline cracks, but they tend to enlarge. Water enters the joint and gradually dissolves the rock so that it becomes decomposed. Decomposed rocks are permeable. The action of the water in decomposing the rocks extends as time passes. Also the movement of water may flush out decomposed or 'weathered' rocks thereby enlarging the openings. High-yielding boreholes are those that pass through layers of decomposing granite with a high permeability.

All openings in rocks such as joints, cleavage planes and random cracks are called fissures. Igneous rocks, that is those originating from volcanic erupted material, are not generally porous unless they are decomposed by weathering. Fissures may also occur in sedimentary rocks, which are sediments compacted by glacial pressure to form solid material.

An unconfined aquifer is open to infiltration of water directly from the ground surface. A confined aquifer is one where the water-bearing ground formation is capped by an impermeable ground layer. Water occurs under pressure in a confined aquifer and once a borehole is drilled water may rise up through the hole under pressure.

The groundwater zone may be imagined as a huge natural reservoir or system of reservoirs in rocks whose capacity is the total volume of pores or openings that are filled with water. Groundwater may be found in one continuous body or in several distinct rock or sediment layers at any one location. Thickness of the groundwater zone is governed by local geology, availability of pores or openings in the rock formation, recharge, and movement of water from areas of recharge toward points or areas of discharge.
It is nearly impossible to adequately summarise all types of geologic environments in which water can exist, but the list below presents some typical types of openings found in rocks.

1. Intergrain pores in unconsolidated sand and gravel
2. Intergrain pores in sandstone
3. Intergrain pores in shale
4. Systematic joints in metamorphic and igneous rocks
5. Cooling fractures in basalt
6. Solution cavities in limestone
7. Gas-bubble holes and lava tubes in basalt
8. Systematic joints in limestone
9. Openings in fault zones

Unfortunately, rock masses are rarely homogeneous and adjacent rock types may vary significantly in their ability to hold water. Nevertheless, intelligent groundwater assessment or use requires an understanding of how water exists in each type of rock or sediment medium.

3. AQUIFERS

The word aquifer comes from the two Latin words, *aqua* (water) and *ferre* (to carry). The aquifer literally carries water - underground. The aquifer may be a layer of gravel or sand, a zone between lava flows or even a large body of massive rocks, such as fractured granite with large opening in it. An aquifer may only be a few metres thick or tens of hundreds of metres thick, it may lie just under the surface or hundreds of metres down, it may underlie a few hectares of land or thousands of square kilometres.

An aquifer is a saturated bed, formation, or group of formations which yields water in sufficient quantity to be economically useful. Water-bearing formations and groundwater reservoirs are synonyms for the word aquifer. To be an aquifer, a geologic formation must contain pores or open spaces (both of these are often called interstices) that are filled with water. These interstices must be large enough to transmit water toward wells at a useful rate.

Both the size of pores and the total number of pores in a formation can vary remarkably, depending on the types of material and the geologic and chemical history. Individual pores in a fine-grained sediment such as clay are extremely small, but the combined volume of the pores can be unusually large. For example, the total pore volume of a recently deposited clay may be as great as 95 %. Subsequent compaction of clay reduces the pore space considerably. Although clay has a large waterholding capacity, water cannot move readily through the tiny open spaces. This means that a clay formation under normal conditions will not yield water to wells, and therefore it is not an aquifer even though it may be water-saturated. However, clays that are squeezed may yield economic amounts of water.

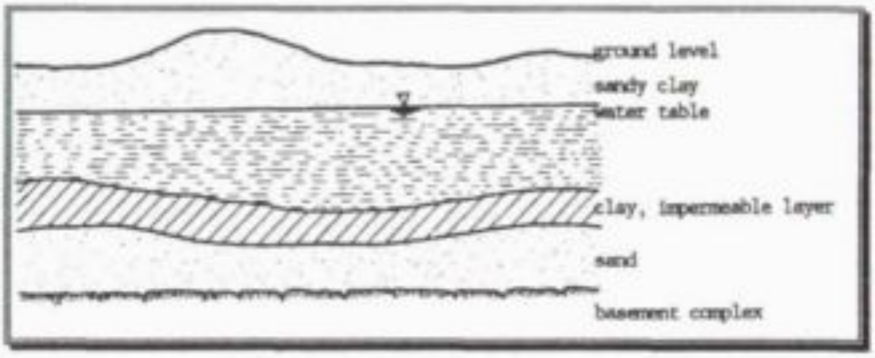
Ordinarily a clay or shale formation is nearly impermeable and is called an aquiclude, or a formation through which virtually no water moves. Formations which do yield some water, but usually not enough to meet even modest demands, are called aquitards. In reality, almost all formations will yield some water, and therefore are classified as either aquifers or aquitards. In water-poor areas, a formation producing small quantities of water may be called an aquifer, whereas the same formation in a water-rich area would be an aquitard.
Water can exist in aquifers under two completely different physical conditions. The most common condition is when the water table is exposed to the atmosphere through openings in the overlying regolith. This type of aquifer is referred to as an unconfined or water-table aquifer; unconfined is the preferred term. Groundwater may also occur under confined conditions. Confined groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations, and the confined aquifer is generally subject to pressures higher than atmospheric pressure. Unconfined conditions exist, however, in recharge areas for confined aquifers.

3.1 TYPES OF AQUIFERS

Often there are different soil layers above each other. They can constitute the following types of aquifers:

1. <u>(Open) Aquifer</u> (unconfined aquifer / open groundwater)

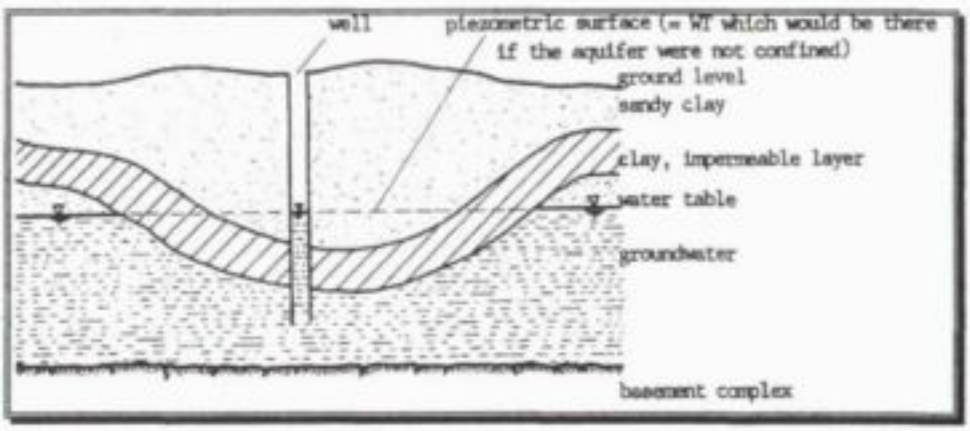
An aquifer is a saturated porous soil layer containing and transporting water. There can be several aquifers above each other, divided by impermeable layers.



An impermeable layer contains no or little water and does not allow water to infiltrate through it. However, impermeable layers are seldom continuous, therefore, water can pass through the incontinuities.

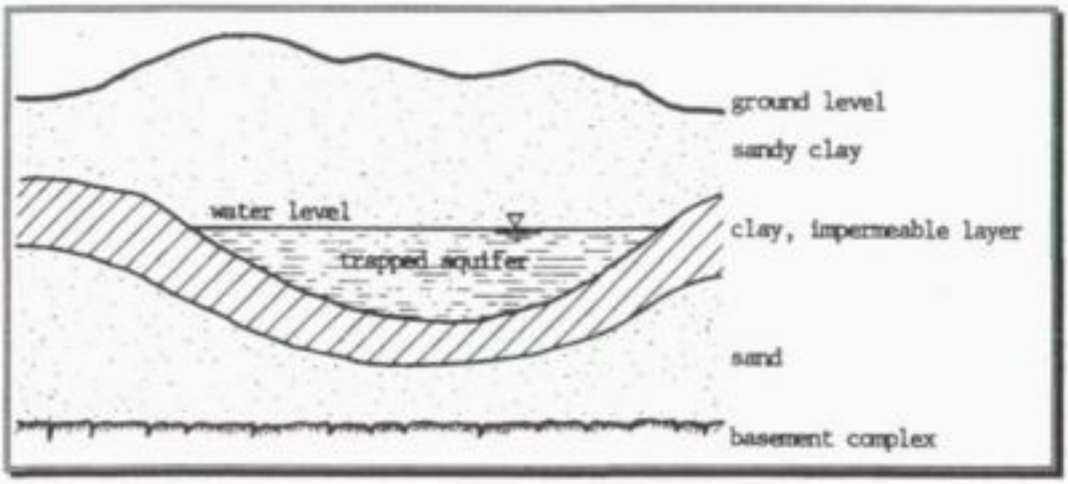
2. <u>Artesian Aquifer</u> (confined aquifer)

An artesian aquifer is confined by an impermeable layer. If tapped by a well, the water table raises in the well up to the "piezometric surface".



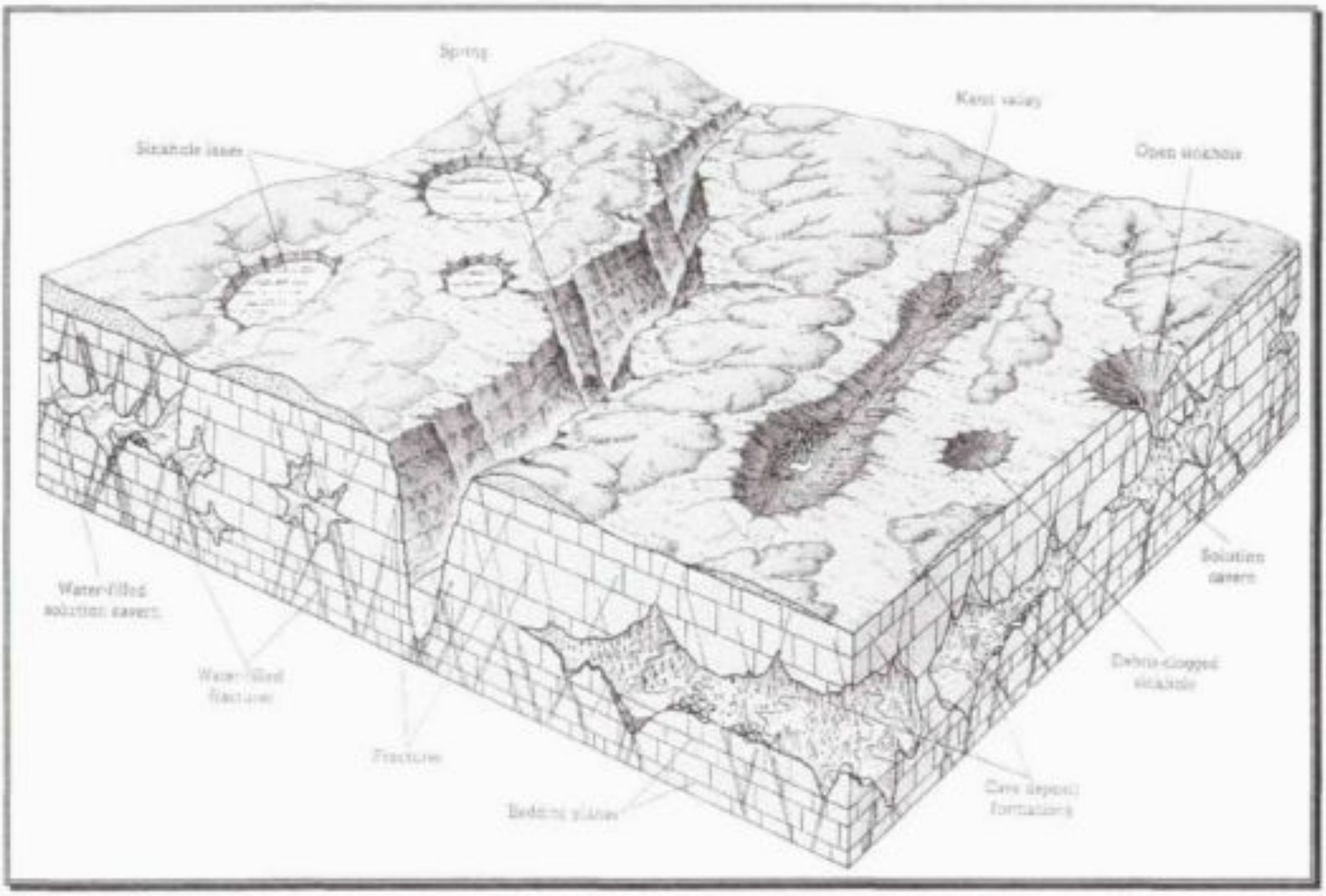
3. Trapped (or Perched) Aquifer

A trapped aquifer is a limited aquifer surrounded by impermeable layers. The recharge is limited; therefore, a well tapping a trapped aquifer can be exhausted and dry out.



The solution of limestone by groundwater produces a number of different features, some of them suggested in the figure below. Caverns are formed in the subsurface. Some of these may be completely filled with water. Others may be drained or partially drained and contain stalctites, stalacmites and related forms. At the surface various types of sinkholes may occur as may karst valleys whose streams disappear into the underground.

Figure 11:



3.2 RECHARGE OF GROUNDWATER

The ultimate source of underground water is precipitation that finds its way below the surface of the land. Some of the water from precipitation seeps into the ground, reaches the zone of saturation, and raises the water table. Continuous masurements over long periods of time at many places in the United States show an intimate connection between the level of the water table and rainfall. Because water moves relatively slowly in the zone of aeration and the zone of saturation, fluctuations in the water table usually lag a little behind fluctuaions in rainfall.

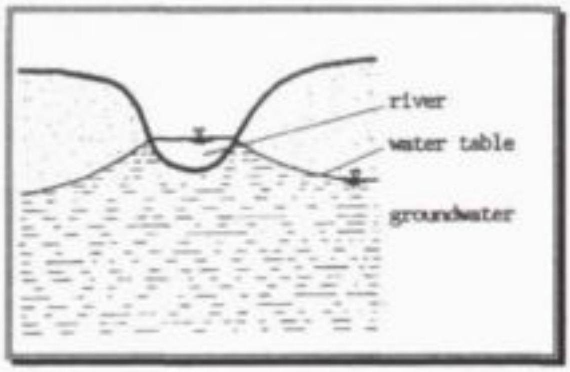
Several factors control the amount of water that actually reaches the zone of saturation. For example, rain that falls during the growing season must first replenish moisture used up by plants or passed off through evaporation. If these demands are great, very little water will find its way down to recharge the zone of saturation. Then, too, during a very rapid, heavy rainfallmay run off directly into the streams instead of soaking down into the ground. A slow, steady rain is much more effective than a heavy, violent rain in replenishing the supply of groundwater. High slopes, lack of vegetation, or the presence of impermeable rock near the surface may promote runoff and reduce the amount of water that reaches the zone of saturation. It is true, however, that some streams themselves are the sources for the recharge of underground water. Water from the streams leak into the zones of saturation, sometimes through a zone of aeration.

In many localities the natural recharge of the underground water cannot keep pace with human demands for water. Consequently attempts are sometimes made to recharge these supplies artificially. On Long Island, New York, for example, water that has been pumped out for air-conditioning purposes is returned to the ground through special recharging wells or, in winter, through idle wells that are used in summer for air-conditioning. In the San Fernando Valley, California, water from the Owens Valley aquaduct is fed into the underground in an attempt to keep the local water table at a high level.

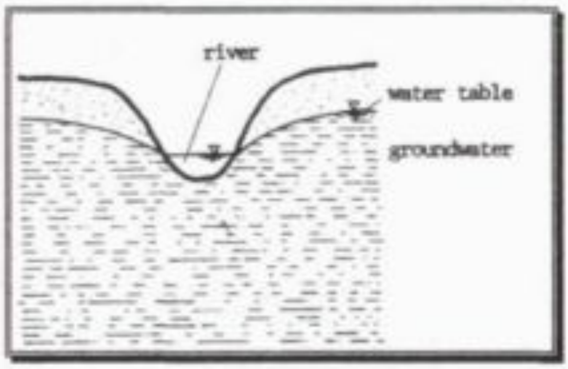
4. CONNECTION BETWEEN RIVERS AND GROUNDWATER

A river and the groundwater can be connected in different ways:

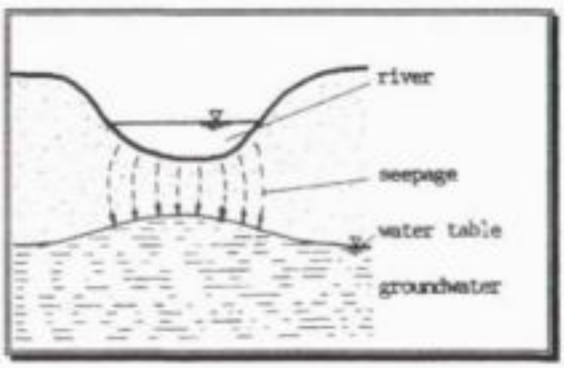
1. Influent stream:
Looses water to the aquifer



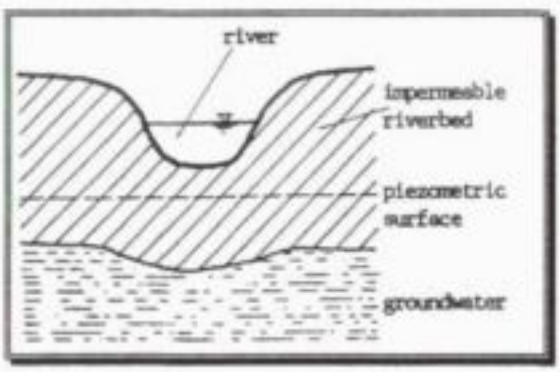
2. Effluent stream:
Gains water from the aquifer
(the same stream may have
influent and effluent sections)



3. Stream only flowing periodically:
dry during drought



4. Stream isolated hydraulically:
from an artesian aquifer below



5. TYPES OF SOILS AS AQUIFERS

Table 1:

Type of soil	Porosity	Permeability	Difference between Unsaturated and Saturated zone	Cleaning capability	Rechargeability	Quality of aquifer	Possible problems
Clay	good	limited or impermeable, however, no continuous layers	several metres	good	fair	fairly good	slow intale, limited recharge
Sand	good	very good	no	very good	very good	very good	quicksand, collapsing
Gravel	very good	very good	no	no	good	very good	collapsing, easily polluted
Weathered rock	good	good	no	bad	very limited	good if nothing else available	only limited layers, thus limited amount of water
rock (base-ment complex)	Not good, except in cracks	Not good, except in cracks	no	no	very limited	good if nothing else available	difficult to hit cracks, limited storage, water may be salty because of dissolved minerals
Mixtures of soil types	properties differ from site to site						

MODULE A3: THE DISTRIBUTION, USE AND POTENTIAL FOR THE EXPLOITATION OF GROUND WATER IN SOUTH AFRICA

1. INTRODUCTION

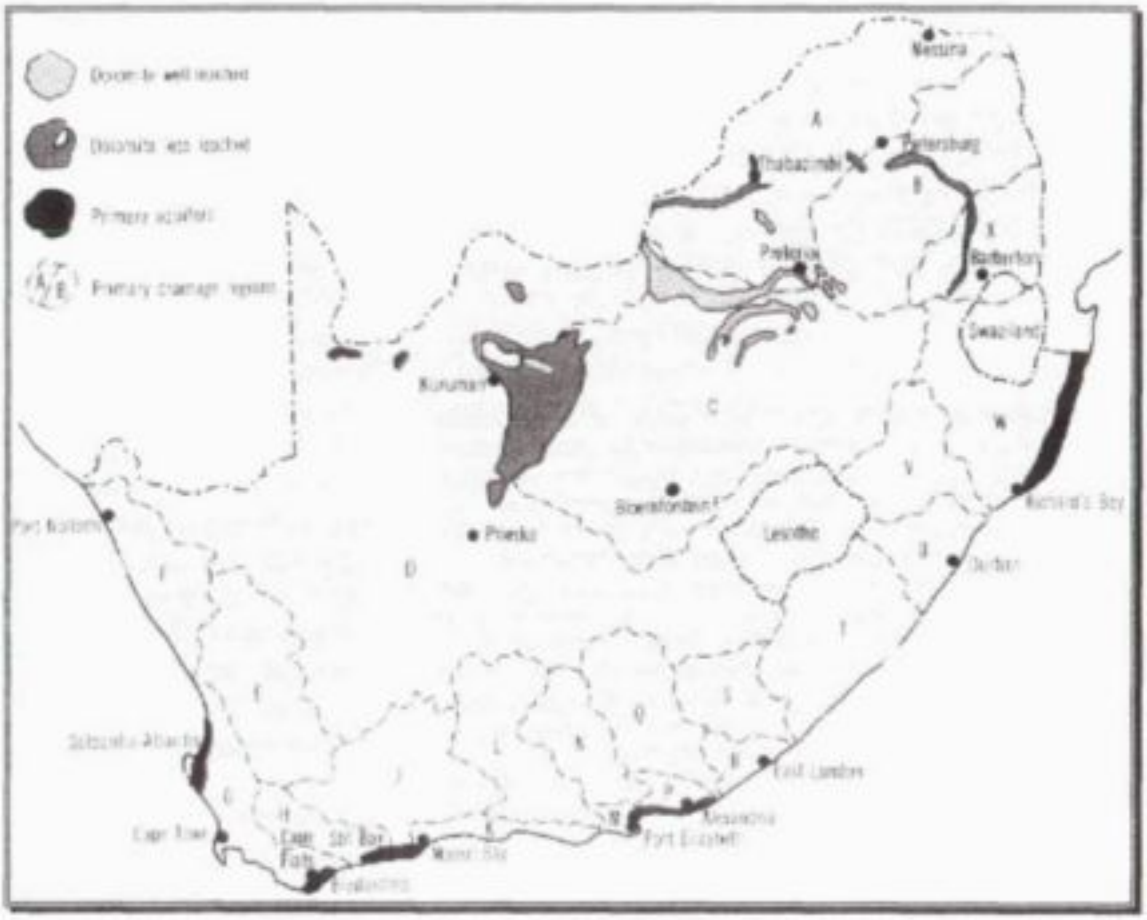
Over more than 80 % of the area of South Africa ground water occurs in secondary aquifers. These are weathered and fractured rocks which lie directly beneath the surface to depths of less than 50 m. At greater depths unweathered rock formations occur which contain very little ground water because of their dense nature.

The quantity of water stored in the saturated portions of these weathered and fractured rocks is generally very limited and the permeability of these secondary aquifers is usually also low. For these reasons few boreholes are capable of yielding more than a few litres per second for any length of time. The possibility of exploitation offered by secondary aquifers is therefore limited and they are used mainly to provide water on farms for domestic use, for stock-watering and for irrigation on a small scale and to provide water for communities ranging from villages to medium-sized towns. Under favourable geohydrological conditions it may be possible to supply a town with up to 5 million m^3 of ground water per year from a number of secondary aquifers located within economic reach of the town.
By contrast, appreciable quantities of ground water can be abstracted at high rates from boreholes judiciously sited on dolomite. The term "dolomite" is generally used to designate strata 200m to 1 900m thick that are composed of dolomitic rock with subordinate interbedded chert, shale and sandstone.

Dolomitic rock consists almost entirely of the mineral dolomite, a double carbonate of calcium and magnesium that is weakly soluble in carbonated water. Extensive leaching of dolomite in places to depths in excess of 150 m, especially in the West Rand, provides ideal sites for high-yield boreholes. Dolomitic aquifers may therefore be exploited for urban supplies and irrigation on a larger scale than ground water in other hard rock formations. The possible incidence of sinkholes resulting from the abstraction of ground water from dolomitic aquifers places a limitation on the degree to which the potential of this source can be exploited.

Primary aquifers, comprising porous deposits of granular material, also contain substantial quantities of exploitable water but the size and distribution of this type of aquifer is limited in South Africa. The figure on the following page shows the distribution of dolomite and some of the larger primary aquifers.

Figure 12:
Distribution of dolomitic and of primary aquifers



The ground water resources of the country should be visualised as being contained in a multitude of mostly secondary aquifers or aquifer systems with limited quantities of extractable ground water. This explains to a large extent why ground water does not play as important a role in the national water supply of this country as it does in other parts of the world where the main source of supply stems from an extensive primary aquifer system. In general, the quality of ground water in the high rainfall regions of South Africa is adequate but problems with poor quality are experienced in some of the more arid areas.

Apart from usually being a dependable supply, ground water can meet the initial demand during early stages of large-scale urban development such as that at Atlantis. Savings can later also be achieved on the cost of pipelines required to obtain water from elsewhere by satisfying peak demand from local ground water sources.

For towns supplied from surface sources, ground water can assist in bridging periodic shortages and in alleviating emergencies, provided investigations and borehole development are undertaken in time.

2. DEFINITIONS

Primary aquifers consist of unconsolidated or consolidated deposits of sand, gravel and pebbles in which the interstices have not been destroyed by subsequent compaction, recrystallization or cementation. Such water-bearing formations are capable of yielding volumes of water varying from 5% to about 30 % of the gross volume of the formation.

In other parts of the world such deposits are known to cover thousands of square kilometres and have thicknesses ranging from several hundred to more than a thousand metres. However, in South Africa these water-bearing deposits are shallow and cover only a small portion of the country. They occur as alluvial deposits in and along surface watercourses.

Secondary aquifers occur in hard rock formations close to the surface over about 80 % of the country. These formations comprise sedimentary, metamorphic and intrusive and extrusive igneous rocks. They contain virtually no primary openings and owe their water-bearing properties to secondary openings caused by the geological processes of deformation (folding, fracturing and faulting), weathering and unloading as a result of the erosion of overlying strata. These openings develop typically in the upper part of the earth's crust, being generally restricted to the first 10 m to 50 m below the surface.

Except in the case of limestone and dolomite, the storage capacity and permeability of secondary aquifers are low and compare poorly with those of primary aquifers. Secondary aquifers vary considerably in their form and in the size of the area which they cover. Areas vary from less than a hectare to several square kilometres and such aquifers are bounded and separated from one another by formations with poor permeability.

3. POTENTIAL FOR THE EXPLOITATION OF GROUND WATER

The potential for the exploitation of ground water depends on the manner in which it is exploited. The possibilities are as follows:

1. As a renewable resource abstracted continuously at a more or less constant daily rate (for example for urban water supply).
2. As a non-renewable resource where recharge is nil or inadequate, which may be abstracted until the stored volume is exhausted.
3. As a combination of (1) and (2).
4. As a renewable resource abstracted at high rates for short periods to supplement other sources during peak periods or in cases of emergency.

Abstraction of ground water from boreholes exploits a renewable resource which, under natural conditions, would emerge as spring flow and seepage to streams or would be lost through evapotranspiration. In some areas, such as mountain catchments, it may be impracticable to intercept seepage to streams by drawing ground water from boreholes and, where this contribution to runoff is required for use downstream, ground water abstraction may even be undesirable.

The amount of infiltration or recharge that can be recovered by pumping from boreholes is difficult to determine. The reason for this is that the establishment of an adequate number of boreholes effectively distributed over a sufficiently large area in order to recover the full aquifer recharge or a predetermined quantity of ground water is limited by practicability and cost. Furthermore, local requirements may not demand full utilisation of the available ground water resources and their full potential may never be realised. With the exception of certain dolomitic and primary aquifers, utilisation of ground water will be limited to relatively smallscale users in the vicinity of the ground water source.

4. GROUNDWATER IN SOUTH AFRICA

The most important aquifers in the country are in karstified dolomite, that is dolomite where networks of caverns and smaller channels have formed along preexisting joints and fractures. These openings as well as those contained in the overlying mantle of weathered material, are capable of storing and transmitting large volumes of water. The dolomitic formations of parts of Gauteng and the Northern Cape province are divided by intrusive dykes of dolerite and syenite into so-called compartments which range in size from a hectare to more than 100 km^2 but unfortunately dolomite has not been subjected to the same degree of karstification everywhere in the country.

The yield of aquifers depends on various factors, one of the more important being the rate of recharge. Estimates of the average volume of precipitation which annually infiltrates the aquifers over the country as a whole varies from 16 000 million m^3 to 37 000 million m^3. However, only a small portion of the infiltrated water can be recovered by means of boreholes because of evaporation, transpiration and seepage losses which do not contribute to stream flow

The estimated quantity of ground water in South African geological formations is given as an equivalent depth of free water in Table 1 and the estimated annual yield of ground water sources is given in Table 2 by main drainage region.

Table 1: Ground water in South African geological formations, expressed as the equivalent depth of free water.

Formation	Equivalent depth of water (m)
Dolomite, Far West Rand (before dewatering)	4.9 - 8.3
Grootfontein compartment (Lichtenburg)	1.9
Coastal sand deposits (Atlantis, Western Cape)	2.5 - 5.0
Typical alluvial deposits along rivers	2.0
Disintegrated, weathered granite	0.5 - 1.0
Karoo sedimentary rocks	0.1 - 0.5

Table 2:

Estimated quantities of ground water that could be abstracted annually from main drainage regions under foreseeable limitations of economics and practicability

Main drainage region	Quantity (million m^3/year)	Quality range (Total dissolved solids - mg/litre)
A	500	300 - 1 500
B	440	200 - 2 000
C	820	200 - 2 000
D	1000	200 - 4 000
E	90	1 000 - 7 000
F	10	1 000 - 6 000
G	175	500 - 3 000
H	175	300 - 4 000
J	100	700 - 4 000
K	90	500 - 2 500
L	50	600 - 5 000
M	15	500 - 3 000
N	50	700 - 3 000
P	25	500 - 5 000
Q	90	800 - 6 000
R	30	800 - 3 000
S	80	300 - 2 000
T	460	200 - 2 000
U	200	200 - 1 000
V	210	400 - 1 500
W	430	200 - 2 500
X	360	200 - 1 500
Total	**5400**	

5. ABSTRACTION

From the preceding discussion it is clear that the vast majority of aquifers occurring in South Africa are secondary and therefore comprise a network of interconnected subsurface cavities such as cracks, fissures and sometimes caverns. Boreholes sunk into such aquifers rarely strike large underground reservoirs but more typically are drilled through one or more water conduits such as cracks or fissures. The artificial "reservoir" created by the drilling of the borehole is fed by water travelling along these conduits. Boreholes are often drilled to reasonably great depths in order to drill through sufficient conduits so that the "reservoir" is fed by numerous sources. ***Each conduit through which a borehole is drilled is called a strike***.

The sketch overleaf depicts a typical borehole. It is clear that if the borehole contractor had ceased drilling at a depth of 10 metres, no water would have been encountered. Furthermore had drilling ceased a a depth of 30 m, the total yield of the borehole would be equivalent to the yield of Strike No.1, ie 0,5 litres per second. However if drilling had continued to a depth of 50 m, the yield of the borehole would be equal to the sum the yields of Strike Nos. 1,2 and 3, ie. 0,5 plus 1,3 plus 0,8 litres per second - or 2,6 litres per second.

Over and above the consideration of encountering more strikes with increasing depth of a borehole, two other depth related borehole performance factors must be taken cognizance of wherever possible.

i) The borehole must ideally be drilled to sufficient depth to ensure that under operating conditions the equilibrium draw down water level is at a depth above that of the strikes. As aquifers occurring in the fracture zone are secondary and are mostly confined by two impermeable layers, ground water is normally under pressure and will tend to rise up the borehole until it reaches an equilibrium level.. Over pumping of the borehole will result in the drawdown level dropping below the strikes which encourages air ingress into the aquifer as well as turbulent flow conditions. These conditions often lead to the choking of the aquifer.

ii) The borehole should be drilled to such a depth to ensure that the pump cylinder is located approximately 10 m below equilibrium draw down level under operating conditions. Furthermore, the pump cylinder should be located at least 5 m above the bottom of the hole to prevent it from being fouled by sediments.

It is vitally important to realise that the hydrological and geological conditions in South Africa are such that we typically have only a three month reserve buffer on our ground water resources. In other words, under drought conditions the impact of reduced or no recharge of the ground water resources through the infiltration of precipitation, will be manifested by dropping water tables and drying boreholes after about three months.

It is imperative that ground water is not deemed to be an infinite resource. The replenishment of groundwater resources, as has been discussed in some detail, is as a result of logical physical processes and not by magical or mystical means.

MODULE A4: QUANTIFICATION OF GROUND WATER RESOURCES

There are a variety of methods which are used to quantify the potential yield of a borehole. One of the methods of testing a borehole, viz. the blow yield test, is quick but not very accurate and provides only an approximate indication of borehole strength. At the other extreme, the constant drawdown test can be time consuming and expensive to perform yet it gives a very accurate result. The method most commonly used however, namely the step and constant draw down method involves pumping the borehole at various rates for specific durations and using measurements of water levels in the borehole to give a relatively reliable estimate of the borehole strength..

1. THE BLOW YIELD METHOD

The Blow Yield Method entails introducing pressurised air into the borehole. The pressurised air displaces the water in the borehole forcing it out at the surface. The yield of the borehole is estimated by measuring the volume of water which exits the hole at the surface whilst the level of water remaining in the hole is approximately constant.

This method has two major shortcomings. Firstly, it is very difficult to collect and accurately measure all of the water which is being forced out of the borehole by the pressurised air. Secondly some of the water is not expelled at the surface but is forced up into cracks and fissures in the rock formation by the air. The net effect of these two shortcomings of the blow yield test is that it tends to underestimate the true yield of the borehole.

2. THE CONSTANT DRAWDOWN LEVEL METHOD

The constant drawdown test entails pumping water from the borehole at various rates until such time as a rate of pumping is determined which results in the level of water in the borehole remaining constant. At this point the rate of extraction of water from the hole is exactly matched by the rate of inflow of water into the hole. The primary drawback of this method is that it is very time consuming and therefore expensive.

3. THE STEP AND CONSTANT PUMPING RATE METHOD

The step and constant pumping rate method is a multi-phased means of yielding a reliable estimate of the strength of a borehole.

Phase 1 entails pumping the borehole at various rates, commencing with a rate equal to half of the blow yield for a period of one hour. After an hour the tempo of pumping is increased to a rate equal to the blow yield of the borehole and pumping continues at this rate for an hour. This procedure is repeated for pumping tempos equal to twice and three times the blow yield. The duration of this phase of the test is therefore 4 hours. The level of water in the borehole is measured and recorded at fixed and frequent intervals for the full duration of the test.

A graph of water level versus time is plotted for each of the four rates of pumping. The time axis (horizontal or "x") is plotted on a log scale whilst the water level is plotted on a natural scale on the vertical or "y" axis. The plotted data curves are then extrapolated to give estimated drawdown water levels after 24 hours of pumping. An estimated pumping rate which will most closely yield a drawdown level just above or equal to the level of the major strike is then selected for the constant yield phase of the test.

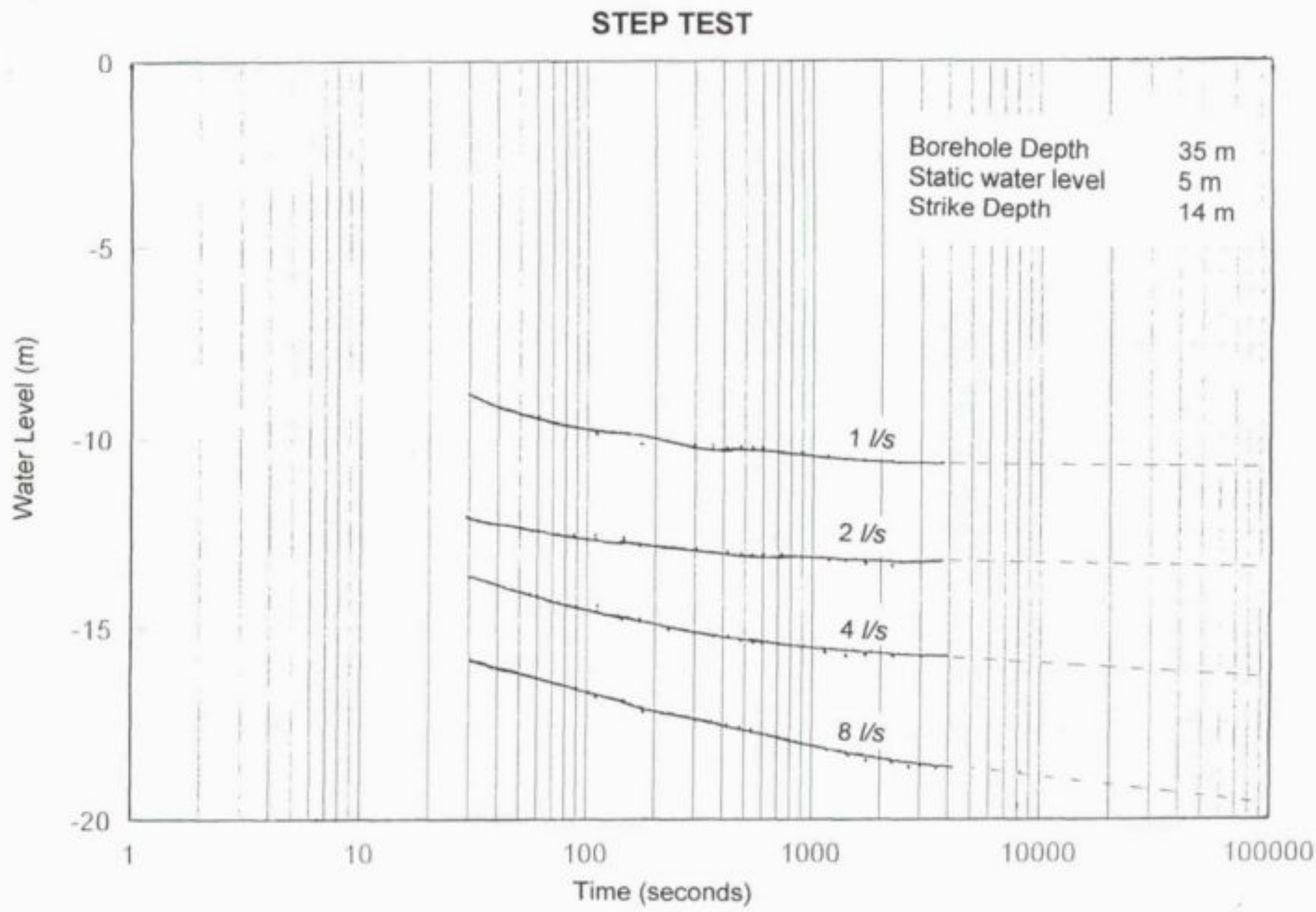
Phase 2 of the test entails pumping the borehole at the tempo determined from the information obtained from Phase 1 for a period of 24 hours. Drawdown water levels are measured and recorded at frequent intervals throughout the duration of this test.

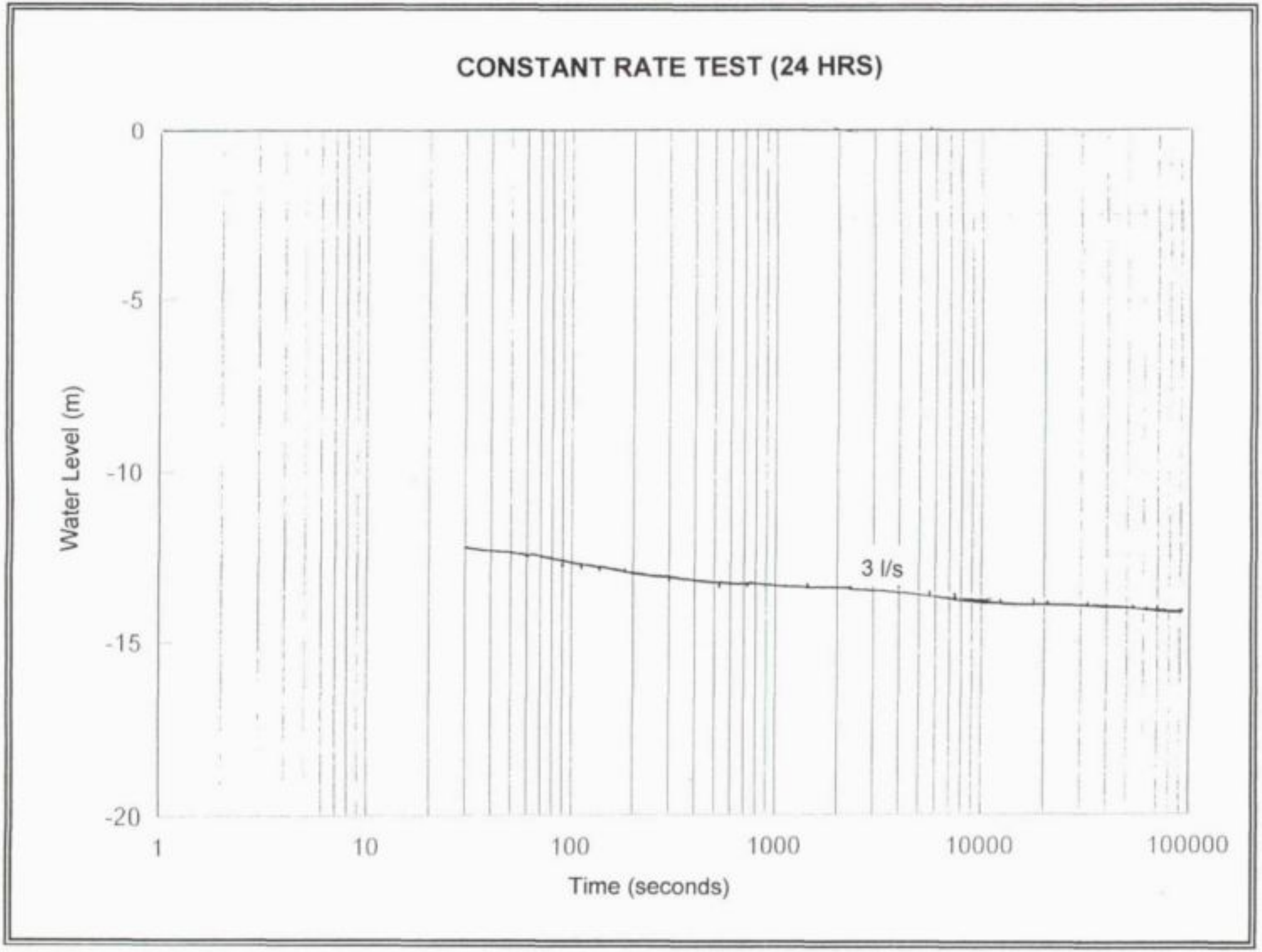
After 24 hours have elapsed the pump is stopped and the borehole is recharged. The rising water levels as the borehole is recharged are recorded and plotted against time. The rising water level plotted on the Y-axis is termed the "residual water level" and is simply the recorded water level at any given time minus the static water level recorded prior to the commencement of pumping. If the borehole recovers completely, the residual water level will be equal to zero as the actual water level will be equal to the static water level. The X-axis term, viz. T/T^1, is calculated by dividing the time "T" since the constant rate pump test commenced, by the time "T^1" which has elapsed since pumping ceased.

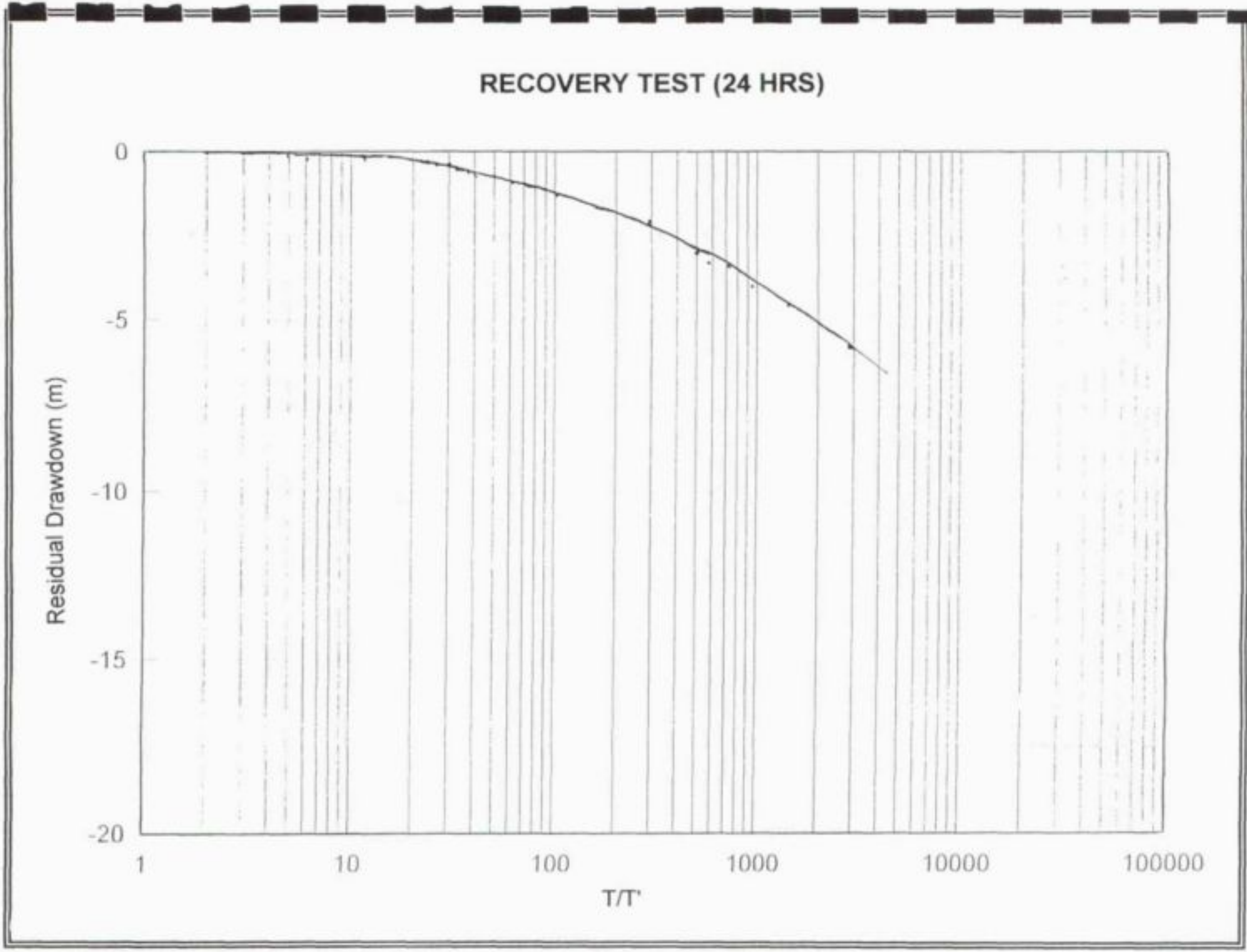
By extrapolating this plot, the residual drawdown water level can be determined. If this level is equal to zero, ie. the extrapolated graph plots goes through the origin, the constant rate of pumping used during Phase 2 is considered to be a safe operational yield. If however the residual drawdown level is deeper than the static water level, in other words the extrapolated graph does not go through the origin but intersects the Y-axis, the constant rate of pumping can be deemed to be greater than the yield of the borehole. The test should then be repeated at a lesser tempo to ensure that a satisfactory residual drawdown level is attained.

IMPORTANT NOTE:

Sound management of a groundwater resource is essential to ensure long-term satisfactory performance. As has been discussed both in this module and in WTA03, the yield of a groundwater source is totally dependent on adequate replenishment of extracted water. This replenishment or recharge is dependent on numerous factors, the most notable of which is the infiltration of rainfall. It cannot be overemphasised that injudicious extraction of water from a groundwater resource will result in its destruction. It is therefore imperative that the extraction of water, in terms of both pumping rate and duration, is cross-checked with drawdown water levels in the borehole. It is vital that the recommended limits of borehole utilisation, ie. pumping tempo and duration of pumping are strictly adhered to. Any deviation from characteristic parameters must be reported to the relevant authority immediately.


STEP TEST
Borehole Depth 35 m
Static water level 5 m
Strike Depth 14 m
1 l/s
2 l/s
4 l/s
8 l/s
Water Level (m)
0
-5
-10
-15
-20
1
10
100
1000
10000
100000
Time (seconds)


CONSTANT RATE TEST (24 HRS)
0
-5
-10
-15
-20
Water Level (m)
3 l/s
1
10
100
1000
10000
100000
Time (seconds)



RECOVERY TEST (24 HRS)
Residual Drawdown (m)
0
-5
-10
-15
-20
1
10
100
1000
10000
100000
T/T'