Approaches to the Teaching of Geography: the Hydrological Cycle and the Drainage Basin

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Approaches to the Teaching of Geography

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Contents

PREFACE

This Education Paper has been primarily written for geography teachers in secondary schools, teachers on training courses, and geography educators in general.

The teaching of geography is currently undergoing radical changes in respect of the ways learning takes place. Notably there is a move towards data handling exercises where students draw out key ideas as they are guided through structured materials. At present, this approach is most frequently used in sixth-form studies and so this is where we have concentrated our efforts. The intention of this paper is to exemplify a data based approach to teaching and learning.

Teachers are encouraged to use the materials in their classrooms. Maps etc have been designed so that they can be readily photocopied. Alternatively class-sets of the paper can be purchased. The authors would welcome comments on the ideas contained in this Education Paper.

Notes on Authors

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INTRODUCTION

The purpose of this paper is to outline an approach to the teaching of geography in the secondary school. It also provides a practical illustration of how the approach can be used in the classroom. The focus of this paper is pedagogic but it has the supplementary aim of providing hydrological data which are particularly relevant for the teaching of physical geography in Hong Kong. Whilst this paper focuses on the teaching of geography, particular strategies are not restricted to any one school subject. Hence, the approach which is illustrated will be of interest to teachers of other subjects both within the environmental sciences and amongst other discipline areas.

Discussion of teaching approaches is important; some approaches are more likely to result in the achievement of intended learning outcomes than others. Indeed, some classroom strategies may actively discourage the development of some objectives. The general, world wide trend towards an emphasis on thinking and other skills has led to the establishment of a new balance between product (teaching about the features of a case) and process (teaching how to do something) in favour of the latter. Implicit is the contrast between simply recalling knowledge and thinking. The exact relationship between the two is immensely important to the philosophy of the education being offered.

The approach illustrated here falls within a general group of strategies termed data based-guided discovery learning. The approach is not new. It has been adopted in a number of curriculum projects in Geography since the pioneering work of the American High School Geography Project in the late 1960s. Despite similar initiatives, however, workers outside the project environment have often been reluctant to adopt data based learning. This has been so in Hong Kong. There are many reasons for this which reflect the perceived "costs" of implementation; nonetheless it is also the result of insufficient understanding of the benefits of using such an approach, a feature which this paper hopes to remedy.

This paper deals specifically with data based learning at sixth-form level (16-19 years). This not to imply that it cannot, or should not, be used with other age groups. The strategy is as appropriate with junior as with senior classes. Moreover, its use with younger pupils is essential if a way of thinking is to be established in children's minds. In this context for teachers in Hong Kong, it is pertinent to note that the approach outlined here is consistent with the exemplar urban studies materials, *Cities as our Living Places*, produced a few years ago by the Education Department of the Hong Kong Government for Form 1 pupils. The exercise on the hydrological cycle, which forms the main part of this paper, complements this earlier work. It is hoped that, in similar vein, it will act as a procedural model, or catalyst for work on other topics. The value of the paper lies in the degree to which it can encourage people to experiment with this style of teaching.

Teaching Strategies

Many general texts on geographical education which discuss teaching methods often emphasise individual techniques such as using maps, pictures, simulations, fieldwork, etc. However, these, in themselves, do not provide an overall basis for structuring lessons. They are just the tools used in carrying out a lesson. Failure to understand this has sometimes led to inappropriate use, frustration and sometimes rejection of ideas with undoubted potential. Techniques need to be viewed in the context of an overall teaching strategy.

Despite changes in the way geography lessons are conducted, there has been only limited discussion in a holistic sense of methods in general, of interrelationships between methods and of the relative merits (and demerits) of individual approaches. The focus has been on specific strategies in isolation. Recently, however (see for example Fien *et al.*, 1984) efforts have been made to bridge the gap through integrating more recent approaches, such as enquiry learning,alongside ways of improving traditional expository teaching.

Graves (1980) dealt with the classification of lesson strategies largely by implication outlining, for example, approaches such as guided discussion, problem solving, and data based learning. However he did not suggest a framework by which these approaches could be contrasted. Robert (1982) addressed this by defining two broad groups: expository methods (namely, lecturing and programmed learning) and inquiry or discovery methods (namely, open enquiry and guided enquiry). Hart (1982) emphasised this dichotomy by noting the attention geographers should give to questions, issues and problems and, hence, the need to adopt strategies which involve pupils in the process of enquiry rather than passive acceptance of other's findings.

Robert and Hart, it can be argued, take a simplistic view by lumping together various attributes of lessons into just two groups. Non-enquiry methods are viewed, in their light, as necessarily passive and unsupportable. Expository methods are seen as being essentially deductive in nature. Hence, as passive deductively based lessons are generally unacceptable, non-enquiry methods must also be unacceptable. The reality of the classroom is more complex and greyer; it reflects the interaction of, among other things, the types of geographical questions being asked, the topic under examination, the balance between skills and knowledge intended and the degree to which pupils can work independently.

One distinguishing feature above all which characterises classrooms is their variability. In which case we need an approach which is flexible and highly adaptable to pupils' individual needs. Questions of norms, standard classroom styles or prescribed approaches are not workable. This is not to deny that in any subject area there are distinctive patterns of classroom behaviour we would like to see. Most practitioners would, we suspect, accept that in reality there is an unwritten, undefined style or narrow range of styles in operation. Professional geography teachers need to evaluate how teaching and learning takes place in their classrooms, to review the extent to which accepted practice is effective and to examine alternatives. Data based learning is one possibility.

Data Based Learning

This style of learning is what it says it is. It is learning which is based on the analysis of data. In this it differs from expository learning where geographical information is acquired from the teacher either through narration or question and answer. Maps, pictures, table of data are frequently used but their function is primarily either to stimulate initial interest or to consolidate ideas which have been transmitted from the teacher to the pupils.

In data based learning information is also used and in part for similar purposes. The data, however, have the additional function of providing the basis on which the ideas are developed by the pupil. In exposition teacher talk is the key, here this is replaced by data. In particular the hope is that the data will stimulate pupils to ask questions themselves fulfilling Bailey and Binns (1987) desire that above all, in geography, children learn how to learn. The data provide pupils with the information which may encourage pupils to ask questions and materials from which they can find answers to questions. By removing some of the need for teacher exposition and pupil guesswork, we can create a better environment for thinking and learning.

Data are central to the learning process as is the pupils' engagement with it. Attention is moved from the teacher as a transmitter of knowledge to the pupil as an acquirer and organiser of information. Teachers become facilitators, managers of information and reference points. Pupils become focused on finding out rather than acting as receptors of accepted knowledge.

The approach is pupil centred although in different situations varying degrees of pupil independence is involved depending on such factors as the task and the ability of the pupils. In one classroom pupils might analyse data using key questions set by the teacher whereas in another a more traditional question and answer approach might be used with the teacher working with the class to examine the data. The use of data is common to both although the mode of working differs considerably. Preferably, however, independent action on the part of pupils should be encouraged because this is more likely to promote deep rather than superficial learning.

The four Hong Kong Geography curricula profess commitment to skills development through the geography. For example, the form 1-3 curriculum has four major aims, the third of which is to develop skills basic to the study of geography. More specifically, in the Certificate of Education syllabus for forms 4 and 5 emphasis is given to the skills of asking questions, extracting information and presenting findings. Similar aims are stated in the curricula for the sixth-form and imply a geography in which pupils are actively involved in handling geographical information. Geographical enquiry needs to be central to our teaching.

Thinking like a geographer cannot occur in a vacuum. In many classes at one time or another we may have been faced with a situation where questions meet with little response. How often have we ascribed this to a combination of laziness, boredom and low ability on the part of the pupils? Are we being fair? Was it a reasonable expectation that they could give correct answers? Often it is not. The pupils sometimes have neither the concepts or the cues which will lead them to what we expect. Data based learning is a strategy which can help solve some of this problem and is means of fulfilling process or skills objectives.

Structuring Data Based Learning

There are two issues here. Firstly what are the elements which go to make a set of data based materials and secondly what framework should we use.

The four elements. Most data based learning materials start with stimulus materials which try to gain the attention of the pupils and set up the key question or issue that is going to be examined. This may take the form of a set newspaper headlines, a photograph, a cartoon, a map, a set of figures or piece of text. Out of this often will come some proposition the class will go on to look at.

The second element is usually a set of questions which will help to direct and structure the work of the pupil. It is important that these are clear and that important steps are not left out. However as pupils become more able so the questions should become more general so that the thinking of the pupils is not constrained.

Thirdly data are needed in as wide range of types as possible. These data, remember, will be the source answers for the pupil.

Finally there needs to be a summary which indicates the sort of conclusions the pupils should have reached and, most importantly, the new question that they should now think about.

Overall, the structure of elements either in a part of a set of data based materials or in the materials as a whole is:

Stimulus/General Proposition

Questions

Data

Conclusion & New Proposition

Framework. This has two dimensions, one geographical in a substantive sense, and the other cognitive concerning how we get our pupils to think about the ideas present within the data.

It is axiomatic that the structure is geographical. Geography as a discipline is distinguished by the questions it asks. The key questions are:

What is located Where?
Why is it located there and
How did this come about?
How will it change in the future?
How ought it to change?

These questions and their elaboration form the basic underlying structure for a data based work in geography.

Secondly questions need to be ordered in a way which will facilitate thinking. In general we would expect to progress from the simple, concrete, relatively known, ideas to more complex, new and abstract ideas. Early questions may expect pupils to extract either single or multiple pieces of information from the data out of which relationships can be seen that provide interpretation. These in turn may form the basis of more abstract generalisation and model building. This in essence is the SOLO (Structure of Observed Learning Outcomes) format (Biggs and Telfer, 1987). SOLO provides one way to organise a sequence of questions. The geographical questions of What-Where broadly correspond the extraction of single or multiple pieces of information; Why-How involve relational thinking and How will-How ought require abstract thinking.

SOLO is not the only way to structure materials and other developers of data based materials might like to use aspects of the Bloom taxonomy. Whatever is used, efforts should be made to structure the materials so that they progress from simpler descriptive questions to more difficult explanatory questions before necessitating pupils to think in a abstract way.

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THE HYDROLOGICAL CYCLE: AN ILLUSTRATION

Introduction

The exercise which follows illustrates data based learning in the context of the Hong Kong A Level curriculum. The hydrological cycle is a part of the study of the Landform System within Natural Landscapes. Whilst the cycle is included in most physical geography texts, the treatment is frequently only at the global scale. There is a need to understand the idea at a smaller scale and within the students' own environment. This exercise attempts to bridge this gap.

The overview of the Hong Kong 16-19 (A Level) curriculum is "man-environment". This implies a study of, on the one hand, the way in which people make use of and alter the environment in which they live; on the other it involves consideration of how the environment constrains the activities of people. The implicit assumption is that these relationships cannot be understood unless the socio-economic and physical processes, which shape the environment we inhabit, are also understood. There is, however, the risk of losing sight of the man-environment perspective. The exercise which follows tries to avoid this pitfall by starting with water as a resource and the problem of variability in supply. This leads to the need to understand the hydrological cycle. At the end we return once more to the question of water as a resource and the way man influences the hydrological cycle.

The exercise is complete in itself and offers a practical suggestion for teaching at A Level. However, this is not to say that it will necessarily fit the intentions of everyone; in which case certain sections can profitably be extracted for use. Indeed, the aim is not to provide a "textbook" but, as was stated in an earlier section, it is to provide a procedural model for a particular approach to teaching which can be adapted to individual needs. The materials comprise text, diagrams and questions with separate Resource Sheets given in the Appendix. The questions are given in bold print and serve to focus the attention of students and to help them become actively involved with the materials. We suggest that students work on these questions by themselves or in groups and that teachers use their skills in bringing together and consolidating the learning.

A Perspective on Water

Water is a resource and some of the uses which people make of water are listed on Resource Sheet 1. **Can you add any more indirect uses of water to those already listed? The Resource Sheet classifies the uses of water by man into direct and indirect. Write a short paragraph explaining the difference between indirect and direct uses?**

Resource Sheet 1 illustrates the importance of water to man. We often use water without thinking and take it for granted. However, at times there is not enough water available. Resource Sheet 2 identifies some newspaper and magazine articles which describe water shortages or droughts in Hong Kong and the Sahel area of Africa. **With reference to both Hong Kong and the Sahel, describe using the appropriate articles: (1) the cause of the drought; and (2) the effect upon man and his environment. For the Sahel, describe how man may have caused desertification.**

In addition to suffering from a shortage of water, man at times also experiences an excess of water. Resource Sheet 3 provides some newspaper accounts of too much water in Hong Kong,

Using the newspaper cuttings contained in Resource Sheet 3, explain what caused the over abundance of water in Hong Kong. Describe the effects of an excess of water on man and the physical environment in Hong Kong.

Water is a resource, but in order to be exact we should say that water is a finite resource. A finite resource is one for which there is a limited quantity available for man's use. If it is a finite resource, we need to know how much water there is and where this water is located.

The Hydrological Cycle

The total volume of water at the surface of the earth and in the surrounding atmosphere is 1,386 million cubic kilometres. This water occurs in a number of natural storage places on the earth and in the atmosphere. Resource Sheet 4 shows the volume of water found in natural storage locations, or stores. The oceans are the largest stores and they contain 96.5% of all known water. However, water in the oceans is salty as a result of the salts which are dissolved from the land. Consequently in terms of supplying water for domestic, agricultural and industrial uses, the oceans are of little value to man. As a resource, freshwater is the most valuable to man but this makes up only 3.5% of the total global water supply. Moreover, much of this freshwater is not readily available for man's consumption; for example, man cannot directly use the water stored in ice sheets, glaciers, the atmosphere or plants.

Using Resource Sheet 4, construct divided bargraphs or pie charts to illustrate the following:

(i) The total water supply of the earth and the atmosphere, and its division into saltwater and freshwater;

(ii) The volume of water in the different freshwater stores.

Write a paragraph explaining why some of the freshwater is not readily available for consumption by man.

Water is stored in a number of locations over the globe. However, water does not remain stationary in these stores, but is transferred from one store to another. Resource Sheet 5 shows the global water stores which are linked by a number of transfer processes. The movement of water between these stores gives rise to the hydrological cycle. At the world scale, this is known as the global hydrological cycle and the term is used to describe the continuous circulation of water as vapour, liquid or solid between the oceans, atmosphere and land.

The global hydrological cycle can be divided into an atmospheric segment, where water is transferred as vapour, and a land based segment, in which the liquid and solid phases dominate. The volume of water which is cycled at the global scale between the oceans, atmosphere and land based stores has been quantified and, hence, we can construct a global water balance. This is examined below.

Resource Sheet 5 presents the volume of water transferred each year around the global hydrological cycle each year. Use the figures for water movement around the global hydrological cycle and the equations below to show that:

(i) the total volume of water in the global hydrological cycle remains the same;

(ii) the total volume of water in the land based segment of the global hydrological cycle remains the same; and

(iii) the total volume of water in the oceans remains the same.

(i) The global hydrological cycle

water lost = water gained

Water evaporated + water evapotranspired from the ocean and land
__ + __cu. m.
=
Precipitation over the land and oceans
__cu. m.+ ___ cu.m.

(ii) The land based hydrological cycle

water lost = water gained

evapotranspiration + runoff = precipitation

___ cu.m + ___ cu.m = _____ cu.m

(iii) Ocean based hydrological cycle

water lost = water gained

evaporation = runoff + precipitation
____ cu.m = ___cu.m + _____ cu.m

The answer to (i) indicates that, for the global hydrological cycle, precipitation input balances the water lost by evapotranspiration. Similarly, for the oceanic and land based segments (ii and iii above), the answers indicate that water input balances water output.

In (i), (ii) and (iii), we were constructing a water balance. This is like an accounting procedure for water in the hydrological cycle. Water balances can be constructed for hydrological studies at many scales. These range from macro scale global analyses of the hydrological cycle to micro investigations of small drainage basins. The water balance can be expressed as an equation which takes the general form:

Precipitation = Evaporation + Runoff
+ or - changes in Storage

The water balance equation for the oceans, given in (iii) above, indicates that water inputs consist of precipitation and runoff. **Write a paragraph explaining the importance of rivers to the maintenance of the global hydrologic balance.**

Hydrological Processes: Precipitation

The simplified diagram of the global hydrological cycle on Resource Sheet 5 indicates that three major processes are responsible for the cycling of water at the global scale. These are: (i) precipitation, which occurs over both the oceans and the landmass; (ii) evaporation from the seas and evapotranspiration from the land and (iii) river runoff, which occurs on the land.

Precipitation is a good starting point because it transfers water from the atmospheric store to the continents and oceans.

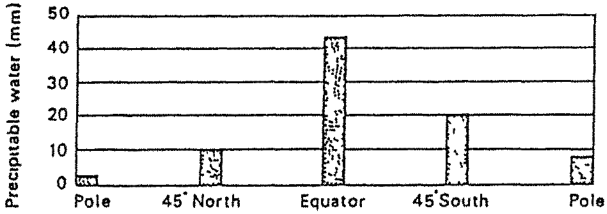
Resource Sheet 6 shows the pattern of precipitation at the surface of the earth. The distribution of precipitation over the globe is uneven. **On the map shade those areas with high precipitation (in excess of 1000mm) and those areas with low precipitation (below 250mm). Is there any pattern to the distribution of areas with high and low precipitation? Write a paragraph describing the global distribution of precipitation.**

Your answer, describing the distribution of high precipitation over the globe, should state that the rainfall is highest at the equator and on western coasts of the mid-latitudes. Precipitation is lowest at the poles and in the arid subtropical zones around 20 to 40^{o} North and South of the equator. Figure 1 contains a diagram which shows the latitudinal variation in rainfall over the globe. The simple north-south or latitudinal variation in precipitation is distorted by the continents. Resource Sheet 6 shows that most continental interior areas receive little rainfall in comparison to coastal areas of the same latitude.

Resource Sheet 6 illustrates the spatial variation of rainfall over the globe; the main feature of this is the latitudinal variation which becomes distorted over the continents. **What causes this variation of rainfall?**

Figure 1 compares the latitudinal variation of precipitation with that of the water vapour content of the atmosphere. Areas with high precipitation correspond to those with high atmospheric water vapour content. Similarly, the Polar regions, having a small amount of

(a)



(b)

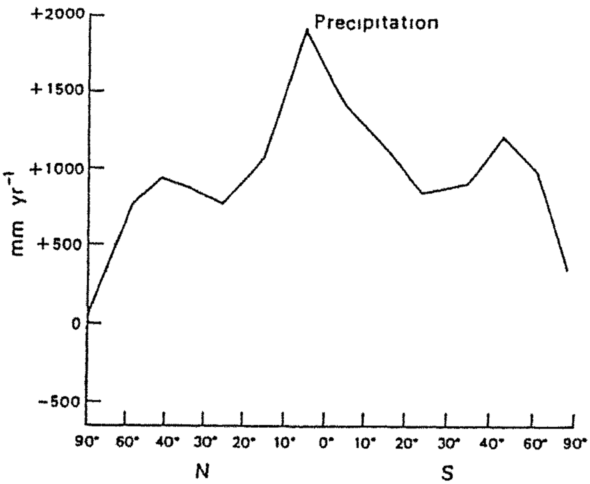
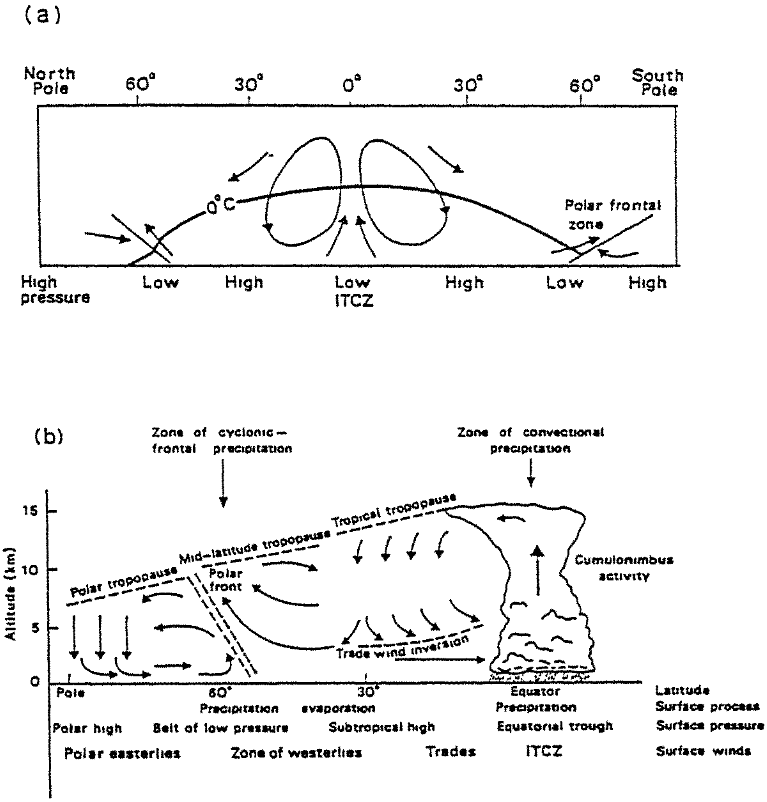


Figure 1 Latitudinal variation in:
(a) Precipitable water or water vapour in the atmosphere.
(b) Precipitation



(After Goudie, 1984)

Figure 2 (a) The general atmospheric circulation
(b) Air movement in a Hadley Cell

rainfall, coincide with areas of the atmosphere with a low water vapour content. It follows, therefore, that if we can explain the controls on atmospheric water vapour content, we can explain latitudinal variation in precipitation.

The primary source for moisture in the atmosphere is the subtropical, particularly oceanic, regions where evaporation proceeds continuously. The moisture from this area is transported, by the global circulation of the atmospheric to regions where uplift of the moist air occurs.

The location of this zone of uplift and its association with the general circulation of the atmosphere is shown in Figure 2. This shows that a Hadley Cell exists in the both hemispheres. In each of these cells the motion consists of air moving in towards the equatorial low pressure belt. The air moving towards the equator is heated principally over the landmass and this results in the warmed air rising at the equator. It is the rising air associated with equatorial limbs of the two Hadley Cells which leads to the term Intertropical Convergence Zone. Once aloft the warmed air moves poleward before sinking at higher latitudes where, once at the earth's surface, part of the by now cold air resumes its journey back towards the equator. The Hadley Cell is a thermically direct cell because air which is heated rises and, when cooled, sinks.

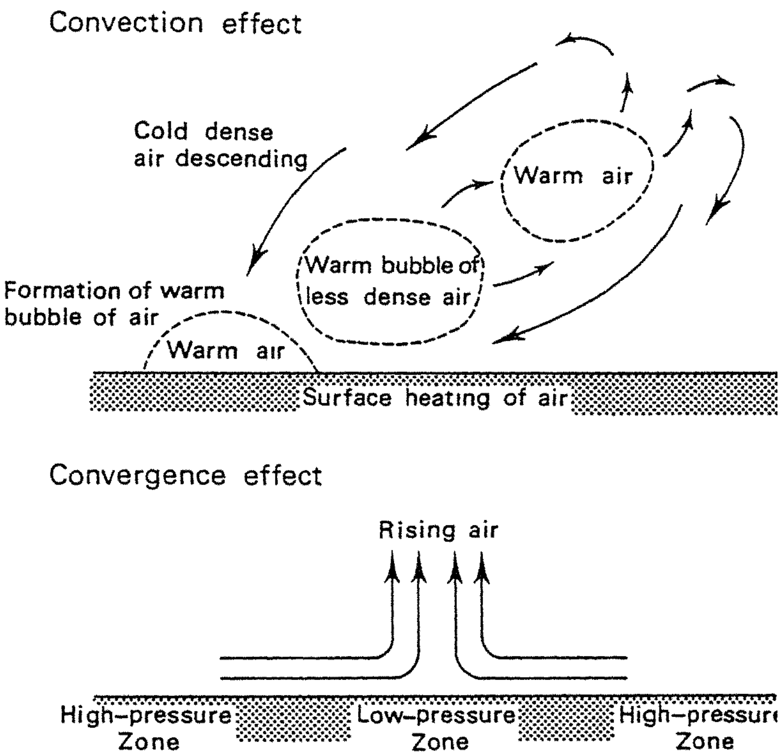
The importance of the Hadley Cell is that it transfer heat energy from the equator towards the polar latitudes.

Figures 3a and 3b explain convergence and convection. Using an atlas maps of surface winds and air temperature, explain why convergence and convection cause air to rise at the equator.

Uplift of moist air and hence precipitation also occurs in the migratory cyclones or depressions found in the mid-latitudes (40^{o} to 60^{o} N or S). These low pressure systems, moving from west to east, can give rise to moderate levels of precipitation over considerable areas. Figure 4 presents a model of the motion of air in a depression with the consequent mixing of air, cooling and precipitation.

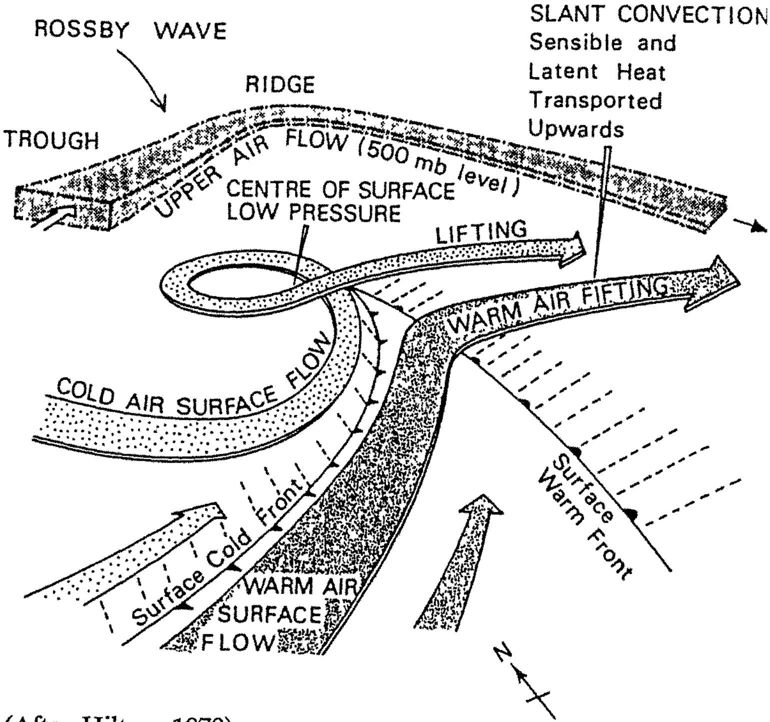
A final source of uplift is topography. Orographic or relief rainfall is generated when moist air is forced to rise over a mountain chain or range of hills.

Resource Sheet 7 presents a model illustrating the development of orographic rainfall. **Describe the orographic model of precipitation and explain why rainfall is less on the lee slope.** In some places in the middle latitudes the effect of topography often enhances precipitation. **Using an atlas maps of surface winds, topography**



(After Ferguson and Clark, 1984)

Figure 3 (a) Convergence effect
(b) Convection effect



(After Hilton, 1979)

Figure 4 Rainfall generation in a depression

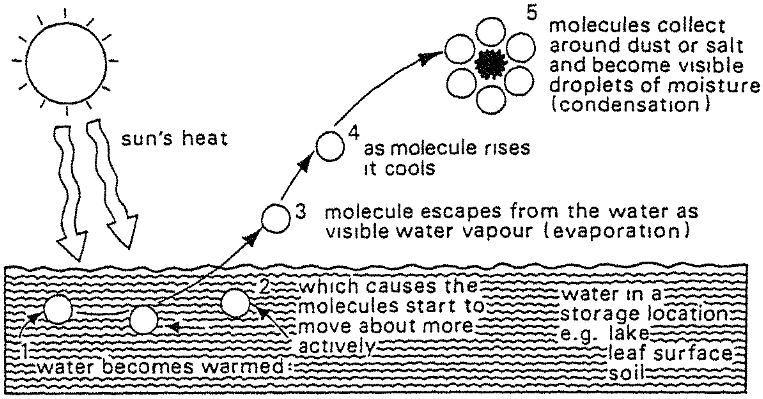
and global precipitation, make a list of examples where relief may cause an increase in precipitation. For one your examples, draw a sketch map showing the direction of onshore winds, relief and the spatial variation in rainfall.

The latitudinal zonation of precipitation, which has been discussed earlier, can be explained as follows. The tropical high in precipitation is caused by the convergence and convective uplift of air associated with the ITCZ or Hadley Cell. Polewards of this zone in the sub-tropics, there is an area of relatively low rainfall. This is caused by the subsiding air associated with the Hadley Cell. Figure 2 shows the general circulation of the atmosphere and the location of the Hadley Cells. The secondary high of precipitation which occurs in the middle latitudes and is caused by frontal rainfall associated with easterly travelling depressions. The effect of topography often acts to concentrate frontal rainfall on the west coast of continents in the middle latitudes and this can distort the simple latitudinal model of rainfall distribution.

Other factors which cause the distortion of the latitudinal model of rainfall variation include the effect of the size of the continents, i.e. continentallity, and the juxtaposition of land and sea. Much of the water vapour, which provides precipitation over the land, comes from the oceans. If we consider a large landmass, such as the Eurasian or North American continents, the prevailing onshore winds often lose much of their water vapour by precipitation near the coast. This is especially so if topography provides a trigger for uplift as in N.W.Europe and in S.E.Asia. In consequence, regions in the interior will in effect be in a rain shadow of the coastal areas. Precipitation will be comparatively low inland because the coastal areas will have "drained" the onshore winds of much of their moisture. For large continental areas, therefore, distance from the ocean, and hence moisture supply, along with the prevailing wind direction, affects the amount of precipitation received.

Resource Sheet 8 shows the location of several towns which are approximately on the same latitude across the Eurasian landmass. **Using the data provided construct a bar graph showing the rainfall at each town. Plot a scattergram of rainfall against distance from the Atlantic Ocean. Describe the relationship between rainfall and distance from the ocean. For the North American continent, use an atlas to determine if rainfall varies with distance from the Pacific Coast. Construct a diagram like that on Resource Sheet 8 and draw a scattergram of rainfall against distance from the ocean.**

The juxtaposition of land and sea, with their differences in



(After Ferguson and Clark, 1984)

Figure 5 The process of evaporation

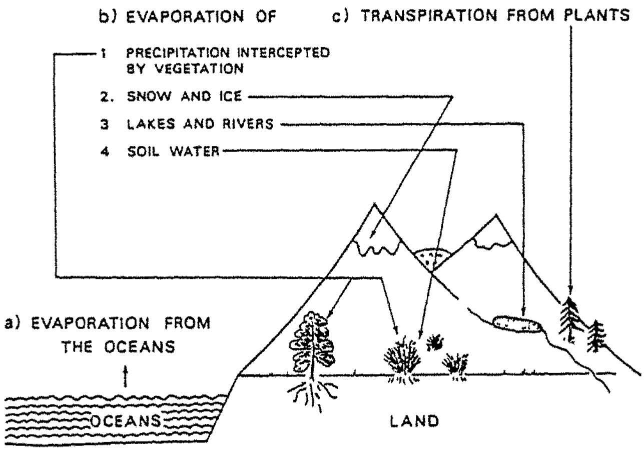


Figure 6 Sources of water for evaporation and evapotranspiration

heating and cooling, can cause a further distortion of the latitudinal variation in precipitation. In the tropics the latitudinal model of rainfall distribution reveals a dip in amount of precipitation. Moreover, this is a spatial average and it hides the fact that, while some areas of the sub-tropics have very low rainfall, others have high levels of precipitation.

Hydrological Processes: Evapotranspiration

Evaporation and evapotranspiration are important processes in the global hydrological cycle because they transfer water, in the form of water vapour, from the oceans and the continents to the atmosphere. Figure 6 shows how the process of evaporation occurs while Figure 7 illustrate the sources of water for the process. On land, where plants grow, an additional process, transpiration, operates to transfer water from the soil and plants to the air.

Transpiration is the process by which water is taken up by plants through their roots, is transported up through the xylem and released, as vapour, through the stomata in the plant leaves. Plants use this water to transport the nutrients which they require for growth, for cooling and in the process of photosynthesis.

Over the oceans, evaporation is the only process which transfers water vapour to the atmosphere. However, on land where there are plants both evaporation and transpiration transfer water to the atmosphere. For the continents the water transferred to the atmosphere by evaporation and transpiration is often referred to as that provided by evapotranspiration. The difference in processes at work on land and sea is clarified in Figure 7.

Oceans	Continents	
No plants	Plants	
Evaporation	Evaporation + Transpiration	Evaporation

Figure 7 Mechanisms of water vapour transfer

Resource Sheet 9 shows the spatial variation of evaporation and evapotranspiration over the globe. The map showing the global pattern of evaporation reveals that, in general, the oceans have higher evaporation losses than the land. **Write a paragraph explaining evaporation is sometimes higher over the oceans than the continents. On the map of evaporation and evapotranspiration in Resource Sheet 9 shade areas with low evaporation and evapotranspiration rates (less than 600mm in the case of the oceans and 300mm in the case of the land). Using a different colour similarly shade areas with high evaporation and evapotranspiration (over 2000mm for the oceans and over 600mm for the land). Describe the distribution of areas of high and low evaporation/evapotranspiration.**

The volume of water evaporated and transpired depends on many factors. For example, it depends upon a supply of energy. Evaporation involves the conversion of water from liquid to vapour and this requires an input of energy This energy comes from the sun. Transpiration also needs energy and is again related to radiation receipt.

Figures 8 and 9a shows the latitudinal variation of solar radiation receipt at the earth's surface. The highest level is located around latitude 20^o because these areas are cloud free. From there, radiation received declines towards the equator and the poles. The equatorial region receives less solar radiation because of the cloud cover in this zone (Figure 8b); this reflects much of the solar radiation back into the atmosphere.

This poleward decline in solar radiation receipt is due to three factors:

(i) On an annual basis, the sun's rays strike the earth at an increasingly oblique angle as one moves poleward from the equator. Compared to the Tropics, the same amount of radiation is spread over a larger surface area and input per unit area is reduced (Figure 10).

(ii) In the middle latitudes, depressions generate considerable cloud cover which reduces radiation receipt near the equator.
Figure 10 also shows that the sun's rays, when at an oblique angle to the earth, travel a greater distance through the atmosphere, and less solar radiation reaches the earth's surface through scattering, reflection and absorption.

(iii) As shown in Figure 8b, polar latitudes have significant cloud cover which further reduces radiation receipt and hence evapotranspiration in these latitudes.

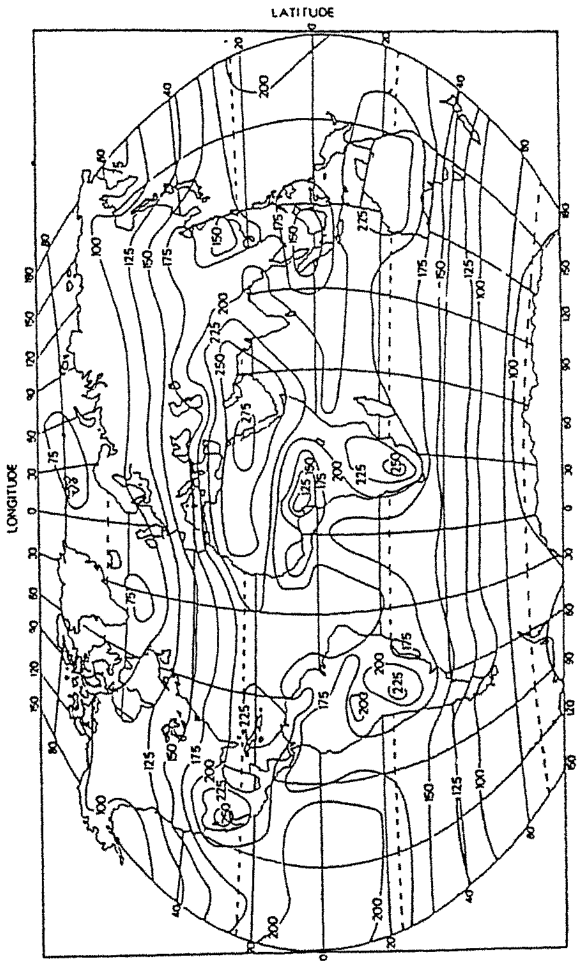


Figure 8 Average annual solar radiation W per sq.m. (after Sellers, 1965)

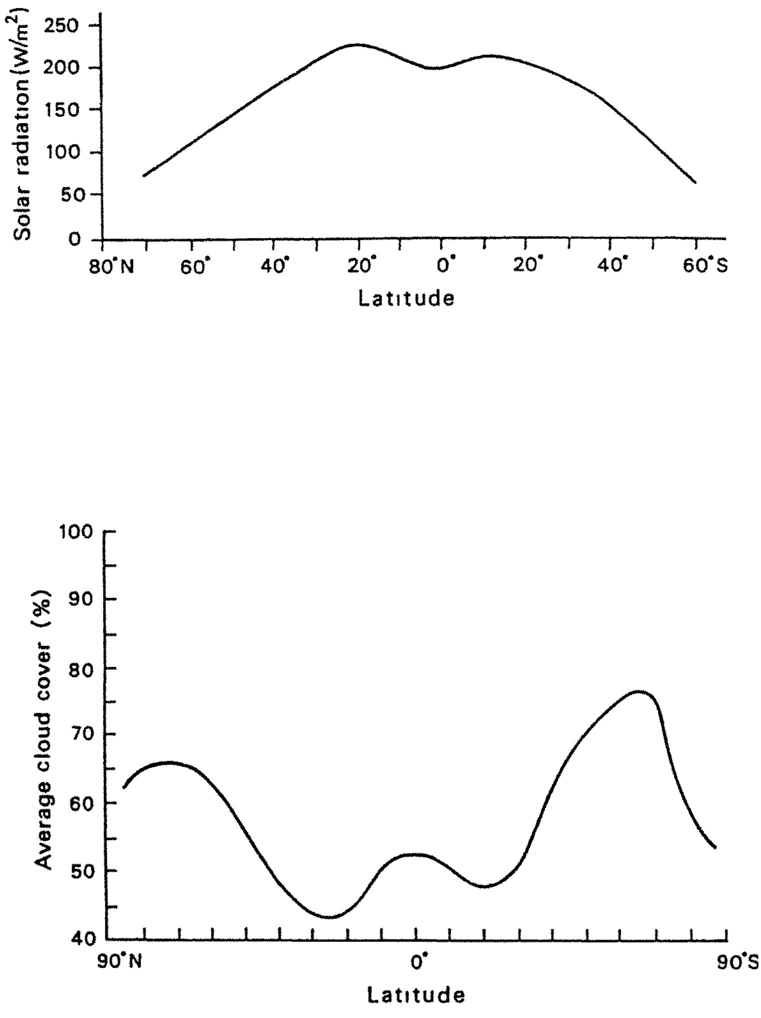


Figure 9 Latitudinal variation in (a) solar radiation receipt and (b) cloud cover

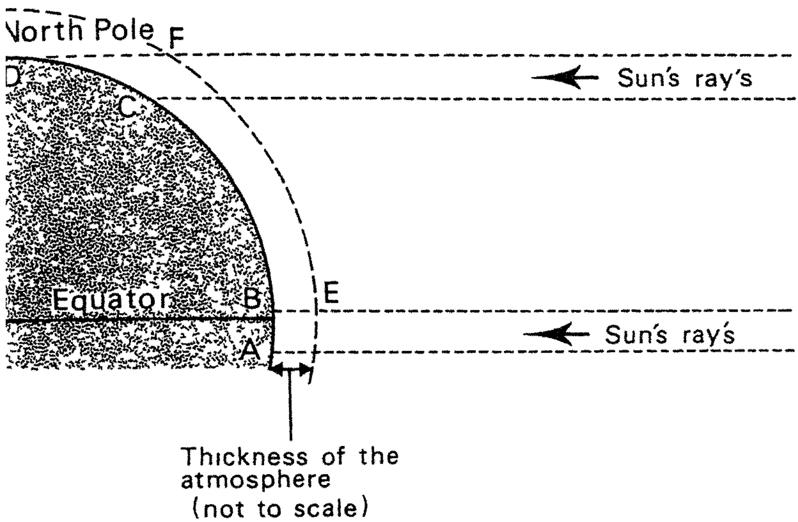


Figure 10 The relationship between latitude and solar energy receipt per unit area

Other things being equal, the greater the receipt of solar radiation the more water will be evaporated and transpired. **Using the map of global evaporation and evapotranspiration rates from Resource Sheet 9 and Figure 8, which describes the global variation in solar radiation receipt, describe the relationship between solar radiation and evaporation/evapotranspiration.**

An additional important factor affecting evaporation and transpiration is the availability of water. If water is freely available, the rate of evaporation will be governed solely by the meteorological conditions controlling the removal of water. This is always the situation over oceans, lakes and reservoirs. On land, however, water is not always readily available. This is because sometimes, due to extended drought, there is very little moisture in the soil. Because of this shortage, evaporation cannot proceed at the rate permitted by the meteorological conditions.

Transpiration is also dependent upon a water supply. Plants will only permit the maximum rate of transpiration (i.e. that governed or allowed by meteorological conditions) provided there is a ready supply of water. If there is little water in the soil because of, for example, drought, plants close their stomata and restrict the emission of water vapour. Consequently, transpiration does not always take place at the maximum rate permitted by the prevailing meteorological conditions. For example, during the dry winters in Hong Kong, transpiration is markedly reduced. We should expect that evaporation and evapotranspiration on land will be less when compared to evaporation from the oceans where water is always readily available. **Using the map of global evaporation and evapotranspiration on Resource Sheet 9, describe the evidence which suggests that the availability of water may affect evaporation and evapotranspiration.**

Evaporation and transpiration is also dependent upon a change of moisture content, or gradient, between the surface from which evaporation takes place and the air above. Water vapour moves from areas of high moisture content to those with a low level of water vapour. In consequence, if the layer of air overlying the surface from which evaporation is taking place becomes saturated with water, evaporation and transpiration will cease. In order for evaporation and transpiration to proceed efficiently, there must be a layer of air with little moisture over the surface from which evaporation is taking place. A moisture gradient can be maintained by the existence of a breeze or wind, which serves to remove the saturated air from evaporative surfaces and leaves, and which replaces it with dry unsaturated air.

At the global scale high evaporation and evapotranspiration is associated with well developed air movement and therefore shows some relationship with the global wind system (see Resource Sheet 10). **Using data from Resource Sheets 9 and 10, write a paragraph describing the relationship between evaporation/evapotranspiration and the global wind system.**

Hydrological Processes: Runoff

The final major transfer process in the global hydrological cycle is runoff. This is confined to the land based portion of the hydrological cycle.

Explain how the process of runoff varies in relation to the spatial pattern of precipitation and evaporation/evapotranspiration and to the other major processes of the global hydrological system. Resource Sheet 11 illustrates the annual average runoff over the continents. On the map, shade those areas with high runoff (over

1000mm of runoff) and, in a different colour, those areas with low runoff (0mm). Describe any regularity you can see in the occurrence of high and low runoff. For example, is their any evidence of latitudinal variation?

For land areas the water balance equation can be written as follows:

Precipitation = Evapotranspiration + Runoff
+ or - changes in storage

Rearranging the equation, we find that river runoff is a function of evapotranspiration and rainfall and the water balance equation becomes:

Runoff = Precipitation - Evapotranspiration
+ or - changes in storage

Using this water balance equation and Resource Sheet 12 which shows the latitudinal variation in runoff, precipitation and evaporation, complete the following laws of runoff generation by deleting the incorrect term.

The Laws of Runoff Generation:
(1) When precipitation exceeds evaporation, river runoff will/ will not occur.
(2) If evaporation exceeds precipitation there will/will not be river runoff.

Resource Sheet 12 shows the globally averaged latitudinal variation in precipitation, evaporation and runoff. **With reference to Resource Sheet 12 describe the latitudes at which surface runoff occurs. Explain why these latitudes have runoff.**

The latitudinal variation of runoff shown in Resource Sheet 12 is a global average. Between latitudes 10° to 35° north, runoff is absent because evaporation exceeds precipitation. However, there are important exceptions to this generalisation. Resource Sheet 11, showing annual average runoff, reveals that some regions located between latitudes 10° and 35° north have large volumes of surface runoff. **With reference to Resource Sheet 11, which areas between these latitudes have high runoff. Using the material from earlier sections which describes global precipitation and evaporation to explain why these areas have large volumes of surface runoff.**

Smaller Scale Variations

Thus far we have looked at the global hydrological cycle. The spatial variation of precipitation, evaporation and river runoff has been described at the global or macro scale. While this large scale investigation is valuable, water as a resource, is most important in the form of freshwater. Freshwater occurs in the atmosphere, on the land surface and within rocks near the surface. If we think of water as a resource, we need to examine its distribution on the continental areas in more detail.

Given that in general individual countries supply their own water, it would seem important to look at the controls on the natural distribution of water within any given political unit. Two such territories, China and Hong Kong, will be used in the next section to examine and illustrate the factors controlling the distribution of water at this scale.

China

Resource Sheet 13 presents a simplified map of annual precipitation in China. **Describe the spatial pattern of precipitation in China. Read the following passage and annotate an outline map of China to illustrate the factors affecting the distribution of annual rainfall.**

The distribution of precipitation in China is uneven. Given the vast size and the varied topography, this is to be expected. In general, the annual precipitation decreases from the south-east to the north-west and with increasing distance from the ocean. This can be discerned from the way that the isohyets (lines joining points with equal precipitation) run parallel to the coast. The regions with the greatest annual rainfall are the coastal hills and mountains which experience 1500 to 2000mm per year. Some of the highest mountains, such as those in Taiwan, receive in excess of 3000mm of rain. In contrast, the central basins of the eastern Tarim and Turfan receive less than 50mm of precipitation each year.

Many regions in China derive their precipitation from the S.E. Monsoon. The atmospheric circulation associated with the S.E. Monsoon brings moist warm air to the land area from the sea. Most of the water is precipitated in the coastal regions and so the mountain enclosed basins of central China receive very small amounts of precipitation because there is little moisture left in the atmosphere.

A further factor which gives rise to high levels of precipitation

in coastal China is the occasional occurrence of typhoons. These mainly develop between June and October in the north Pacific when the S.E. Monsoon is blowing. Typhoons give rise to large amounts of rain as they move over the land from the sea. However, because they dissipate as they move inland because their supply of energy is cut off, there is only heavy precipitation near the coast.

If we consider a second major transfer process in the hydrological cycle, namely evaporation, then this too exhibits spatial variation within China.

Resource Sheet 14 presents a map showing the spatial variation of evaporation in China. **Describe the spatial variation in evaporation. Maps of solar radiation receipt, precipitation are also provided in Resource Sheet 14, use these to explain the spatial variation in evaporation you have just described.**

Precipitation and evaporation exhibit considerable spatial variation within China. If we remember the modified form of the water balance equation (runoff equals precipitation minus evaporation) then it should come as no surprise that runoff also varies spatially in China. **Using Resource Sheets 13 and 14, which show the variation of precipitation and evaporation in China, shade on an outline map of China those areas where you would expect a large volume of surface runoff. Using a different colour, shade those areas where you would expect little runoff. Explain why you selected some areas as having high runoff and other areas as experiencing low runoff.**

Resource Sheet 15 contains a map showing the distribution of runoff in China. **Examine Resource Sheet 15 and compare this with the areas you have identified within China as experiencing low and high runoff. Do your areas of high and low runoff compare with those on Resource Sheet 15? If not, state why there is a difference.**

A cross-section through China which shows precipitation, evaporation and runoff is given in Resource Sheet 16. **Using Resource Sheet 16 explain:**

(1) why in general runoff decreases with distance from the coast;

(2) why there are secondary peaks of runoff which distort the overall decline in runoff as you move inland; and

(3) why, in some areas, evaporation decreases despite an increase in precipitation.

On your cross-section, mark at least one region which is in a rainshadow.

Hong Kong

Much less information is available the variation of precipitation, evaporation and runoff in Hong Kong. Of the three major transfer processes in the hydrological cycle for Hong Kong, precipitation is the only one for which a map exists.

Resource Sheet 17 presents a map of the annual rainfall in Hong Kong. **Describe the spatial variation in precipitation. Because of its location most rainfall in Hong Kong is brought by westerly or southerly winds; explain why is this so.** In general nearly one quarter of the rainfall in Hong kong is caused by tropical cyclones. Resource Sheet 18 presents annual rainfall data and the altitude of a number of measurement stations in the territory. **Using graph paper, construct a scattergram of rainfall against altitude. Describe the relationship between rainfall and height above sea level in Hong Kong which is revealed by the scattergram. Using this plot and Resource Sheet 17, explain the spatial pattern of rainfall in Hong Kong.**

Unfortunately there is no data which permits us to draw maps of either spatial variation of evapotranspiration or runoff in Hong Kong. However, we can illustrate the spatial variation in runoff using data collected for a number of small drainage basins. Resource Sheet 18 contains data on the runoff from nine drainage basins. The units used are mm per year; this measure has been used because it allows direct comparison of the drainage basins. This is because in order to calculate runoff in mm per year we must divide the runoff by the catchment area, so in effect we are holding catchment area constant. In consequence, we are comparing like with like which is important in geographical studies.

Using the data in Resource Sheet 18, rank the runoff from the highest to the lowest. Determine the range of runoff shown by the nine drainage basins. Calculate how many times greater is the highest value of runoff in comparison to the lowest. Describe and attempt to explain the spatial variation illustrated by the data.

Temporal Variations:A Matter of Reliability

So far we have concentrated upon the spatial variation of precipitation, evaporation and runoff. In addition to varying in space, these transfer processes also vary with time. In terms of a resource, it can be argues that reliability of rainfall and river discharge is just as important as amount or volume.

Resource Sheet 19 presents a map showing the reliability of rainfall at the global scale **Describe the variability which is shown.** Figure 11 shows the hypothetical relationship between reliability of rainfall and the amount of rainfall. It can be seen from Figure 11 that, as rainfall increases, so does the reliability. **Using the map of global rainfall in Resource Sheet 6 and that showing variability of precipitation in Resource Sheet 19, discuss if the relationship between rainfall amount and rainfall reliability applies at the global scale.**

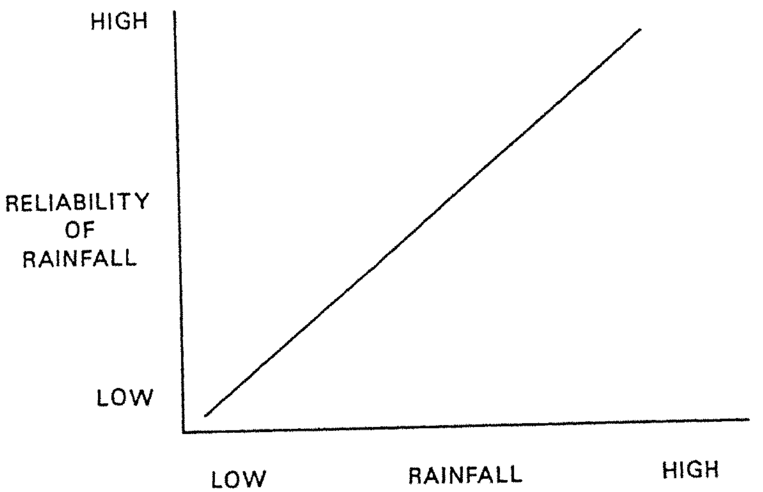


Figure 11 The hypothetical relationship between rainfall amount and reliability

The significance to man of temporal variations in rainfall and runoff can be illustrated by looking at the Sahel region of Africa Resource Sheet 20 presents diagrams showing the long term variation of rainfall and runoff in this region The diagram on variation of precipitation reveals that two periods of extremely low rainfall have occurred in this region.

From the diagram, when were these two time periods of low rainfall? What terms best describe the consequences of these periods of low rainfall. Have there been other, less dramatic, periods of drought? The second diagram on Resource Sheet 20 plots variation of runoff of the river Dire in Mali, which is a country in the Sahel. Does the fluctuation in runoff show any similarity to that of precipitation?

Your examination of rainfall and runoff for the Sahel should have revealed that both rainfall and runoff exhibit long term fluctuations. Runoff variation is a response to the changes in precipitation. In the Sahel region the population suffered greatly because of the recent drought. The problems were probably made much worse by the preceding period of high rainfall and runoff. These encouraged an expansion of livestock numbers and a change in agricultural practices which could not be sustained in the long term.

Hong Kong also experiences fluctuations in rainfall which cause problems for water supply in the territory. Resource Sheet 21a shows the annual rainfall recorded at the Royal Observatory between 1951 and 1985.

Resource Sheet 21b shows restrictions in water supply during the period. Do those periods coincide with years of below average rainfall? If not what other factors affect water supply. Using Resource Sheet 21b, explain why water needs to be stored in reservoirs to maintain the water supply in Hong Kong. Suggest why, despite the existence of these reservoirs a full supply of water cannot always be maintained.

Hong Kong has no major ground-water reserves. The water used in the territory is either from surface runoff, collected in water gathering grounds and fed by means of catchwaters, tunnels and natural streams into reservoirs, or from water piped in from China.

Resource Sheet 22 contains a graph of the mean monthly precipitation recorded at the Royal Observatory. **Using this data, explain why it is necessary to store water in reservoirs to maintain water supply in Hong Kong.**

The Hydrological Cycle and Resources

Water is a finite resource and at this stage you should now be aware that:

1. The world's water resources are located in a number of natural stores and water is continually being cycled between these stores.

2. Rivers transfer runoff from the land to the oceans and this is important because it means that the potential deficit of water in the oceans, caused by an excess of evaporation over precipitation, is avoided. This transfer of excess water from the continental areas by rivers maintains the global water balance.

3. The processes acting to cycle the water which generates the global water cycle are: precipitation, condensation, evaporation, transpiration and runoff in rivers.

4. Precipitation, evaporation, transpiration and runoff in rivers vary spatially and vary with the environmental conditions.

5. The spatial variation in China and Hong Kong illustrate the impact of these environmental controls.

6. The hydrological processes of precipitation, evaporation and runoff also vary over time. This has important implications for water as a resource.

The Drainage Basin as a Unit Study

The study of water so far has been at the macro scale and has shown that it is water on the land which is most important as a resource. Furthermore, it is the volume of precipitation and its reliability which in part govern the availability of water to people.

At this point we need to know more about how the precipitation input forms either groundwater or stream flow both of which form a store of water which is useful to people. To do this it is necessary to adopt a smaller scale of study, the drainage basin.

The drainage basin is commonly used as a physical unit of investigation in hydrological studies. It can be defined as an area that supplies water to a drainage system which consists of a number of streams and rivers. It is separated from its neighbours by a divide or watershed which is often formed by hills or mountains (Figure 12).

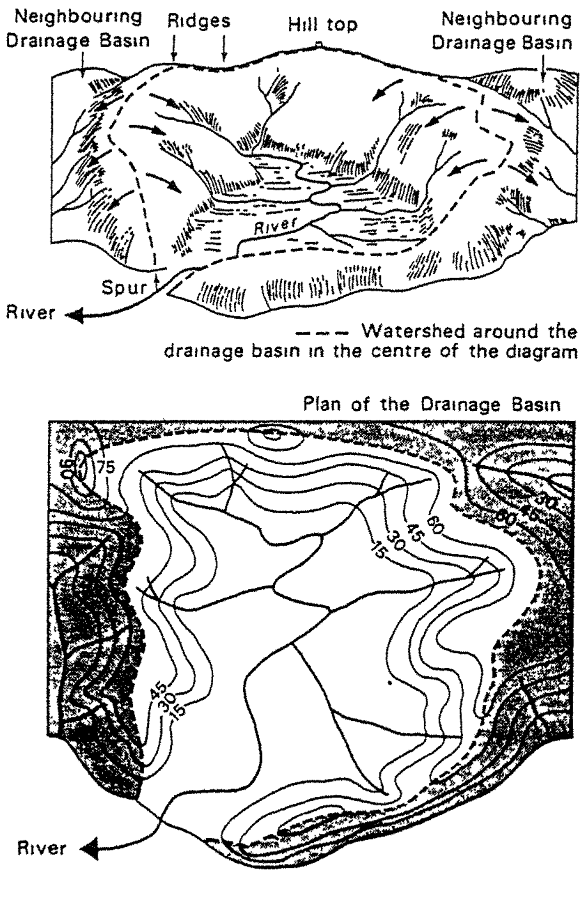


Figure 12 Drainage basin, catchment and watershed

An alternative name for a drainage basin is a catchment. This name may be derived from the fact that an area enclosed by a divide or watershed "catches" the rain fall in that area.

Resource Sheet 23 illustrates diagrammatically the delimitation of a drainage basin. Also shown are the lowest points of the of two other drainage basins in Hong Kong. The site at which water discharge or streamflow is measured marks the lowest point of the drainage basin. **For the two catchments in Resource Sheet 23 and using the appropriate topographic maps, mark the watersheds and determine the catchment area. Do the small catchment first. What were the probin delimiting the two drainage basins.**

We can look at how rainfall becomes available to people by using the drainage basin as the unit of study and evaluating the water balance equation of the catchment. This takes the form:

River flow = Precipitation - Evapotranspiration
+ or - changes in storage

Before we can evaluate this equation for our drainage basin, we must be certain that the catchment is "watertight". By this it is meant that only rainfall falling within the drainage basin provides input. There are two alternative sources of water input for drainage basins: (i) groundwater from adjacent catchments and (ii) catchwaters or rivers which is diverted to flow into adjacent drainage basins. A further requirement for a catchment to be watertight is that all the precipitation input must leave the basin either by evapotranspiration and streamflow, or be stored in the soil or rock. These factors can be evaluated and a water balance constructed. However, if water is transferred out of the drainage basin either by groundwater or flow within the soil, there will be an error. Similarly if man transfers water out of the basin for use in towns, this will also cause an error in the water balance. Errors also occur because it is difficult to quantify these transfer processes. For example, it is not easy to check for groundwater transfer from a drainage basin.

Using the two drainage basins shown in Resource Sheet 23 comment upon their suitability for use in a hydrologic study?

Data from drainage basins in Hong Kong will be used to examine the functioning of the hydrologic cycle. Resource Sheet 24 shows that the volume of runoff from 10 catchments in Hong Kong varies according to the area of the basin.

To confirm this, plot a scattergraph of runoff (in thousands of cubic metres) against catchment area.

The scattergraph shows that, other things being equal, as catchment area increases so does the volume of runoff produced. The number of points used to construct our scattergraph is small. If we use data from elsewhere, we can obtain more data points. Resource Sheet 25 presents catchment areas and runoff in millions of cubic metres ($m^3 \times 10^6$) for 25 U.K. basins.

Construct a scattergraph to show the association between catchment area and runoff and describe this relationship. Does it confirm our findings for Hong Kong?

If we are to contrast the functioning of the hydrologic cycle between drainage basins, ww must hold constant the effect of catchment area. We did this earlier by converting the volume of runoff to mm. Resource Sheet 24 tells us that the volume of runoff in mm produced during the water year 1981-1982 ranges from a low of 672mm at LO SHU LING to a high of 3134mm at the Yuen Long Flood channel. As these values are independent of catchment area and are for the same year, we might expect identical values of runoff. However, the natural environment is complex and many other factors affect the production of runoffsome of which are shown in Figure 13. The factors in Figure 13 can be classified into climatic and catchment characteristics. **Classify the factors shown in Figure 13.**

The transformation of precipitation into streamflow can be looked at using the systems approach. The drainage basin hydrological cycle is shown in the form of a system in Figure 14. This 14 shows that precipitation, before it can become streamflow, must pass through a number of stores by a variety of transfer processes. **List the transfer processes and write definitions for each term.** Figure 14 also indicates that not all precipitation becomes runoff. **What are the other possible outputs of water from a drainage basin? Is all the precipitation released as streamflow?**

The variability of runoff production from drainage basins in Hong Kong has been illustrated in Resource Sheet 24. What are the reasons for this variation in streamflow in Hong Kong. Other things being equal the basin with the highest rainfall will generate the highest volume of streamflow.

We can test this hypothesis by constructing a scattergraph showing rainfall and runoff for the catchments. Resource Sheet 24 presents data for rainfall and runoff for basins in Hong Kong. Construct a scattergraph showing the relationship between the two variables, remembering to use runoff in mm.

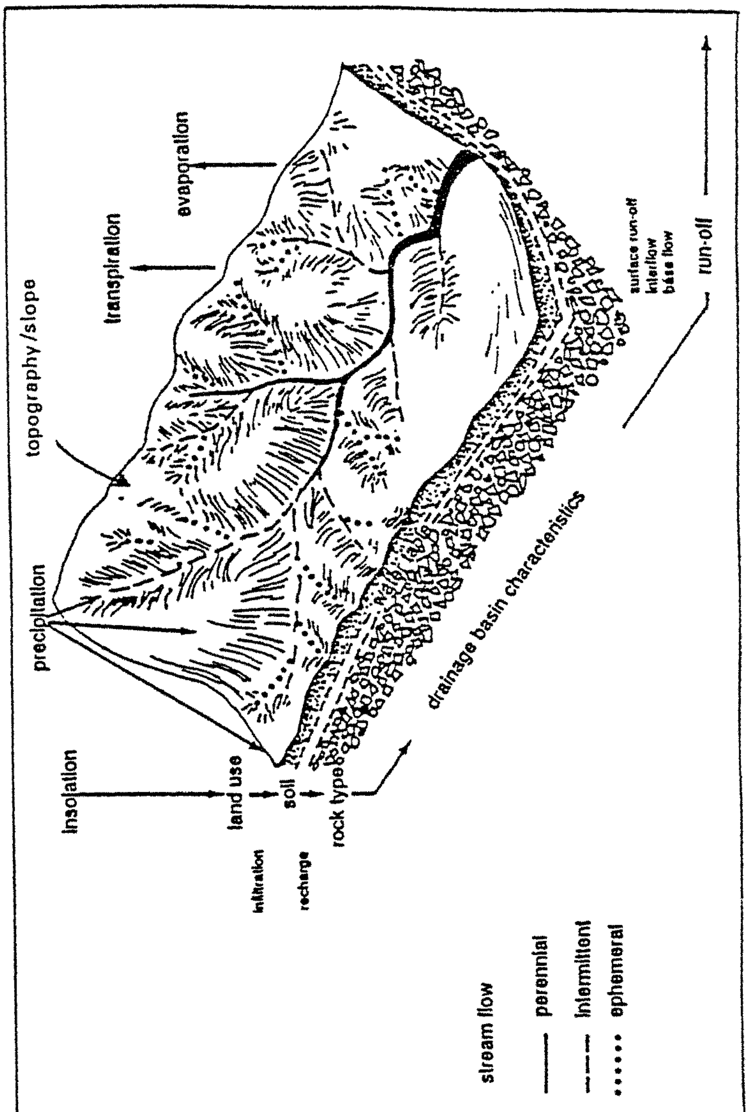
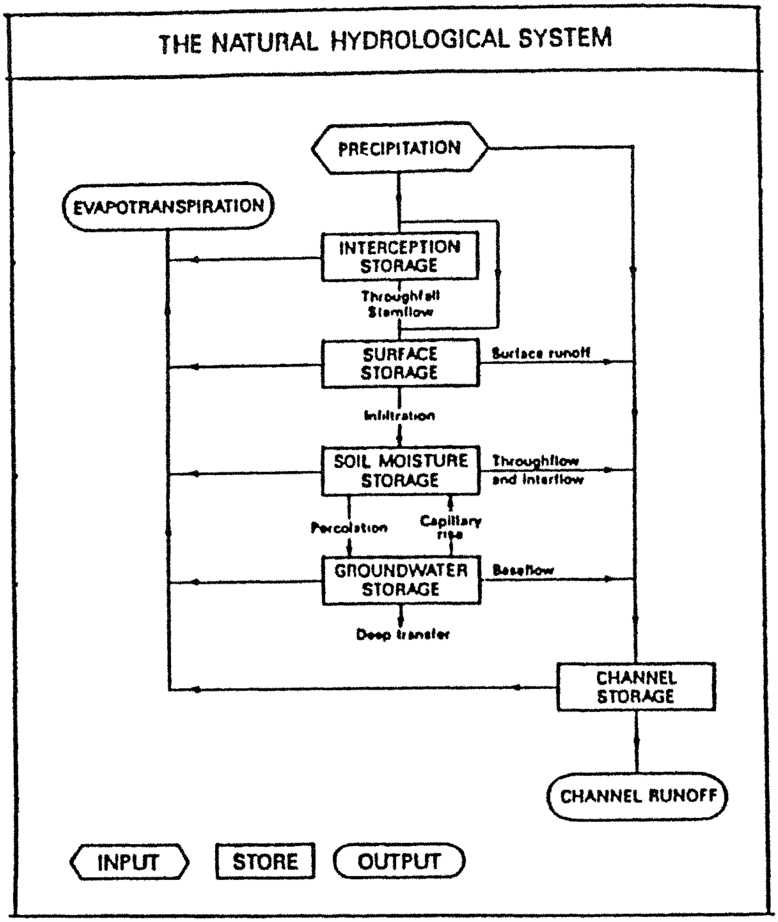


Figure 13 Factors affecting the volume of runoff in a drainage basin



(After Walling, 1979)

Figure 14 The natural hydrological system

The scattergraph tells you that as rainfall increases so the volume of runoff produced rises. The relationship is not perfect; the points do not form a single line, but are scattered about a general trend. The scattergraph tells us that, although precipitation exerts an influence over amount of runoff, it is not the only control. If this were so, all the points would lie on a single line with no scatter.

The number of data points available to analyse rainfall and runoff in Hong Kong is small. We can confirm our comments about rainfall not being the only control, if we use a bigger data base. Resource Sheet 25 presents rainfall and runoff data in mm for 25 basins in the U.K.

Construct a scattergraph of rainfall against runoff and describe the relationship between the two variables. Does it confirm our findings for Hong Kong? Using Figures 13 and 14 suggest what other factors might govern the volume of runoff produced by rainfall?

Those factors in Figure 13 which you classified as affecting runoff production may explain the scatter in the rainfall-runoff scattergraph for Hong Kong and Great Britain

Vegetation and land use is an important catchment characteristic affecting the conversion of rainfall to runoff. Plants affect the volume of runoff produced by a drainage basin in two ways:

1. They intercept precipitation, some of which is then transferred back to the atmosphere by evaporation.
2. Plants use water for growth and roots draw up a continuous supply from the soil in response to that lost through the stomata of leaves. The movement of water from roots to leaves and subsequent loss by evaporation from the plant surface is known as transpiration. Let us now look at these processes in a little more detail.

Precipitation upon reaching many parts of the earth's surface meets a layer of vegetation. The vegetation canopy catches, or intercepts, some of the precipitation, while a portion, depending on the vegetation type, density, etc, passes through the canopy to the ground. Some of the intercepted water eventually reaches the ground by either leaf drip or stemflow. A further portion of the intercepted water is evaporated back to the atmosphere. Catchments in which the vegetation intercepts most rainfall and have high evaporative losses from this store will have a lower volume of runoff than drainage basins in which vegetation intercepts less precipitation, all other things being equal. Resource Sheet 26 presents some typical interception values in terms of percent of rainfall evaporated as opposed to reaching the ground for a number of vegetation types.

Write a paragraph describing the variation in interception between the vegetation types and also account for the variation? It may help you to know that some grasses have a leaf area to ground area ratio approaching that of trees.

The contrasting interception losses between plant types are caused by a number of factors. Coniferous vegetation intercepts more precipitation than deciduous trees because (1) they retain their leaves all year, unlike deciduous trees which shed their leaves in winter, and (2) the needle like leaves of conifers hold intercepted water move efficiently than deciduous vegetation and conifers have a greater storage capacity in the canopy. Some grasses have quite high interception levels because, in places, they form a dense vegetation with a similar leaf area to ground area ratio to that of trees. The interception levels for the tropical forest are intermediate between conifers and deciduous trees because, although the numerous vegetation layers in some tropical forests provide a large leaf surface area for storage, the leaves are not as efficient as conifers in holding the water. Furthermore, the intense nature of the rainfall in some tropical areas is such that the rain drops bounce off the leaf surface. The rain drops fall with such momentum because of their size, that they are not held by the plant.

The second way that plants reduce the amount of streamflow is through transpiration. Resource Sheet 27 presents the results of a study of the hydrologic cycle in a small catchment in England. The input of precipitation remained the same as did all the drainage basin characteristics except for vegetation. The investigation was run four times, each with a different type of vegetation covering the catchment. **From the data presented in Resource Sheet 27 describe which vegetative cover transpired most water vapour. Account for the variation.**

The contrasts between the pine and the oak can be explained by the fact that coniferous trees retain their leaves and thus can transpire water all year. In contrast, the deciduous oak, sheds it's leaves, is dormant, and does not transpire in winter. Therefore, although conifers and deciduous trees have similar rates of transpiration when in leaf, there is a considerable difference in the volume of water transpired on an annual basis. Wheat transpires the least because it has a short life cycle in comparison to the other types of vegetation, being planted in spring and harvested in the summer; it has a life cycle of only 180 days compared to 365 days in conifers.

Grass has a similar transpiration rate to the coniferous pine and this reflects it's relatively large leaf area and the fact that it retains it's foliage, or leaves, all the year.

Resource Sheet 27 also presents results for interception losses along with evaporation from the soil. These results confirm some of the findings you observed from Resource Sheet 26. For example, pine, an evergreen, removes more water from the basin than oak, a deciduous tree. The interception loss by grass seems low compared to some of the findings in Resource Sheet 26. The model utilises the same volume of precipitation input for each simulation or run, and therefore, the volume of runoff produced by each vegetation type is directly comparable. The variation in runoff is mostly a function of the contrasting volume of water transferred by evaporation of intercepted water along with differences in transpiration between the vegetation types. Differences in evaporation from soil may also play a role in this variation. **From Resource Sheet 26, describe and explain the variation in runoff produced by the different vegetation types.**

Wheat produces the highest volume of runoff. This reflects the low transfer of precipitation out of the basin by transpiration and interception along with soil evaporation. The catchment with the least streamflow is that covered by pine trees. This reflects the high interception and soil evaporation, along with large transpiration losses, associated with pines. Deciduous forests, as represented by oak trees, provide the second lowest volume of runoff. This is because the removal of water from the drainage basin by transpiration, interception loss and soil evaporation is quite high despite the fact that the tree sheds it's leaves in winter. Grass produces a more runoff than Oak because of lower interception losses.

The reality of water use by plants which results in transpiration and interception loss is illustrated in an experiment in the U.S.A. At the Coweeta drainage basin in North Carolina, two similar catchments were monitored for streamflow. After a calibration period, during which the output of each basin was compared, the vegetation was cut down in one catchments. The increase in water yield is shown in Figure 15.

The increase in runoff after clearfelling was quantified by using the output of the unaltered and forested catchment to predict. **Using a relationship developed during the calibration period, what the output of the clearfelled basin would have been before cutting down the vegetation.** Subtraction of the measured streamflow after clearfelling from that predicted for the catchment in it's vegetated

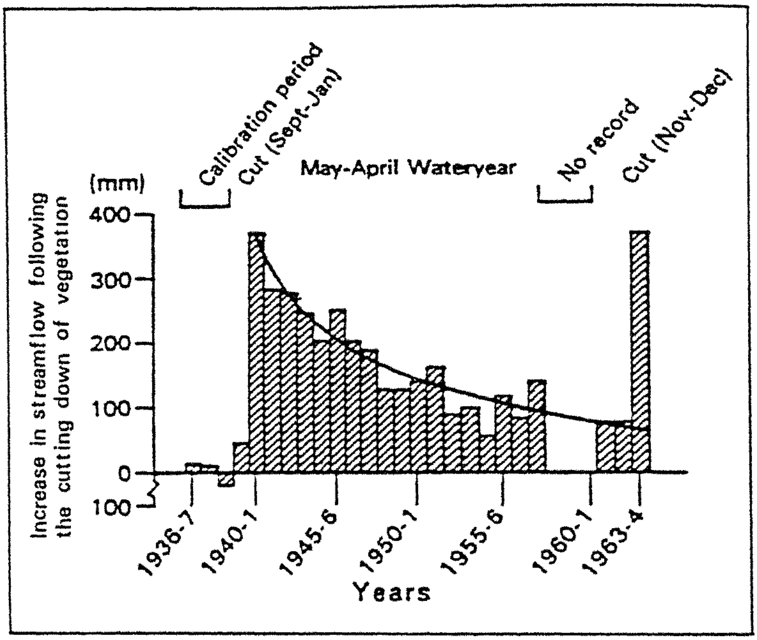


Figure 15 Increased runoff after clearfelling a forest (after Pereira, 1973)

state gives the value by which runoff increased after clearfelling.

Figure 15 poses two questions for explanation:

(1) why did the runoff increase following clearfelling?

(2) why did the increase in streamflow following clearfelling decreases with time?

The answer to (1) is that transpiration and interception losses are reduced, although because the vegetation was not removed until the foliage decayed, a certain amount of interception would still occur. In a further experiment at Coweeta deciduous hardwoods were replaced by white pine. When the pine trees reached maturity they generated 20% less annual runoff. This is similar to results from elsewhere. Using two catchments in Upland Wales, the Institute of Hydrology compared the water loss from a catchment where grass predominated, the R. Wye, with a pine forested basin, the R. Severn. They found that between 1972 and 1975, the mean output of water due to evapotranspiration was 706mm/yr from the forested basin while the grass catchment ost only 425mm.

We moved away from Hong Kong in the preceding discussion. Perhaps it is time to outline it's relevance to the study of hydrology in the territory. The preceding section showed that if we have differing vegetation covers in drainage basins we should expect contrasting levels of runoff. This is because of the differing losses of water by transpiration and interception associated with each species. Thus, if the vegetation varies in our 11 study basins in Hong Kong, then we should also expect runoff to vary.

Resource Sheet 28 indicates that the forested areain Hong Kong is increasing as land is being afforested or undergoing natural regeneration. What is important is that the area of land under scrubland or grassland is declining. The data in Table 1 contains measurements of interception made in Hong Kong under Pine trees. It records the total rainfall falling in an area (Gross rainfall) and the volume of rainfall intercepted. The volume of rainfall intercepted is also expressed as a percentage of total rainfall. Remember some of this intercepted water may reach the ground as stemflow or leaf drip, but much is likely to be evaporated back to the atmosphere. Table 1 illustrates the reality of the interception process in Hong Kong at least under Pine trees. **Using the data in Table 1, assess the impact of the increasing area of forest upon runoff generation in Hong Kong.**

If the afforested areas had little vegetative cover, these areas would generate less runoff. However, if the interception rates for the Pine trees are typical of other trees for Hong Kong, then conversion from scrubland or grass may not cause a major change in runoff generation. This is because the interception rates recorded under the trees in Hong Kong are lower than for those described in Resource Sheet 27. They are most similar to the rates for grass if we allow that

Table 1 Interception Measurements

Date (Study Period)	Rainfall (mm)	Gross Interception Amount (mm)	Gross Interception Percentage (%)
5.4 - 12.4	87.4	5.3	6.07
12.4 - 19.4	0.5	0.43	86.00
19.4 - 28.4	0.2	0.20	100
28.4 - 2.5	34.2	6.43	18.81
17.5 - 23.5	96.4	2.0	2.07
23.5 - 1.6	18.20	5.47	30.03
1.6 - 6.6	90.2	5.04	5.58
6.6 - 12.6	15.2	6.87	45.22
21.6 - 1.7	11.5	4.94	42.99
1.7 - 10.7	9.8	2.62	26.70
10.7 - 18.7	52.8	12.15	23.01
18.7 - 25.7	51.2	4.87	9.51
25.7 - 30.7	16.30	5.85	35.87
30.7 - 5.8	28.20	1.97	6.99
5.8 - 10.8	96.40	2.59	2.69
10.8 - 11.8	24.80	4.14	16.70
11.8 - 14.8	45.9	2.96	6.90
14.8 - 19.8	44.0	3.61	9.19
19.8 - 20.8	77.20	3.01	3.89
20.8 - 21.8	49.6	1.75	3.52
21.8 - 1.9	58.19	4.97	8.5
1.9 - 9.9	18.68	9.28	49.7
9.9 - 18.9	22.46	6.50	28.94
18.9 - 26.9	46.1	5.15	4.66
26.9 - 30.9	52.78	9.05	17.15
30.9 - 6.10	5.82	1.09	18.73
6.10- 16.10	13.27	1.06	7.96

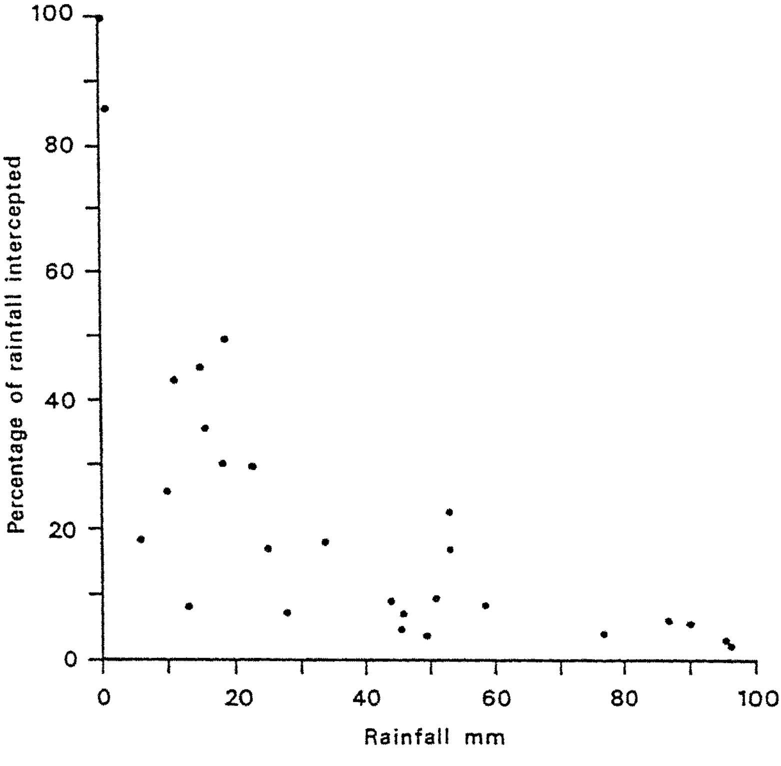


Figure 16 Weekly Interception and Precipitation from April to Oct.,1972. (Data from Lam, 1974)

the volume intercepted will be lowered if it is corrected for stemflow. The data in Table 1 also tells us more about the interception process. Figure 16 is a plot of interception against total rainfall. The scattergraph exhibits a degree of variation but it is possible to make some generalisations. For example, very low volumes of interception are generally associated with high precipitation. In contrast, the high levels of interception occur during periods of low rainfall. **Explain why high rainfall results in low interception, and low precipitation generally permits higher interception.**

During periods of high precipitation the storage capacity of the leaves will be saturated and then the water will form stemflow or drip form the leaves. In this situation interception is a function of the evaporation rate from the leaves, because, the only space for interception is that created by evaporation. In contrast, when rainfall arrives at a leaf surface which is dry the volume of interception is a function of both storage space on the leaf, plus, that created by evaporation from intercepted water. We can show this difference in equation form:

Wet Leaves: Interception is a function of Evaporation

Dry Leaves: Interception is a function of Storage Capacity
+ Evaporation

During periods of very low rainfall interception will be a function of storage on the leaf plus evaporation. However, during periods of heavy rainfall the influence of storage is negligible and interception becomes a function of evaporation only.

The scatter in the rainfall runoff relationship for Hong Kong is not only explained by the effect of vegetation upon interception and transpiration. Figure 14 tells us that water being applied to the soil surface can either form overland-flow, after depression storage has been filled, OR, it can enter (infiltrate) into the soil column. The surface of the soil may be regarded as a switch acting to divert rainfall to either overland-flow or into the soil. This division is important because the higher the proportion of rainfall which is diverted to overland-flow the greater the volume of streamflow. **Why should this be the case?** Although some of the water entering the soil may eventually become streamflow Figure 14 indicates that there are many other ways for this water to be removed from the catchment, or held in storage in the basin, and, therefore, not contribute to streamflow. Using Figure 14 list the processes by which water infiltrating the soil may be transferred out of the basin in addition to streamflow and list the stores in which water may be detained before it becomes streamflow? It is possible to conclude, therefore, that a drainage basin with the greatest infiltration rate will, other things being equal, exhibit the lowest annual runoff. We should, therefore, now examine the factors which affect infiltration and see if they vary in Hong Kong.

Many factors affect infiltration and they include, vegetation or land use, soil particle size, and slope angle. Resource Sheet 29 presents some data illustrating the effects of these factors upon infiltration. **Using Resource Sheet 29 describe and explain the influence of vegetation/land-use; particle-size, moisture content and slope upon infiltration.**

The influence of slope upon infiltration is perhaps the easiest to explain. On steep slopes, after depression storage has been filled, the water moves rapidly over the surface and this allows little time for infiltration. In contrast, on flat land, or on very gentle slopes, water either moves slowly, or is ponded back, giving a longer time on the surface which provides a greater opportunity for infiltration. The influence of particle size upon infiltration is also relatively simple. As particle size increases the pore size between the particles becomes larger enabling the water to move more rapidly through the soil. Particle size also influences the existence of macropores (large cracks) within the soil. Clay soils are most likely to crack when dried (for example, have you noticed the cracks in the bottom of dried up ponds?) and if rain falls on this soil with large cracks infiltration will be high. Furthermore, clays retain water more effectively than a coarser sandy soil. Therefore, other things being equal clay soils have a higher initial soil moisture content and, in comparison, to sand will be able to absorb less water. We should also note that a wet soil will absorb less water than a dry soil.

Vegetation and land use also have a great effect upon infiltration. Rain falling on bare ground may compact the surface layer of the soil causing it to become impermeable. This sealing of the surface is more effective for clay than sandy soils. A vegetative cover will virtually eliminate this effect. The maintenance of vegetation also promotes a good soil structure permitting macro pores or large cracks to exist in the soil. The promotion of macro pores under the influence of vegetation can be achieved by:

(1) the decay of plant roots;

(2) the organic matter produced by vegetation causing the mineral soil to aggregate into peds or blocks.

If we look at topographic, soil and land use maps of Hong Kong we can see that many of the factors shown above to affect infiltration exhibit great spatial variation in the territory. For example, the soil map presented in Figure 17 suggests there is considerable variation in soils. Given their control on infiltration and it's control

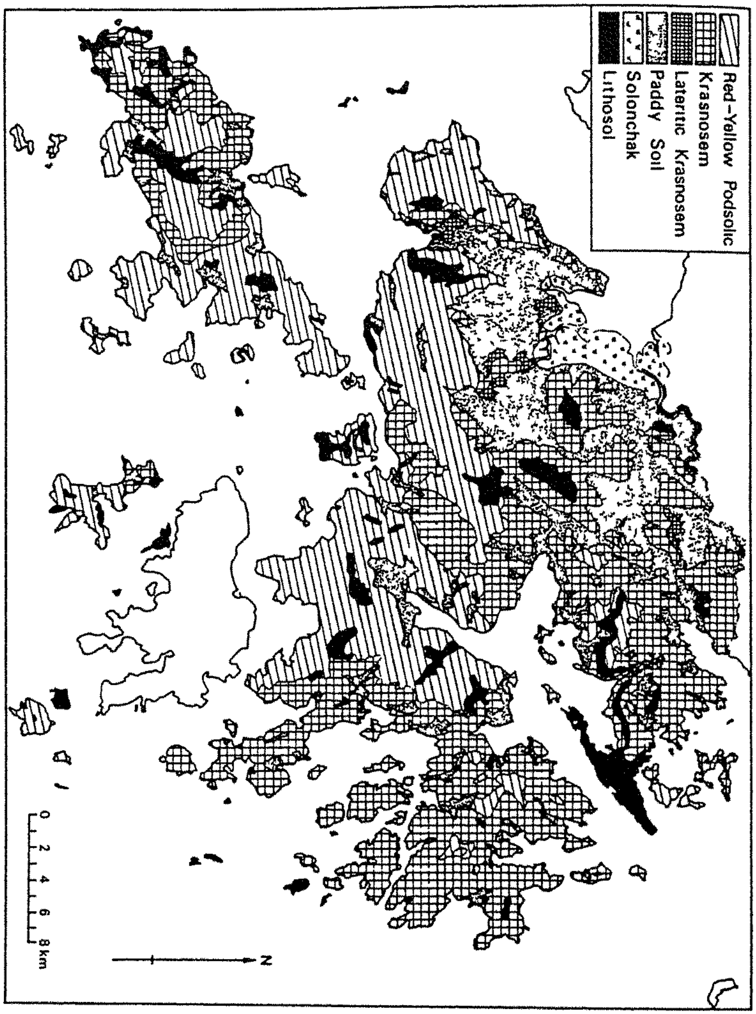


Figure 17 The soils of Hong Kong (After Grant, 1983)

on streamflow we might expect runoff to vary spatially in Hong Kong.

There are few observations of infiltration in Hong Kong but they do illustrate the influence of some of the controls on this process outlined above. Furthermore their variation gives us further cause to accept the spatial variation of this process and hence runoff in Hong Kong. Table 2 lists some measured infiltration rates in Hong Kong.

Table 2 Measured mean infiltration rates in Hong Kong (after Lam 1974)

VEGETATION	INITIAL RATE mm/hr	STEADY STATE RATE mm/hr
BARE	40.82	19 87
SCRUBLAND	<100 00	40.50
GRASSLAND	100.00	NOT ACHIEVED BUT <38

Table 2 confirms that on these slopes it is the vegetated sloped which have higher infiltration rates. **Can you remember why this should be so?**

The discussion about infiltration has indicated that this process serves to direct water into soil moisture storage and perhaps from there into groundwater storage. Storage of water either within the soil or in bedrock can also cause scatter in rainfall runoff scattergraphs. Why? Well if we have a very dry period the baseflow runoff in our stream is supplied from either groundwater or soil water. Where stormflow runoff does not dominate water discharge and where drainage basins are identical in terms of climatic and physical conditions, it will be those with the highest soil moisture and groundwater levels which will generate the most runoff. Therefore, contrasting soil moisture storage capacities and groundwater levels are a further factor causing scatter in rainfall runoff relationships.

We can summarise the preceding discussion about the causes of the scatter in our plot of rainfall and runoff for the study basins in Hong Kong as follows. Each basin responds in a different way to a given precipitation input because of the influence of vegetation, soil type and the volume of water held in storage in the basin.

It is possible to find some evidence to illustrate the effects of the factors discussed above upon runoff in Hong Kong. Resource Sheet

30 presents some data from a number of studies in Hong Kong. **Using the information in Resource Sheet 30, describe and explain the variation in runoff produced by rainfall in Hong Kong.**

The data presented on Resource Sheet 30 indicate that in general barren slopes will generate more runoff than vegetated slopes. This can be explained by the interception of rainfall by (a) the vegetative canopy and the subsequent evaporation of much of this; and (b) the higher rates and volumes of infiltration associated with vegetated slopes.

For storm period studies transpiration losses are not likely to be significant. This is because when leaves are covered with a film of water (as they would be during rainfall, the stomata are inactivated, transpiration effectively ceases and evaporation then takes place only from the intercepted water on the leaf surface. Only when the leaves have been dried by evaporation will the transpiration of water from the leaves be resumed.

Furthermore, for plot studies, which do not have permanent streams, all runoff is produced by overland-flow. In plot studies water loss by transpiration affects runoff only indirectly in that the greater the transpiration loss the more water that must be added before saturated overland-flow occurs. Alternatively, if the Horton model of runoff generation applies, the more water removed by transpiration the drier the soil will be, and hence, the greater will be the infiltration rate and capacity of the soil and in consequence the smaller the volume of runoff. However, in catchment studies with permanent streams total runoff is a function of baseflow plus stormflow. Baseflow runoff is derived from groundwater and soil water which drains into the stream. Transpiration depletes water from the soil and groundwater stores and therefore deprives the stream of water which would otherwise form baseflow. In drainage basins with permanent streams transpiration can act directly to influence the volume of runoff.

Up to this point we have examined the functioning of the hydrologic cycle at one point in time, the water year 1980/81 for a number of drainage basins in Hong Kong. We might learn more about how the hydrologic cycle affects the movement of water by examining one drainage basin at many points in time.

Resource Sheet 31 presents data for rainfall and runoff for the Tai Lam Chung 'A' catchment for the water years 1964-65 to 1983-84. **Construct a scattergram and describe the relationship between rainfall and runoff for this basin.**

The scattergraph of rainfall against runoff indicates that over the study period in basin runoff is dependent upon precipitation input. However, the scatter in the relationship tells us that something other than precipitation governs the volume of runoff produced. This finding agrees with our earlier comments about the spatial variation of runoff.

Two factors may explain the scatter in the rainfall-runoff relationship. Water is not only removed from a drainage basin by streamflow but also by evapotranspiration. Figure 18 plots runoff against evaporation measured at King's Park, Kowloon for the study basin. Evaporation as determined from an evaporation pan does not provide an exact measure of the evapotranspiration in each basin but it does serve as an index of the volume we might expect each year.

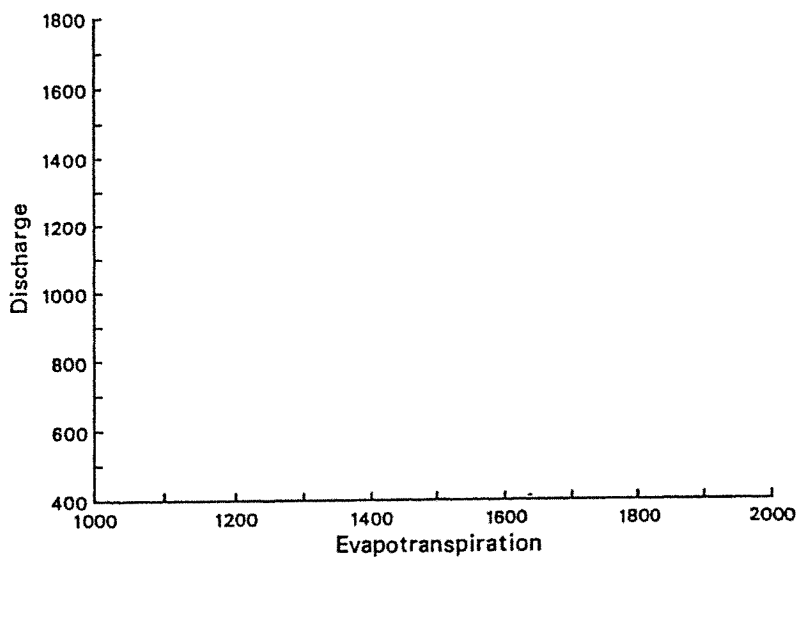


Figure 18 Discharge at Tai Lam Chung A and evaporation at Kings Park for 20 years in Hong Kong

The scattergram of evaporation and runoff reveal a negative association. From this relationship we can argue that as evapotranspiration rates increase in our drainage basins so that volume of streamflow decreases. Evapotranspiration in a given catchment depends on many factors including soil moisture, vegetation/landuse, wind speed, radiation, humidity and so forth. These factors will vary from year to year and, therefore, evapotranspiration in any given basin will vary. In consequence, other things being equal, the volume of precipitation being converted to runoff will vary between years and hence our plot of rainfall against runoff will not exhibit a perfect relationship.

A further factor causing scatter in the rainfall runoff relationship is water storage in the catchment. Figure 14 tells us that there are many storage locations for water in the drainage basin. This means that not all the precipitation delivered to the drainage basin need be transferred out of the drainage basin by either streamflow or evapotranspiration. Unfortunately, there is no record of the volume of water stored in our drainage basins but it is possible to illustrate the reality of it in Hong Kong. The simplest way to measure the change in the volume of water stored is to measure the height of the water table below the surface. The Water Supplies Department of Hong Kong monitor the level of the water table at a number of locations. Their published results for 18 stations over the water year 1984, which includes observations from April 1984 to March 1985, show that, on average over this period, the water table was some 0.75m closer to the surface. This signifies an increase in storage of water in the ground and would be derived from the precipitation input. If some of the precipitation is diverted into storage then it follows that it cannot become streamflow. However, water is not necessarily added to storage it can also be released from storage. If water is released from storage during a study period the streamflow will be higher than that predicted from the precipitation input. Changes in storage can therefore cause scatter to be exhibited in the rainfall-runoff relationship.

Resource Sheet 32 presents a diagram showing the variation of the water table position for the period April 1984 to March 1985 for an observation site in the New Territories. From Resource Sheet 30 describe and explain the variation in water table depth. The graph showing monthly rainfall may help you.

The water in the ground is replenished during the wet season because of precipitation. During the dry season water is lost by providing baseflow runoff to streams by soil moisture may then be evaporated or transpirated thereby lowering the water table.

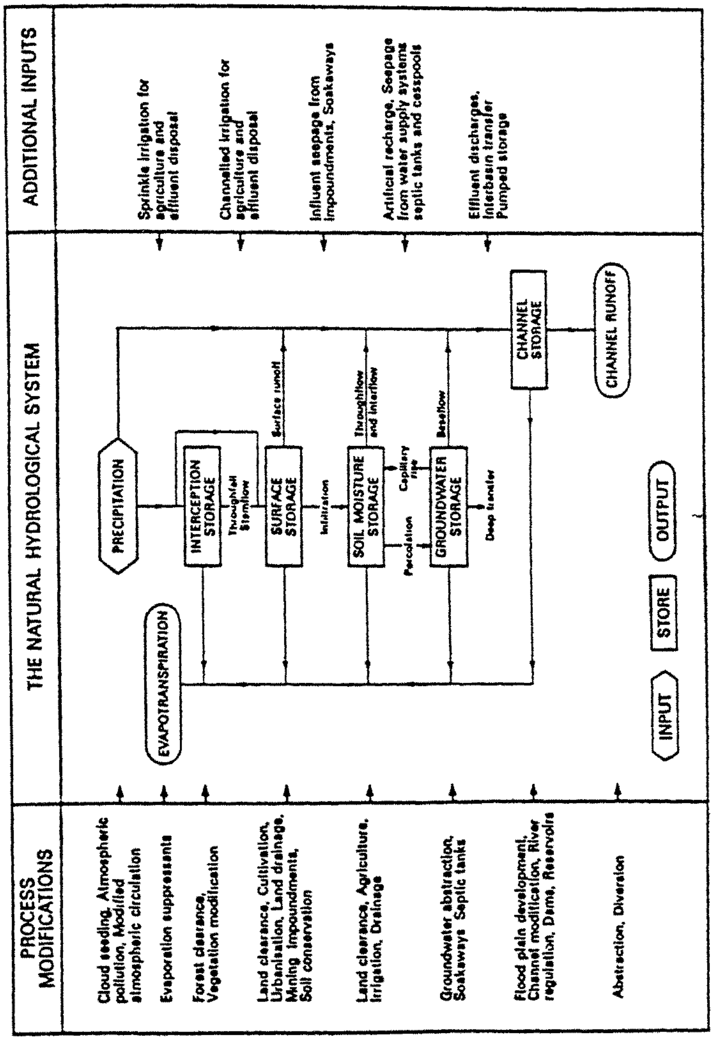


Figure 19 Man and the Natural Hydrological System
(From Walling, 1979)

Conclusion

We started this study of hydrology by looking at water as a resource. The study will close by looking again at it as resource and at the movement of water in the hydrological cycle using a systems approach.

At the global scale the hydrological cycle is a closed system. It is a closed system because, although it may exchange energy in the form of radiation across its boundaries, it does not suffer from a loss or gain of water. This is important because it means that the volume of water in the global hydrological cycle remains constant.

However, if we divide the global hydrological cycle into its subsystems, such as the oceans and continents, we find that at this scale the system becomes open. An open system is one in which there is an exchange of mass and energy.

The reality of these open systems at this scale is evidenced by the occurrence of Ice Ages, the most recent being during the PLeistocene, which cause a reduction in the volume of water in the oceans by transferring it to glaciers and ice sheets on the land. During an Ice Age, the land based hydrologic subsystem receives an increased input and experiences a decreased output. In contrast, the oceans receive decreased input because runoff from the land is less as a consequence of the water becoming stored as ice in glaciers. There is also increased loss due to the fact that water, being removed by evaporation for precipitation, is not totally replaced. Hence, we can see that in an open system the volume of water stored within the system can change.

At the drainage basin scale, we have seen how the water inputs and outputs, and hence the volume of water storage in the open system can change. This is important in terms of water as a resource because it explains why at times we have too much and at other times too little.

The drainage basin hydrological cycle is illustrated in figure 19 which also shows the many points at which man can interfere with the hydrologic system. We can see from this that inputs and outputs from the drainage basin are susceptible to change by man. Water is a resource and the figure tells us directly that man exerts a considerable degree of control over it. This is a topic that you might like to consider in more detail and it forms a good area for the further expansion of your study of hydrology.

RESOURCE SHEETS

Resource Sheet 1

Water as a Resource

man's use of water	
direct uses	indirect uses
1. Drinking	1. Transport
2. Washing	2. Recreation
3. Cooking	3. Power (HEP)

Resource Sheet 2

Selected Readings on Drought in the Sahel and Hong Kong

(a) Drought in the Sahel and Other Areas

Tinker, J. (1985) Africa: A bankrupt environment. *Earthwatch*, 21, p.1-7.

Mensching, H. (1986) Is the desert spreading? Desertification in the Sahel zone of Africa. *Applied Geography and Development*, 27, p.7-18

Cant, G. (1986) Famine in the Sahel: Natural disaster or structural violence? *New Zealand Journal of Geography*, April, p.2-5.

(b) Drought in Hong Kong

The following newspaper articles are held in the Hong Kong Collection of the University of Hong Kong Library in the water supply file.

South China Morning Post, June, 15th, 1977, "Water: How we stand."

The Hong Kong Standard, June, 15th, 1977, "Water curbs if the rains don't come."

South China Morning Post, June, 28th, 1982, "Major water cuts are unlikely in the future."

Water Supplies Department (1987) "Hong Kong's water." Lands and Water Branch.

Resource Sheet 3

Resources on Flooding in Hong Kong

The Monthly Weather Reports published by the Royal Observatory are a good source of information on flooding. Those for the December of each year contain an annual weather summary and are a good first point of reference.

The Tropical Cyclone Reports issued by the Royal Observatory are also and excellent source of material on flooding and other hazards, in particular the reports for 1983 and 1988.

The annual report of the Agriculture and Fisheries Department for 1983-4 in paragraph 133 contains reference to relief payments made as a result of Typhoon Ellen.

Newspapers such as the South China Morning Post and the Hong Kong Standard also provide excellent resources on flooding.

Resource Sheet 4

Forms of Water

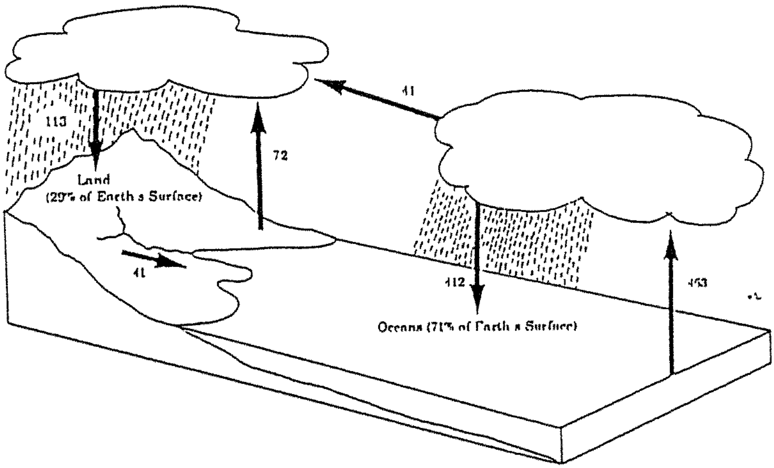
form of water	% of volume	% of total fresh water
1,338,000,000	96.50	0.00
Groundwater 23,400,000	1.70	0.00
(10,530,000=Fresh)	-	30.10
Soil moisture 16,500	0.001	0.05
Glaciers 4,064,100	1.74	68.70
Ground-ice in 300,000 Permafrost	0.022	0.86
freshwater lakes 91,000	0.007	0.26
Saltwater lakes 85,400	0.006	0.00
Marshwater 11,470	0.0008	0.00
River water 2,120	0.0002	0.006
Biologic water 1,120	0.0001	0.003
Atmospheric water 12,900	0.001	0.04
Total water 1,385,984,610	100.00%	
Reserves freshwater 35,029,210	2.53%	100.00%

Resource Sheet 5

The Global Circulation of Water

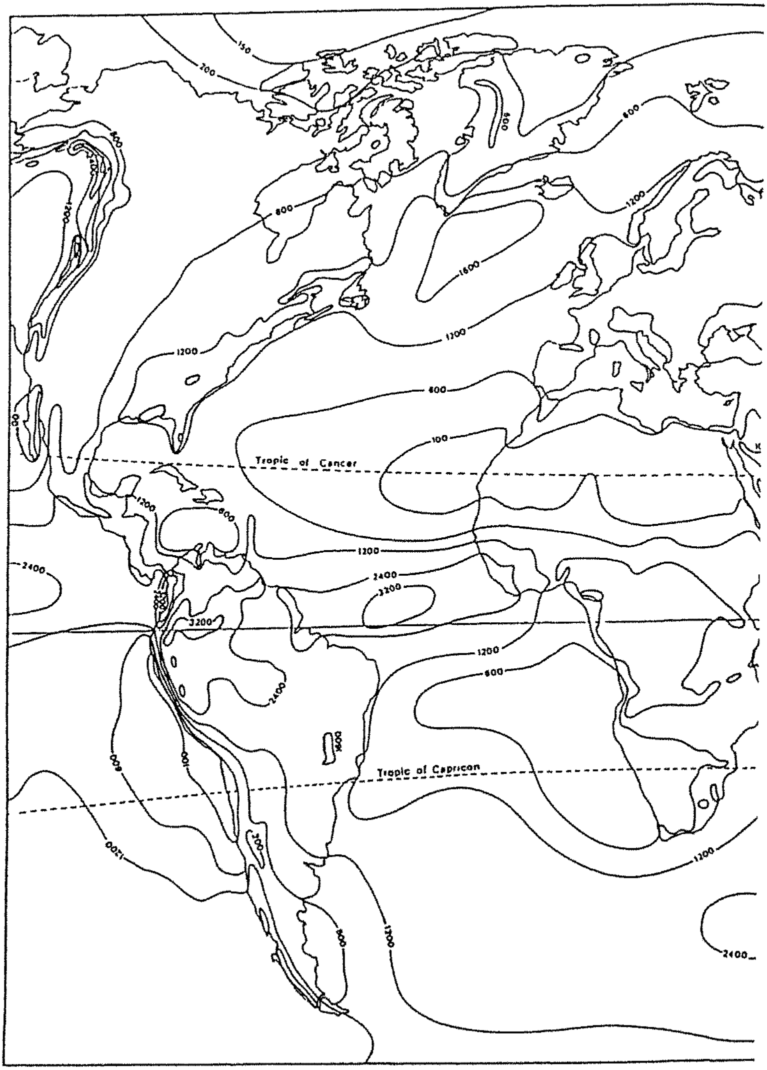
('000 cubic metres per year)

Global circulation of water (000 cubic metres per year)

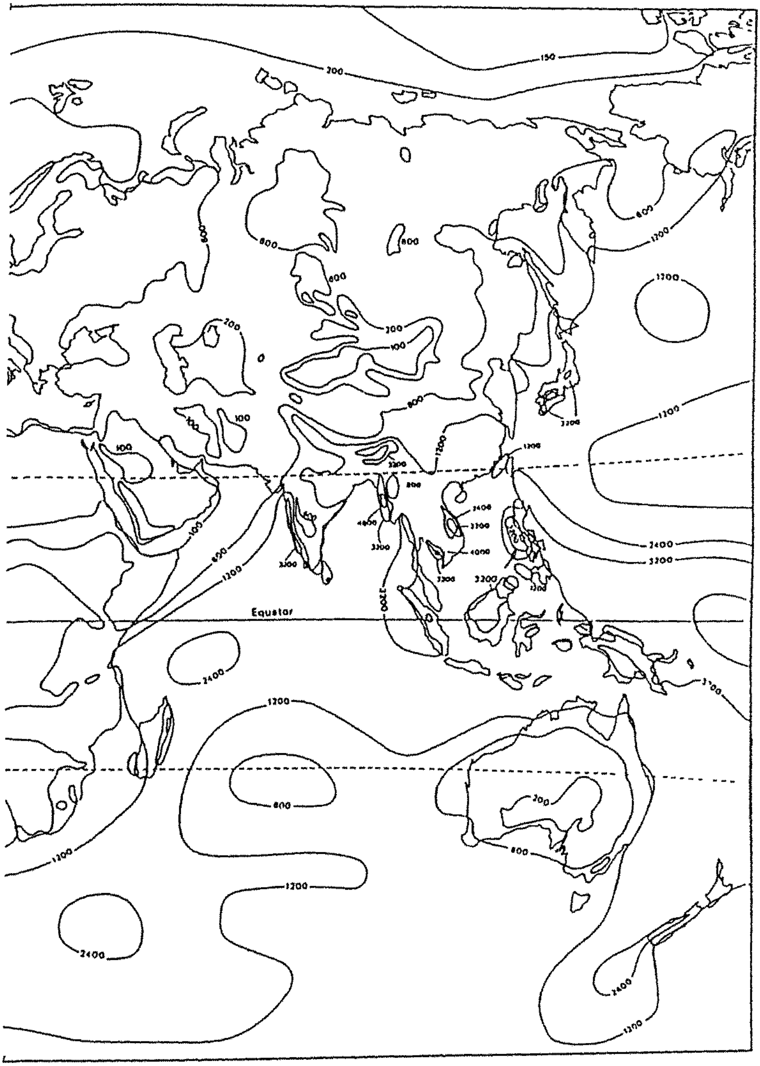


Resource Sheet 6

Global Pattern of Precipitation

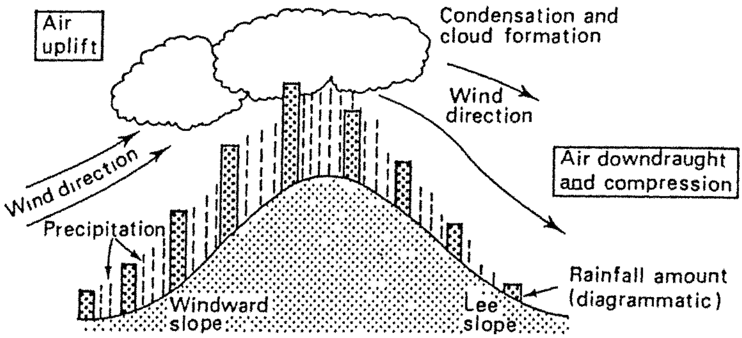


ANNUAL PRECIPITATION (mm)


Equator

Resource Sheet 7

The Formation of Orographic (Relief) Rainfall



Resource Sheet 8

Variation in Precipitation with Distance from the Sea

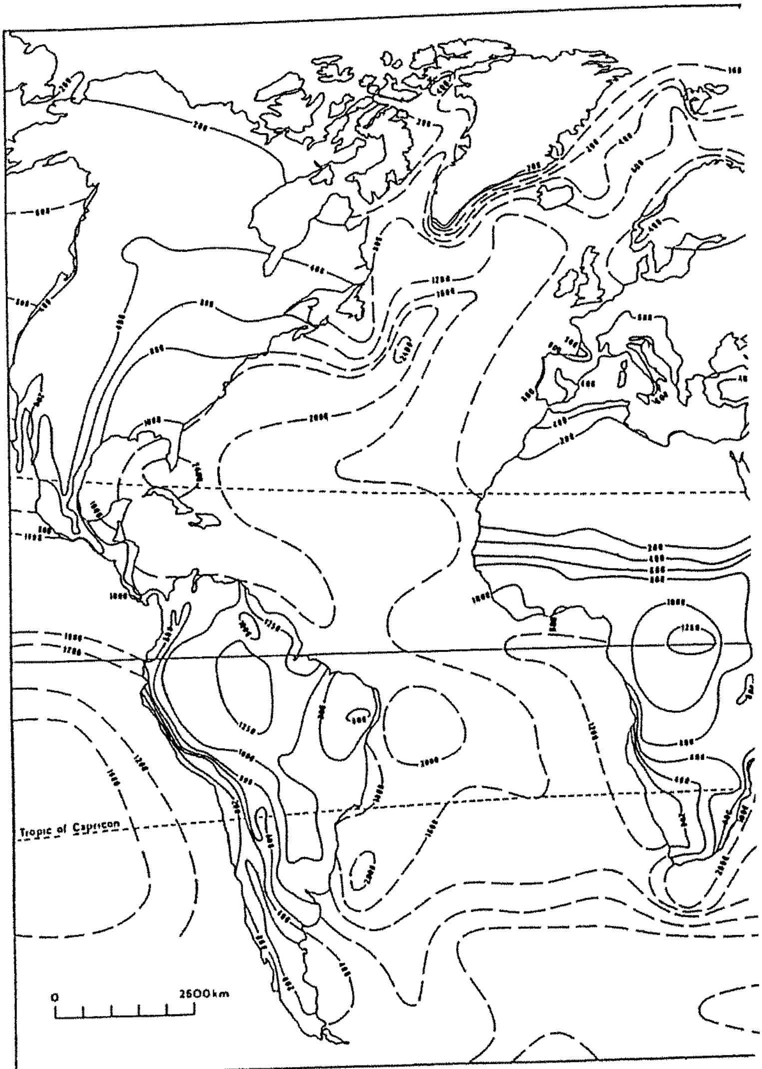
location	annual precipitation mm	distance from the atlantic km
Shannon	929	80
Berlin	603	1,600
Warsaw	555	2,100
Odessa	473	2,850
Kazalinsk	125	5,150


S

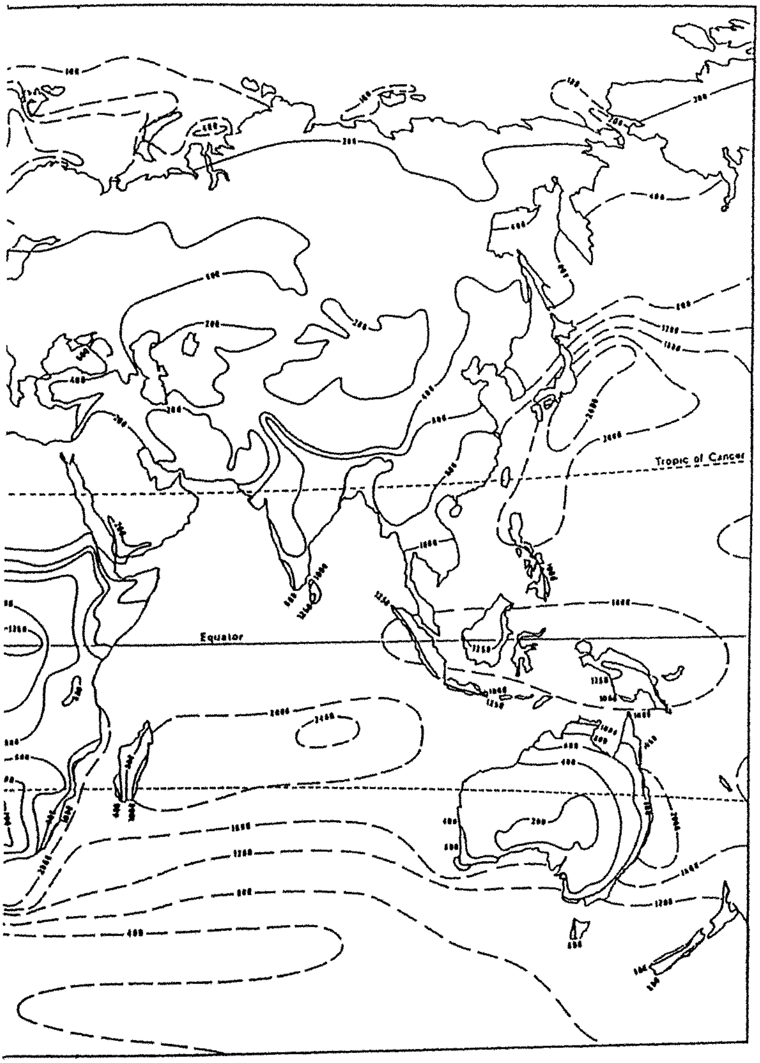

S
B
W
O
K
0 1000 2000 3000 4000 km

Resource Sheet 9

Global Evaporation and Evapotranspiration



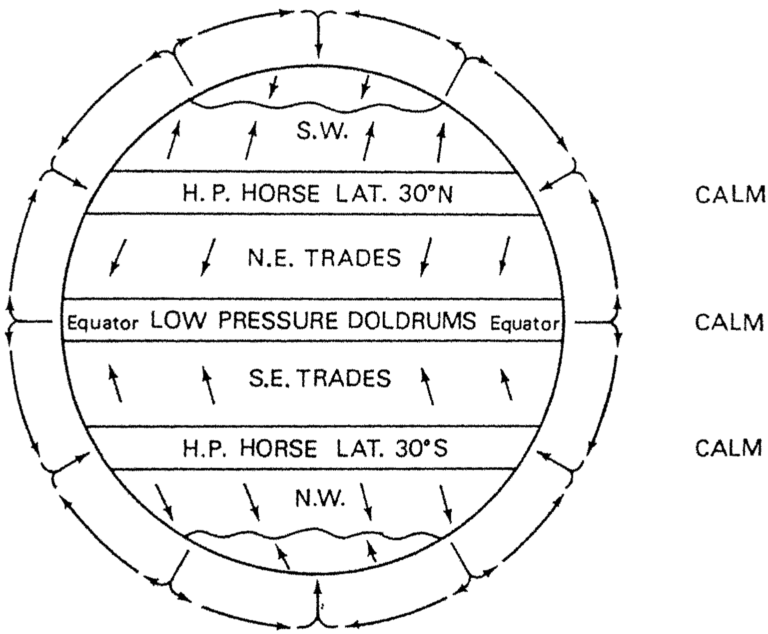
ANNUAL EVAPOTRANSPIRATION OVER LAND AND EVAPORATION



OVER OCEAN (mm)

Resource Sheet 10

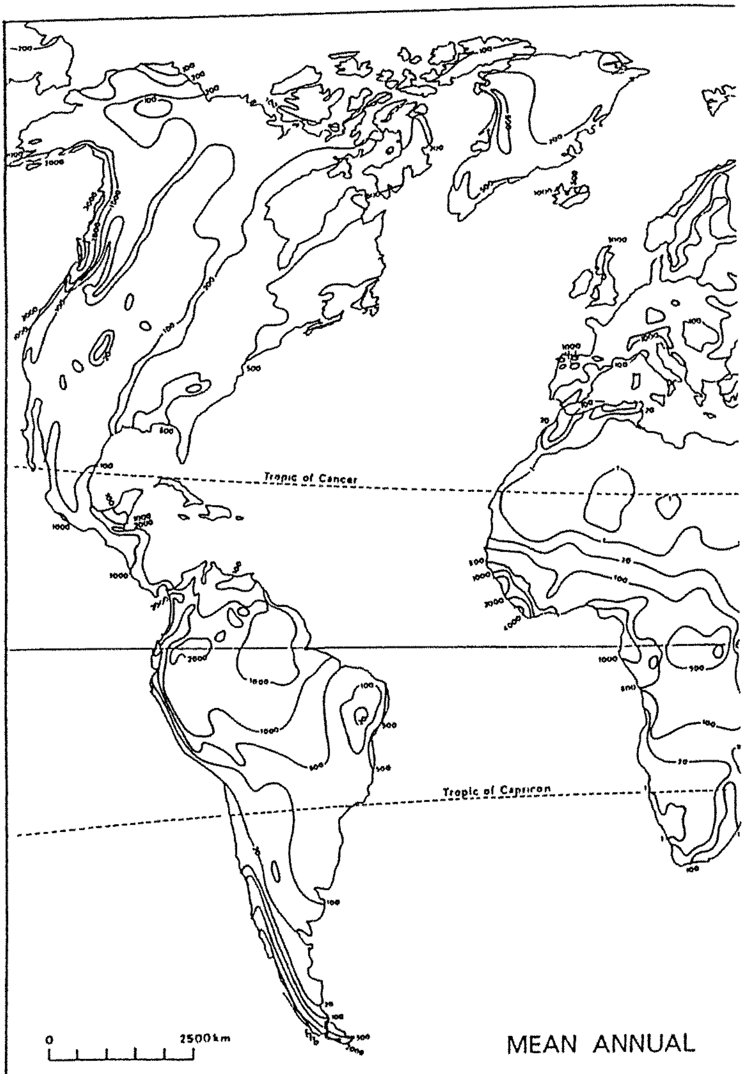
Global Wind Systems

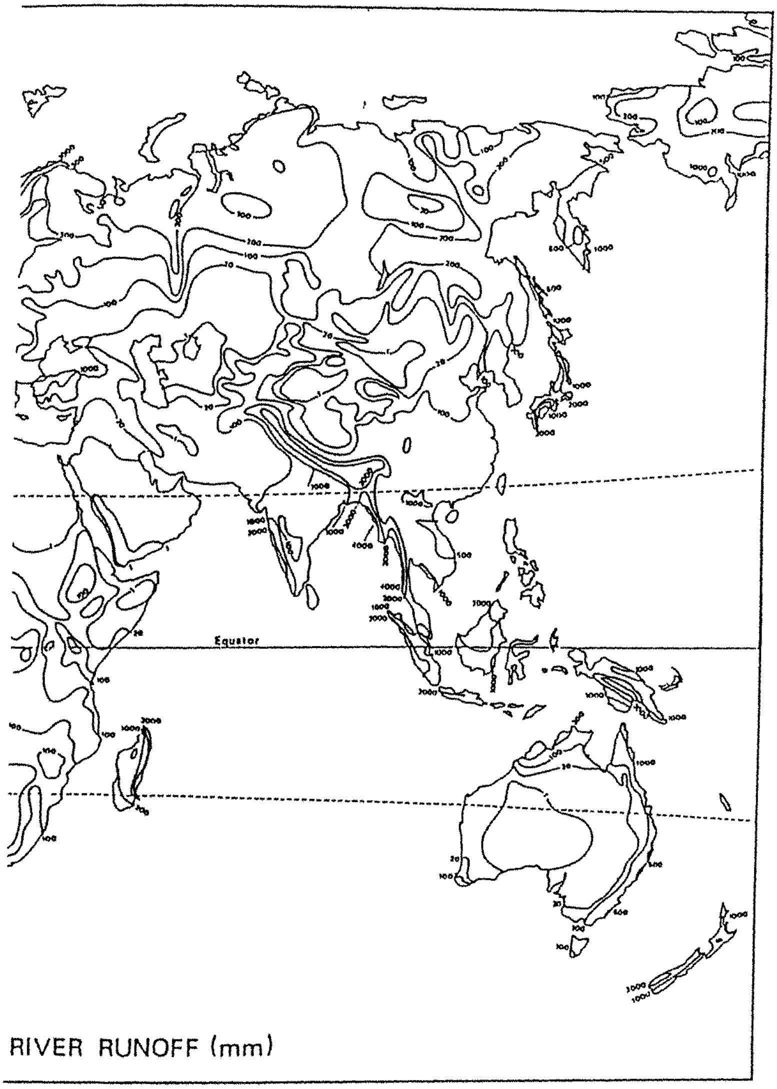


The Low Pressure area of the equator, called the Doldrums is an area of calm. The High Pressure Horse latitudes also experience clam. However between and from these areas relatively strong prevailing winds below. This is because air moves from areas of high to low pressure, the curved nature of the path followed by the wind being due to deflection by the earth's rotation.

Resource Sheet 11

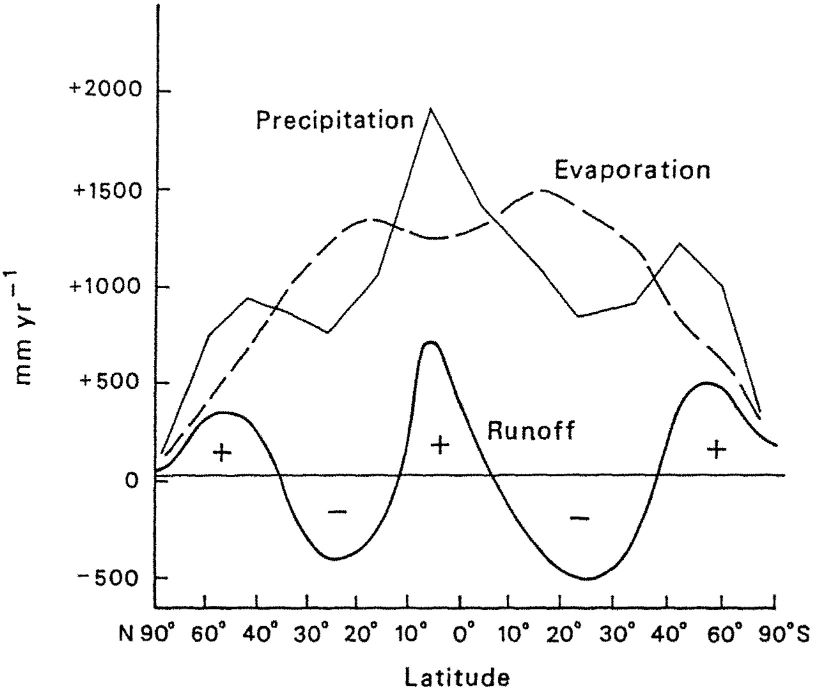
Annual Runoff on the Continents




Equator
RIVER RUNOFF (mm)

Resource Sheet 12

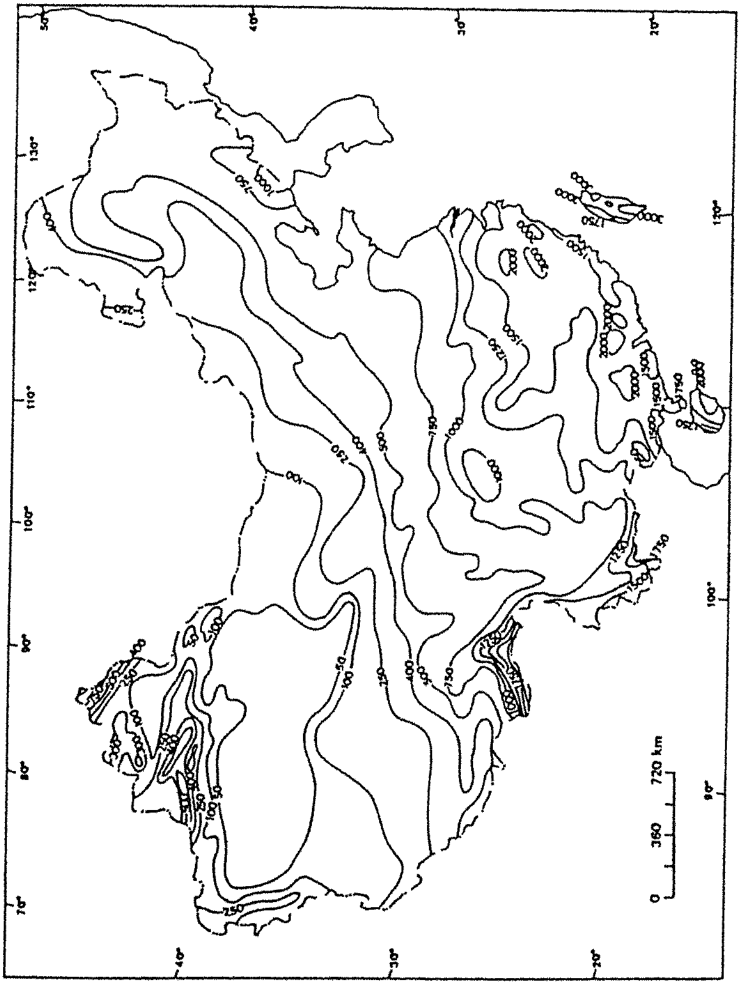
Latitudinal Variation of Rainfall, Evaporation and Runoff



(After Goudie, 1984)

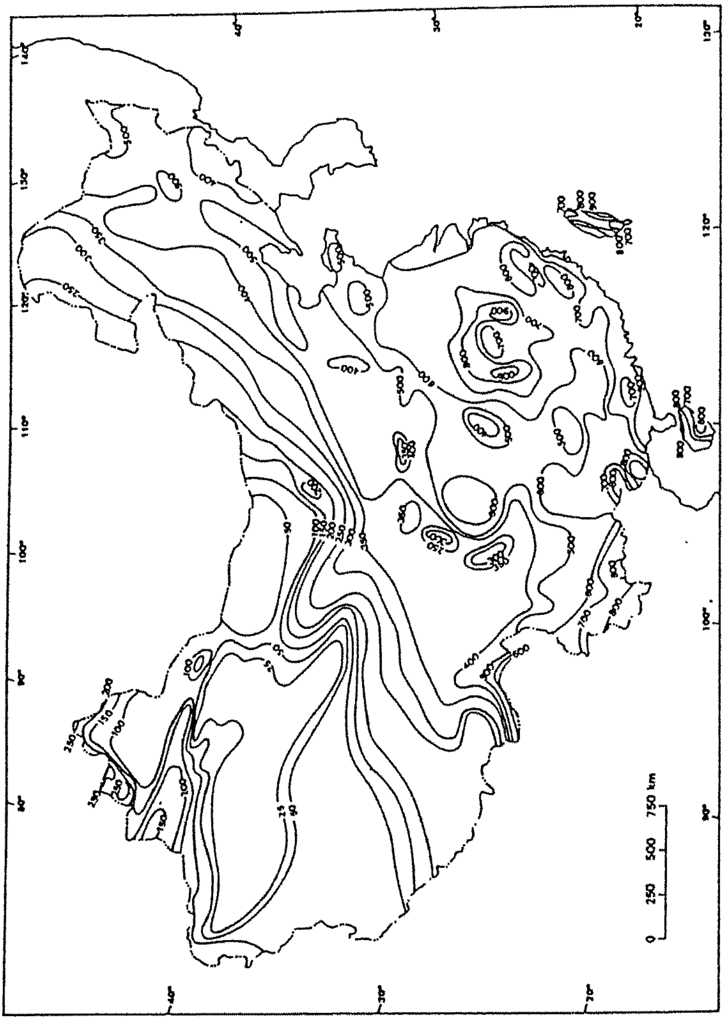
Resource Sheet 13

Precipitation in China
(mm/year)



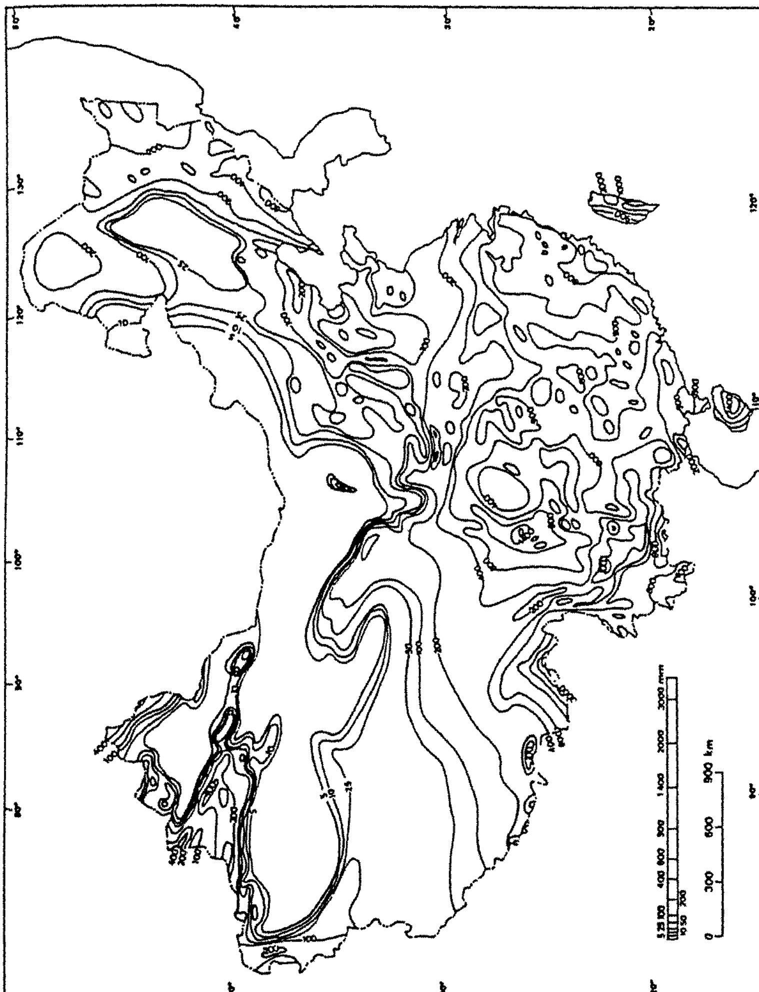
Resource Sheet 14

Evaporation in China
(mm/year)



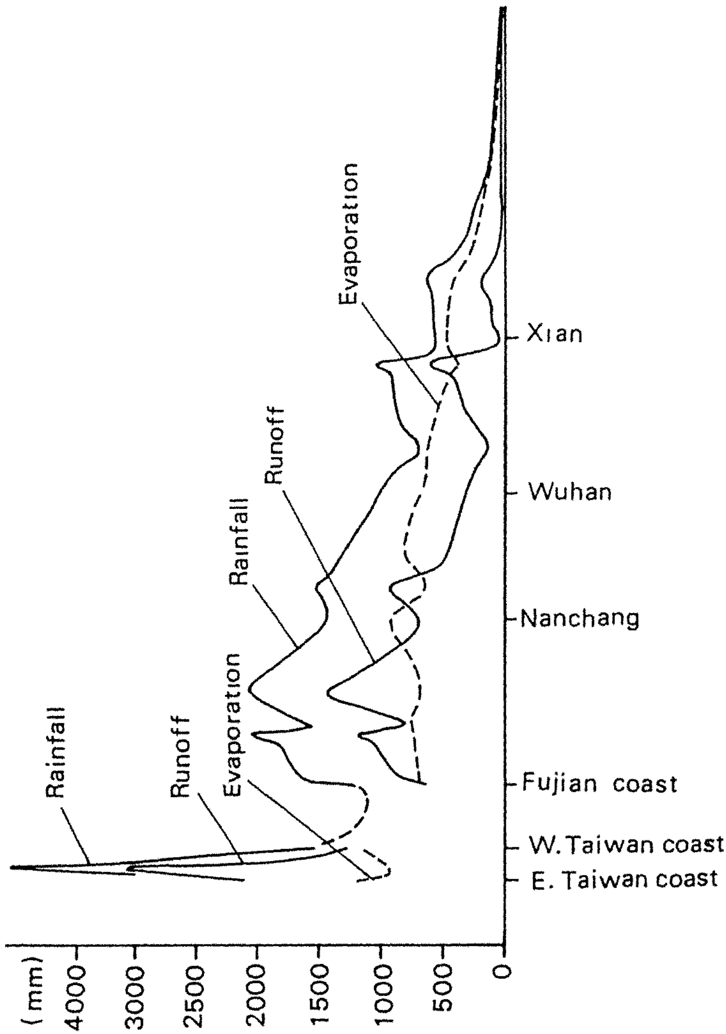
Resource Sheet 15

Annual Runoff in China



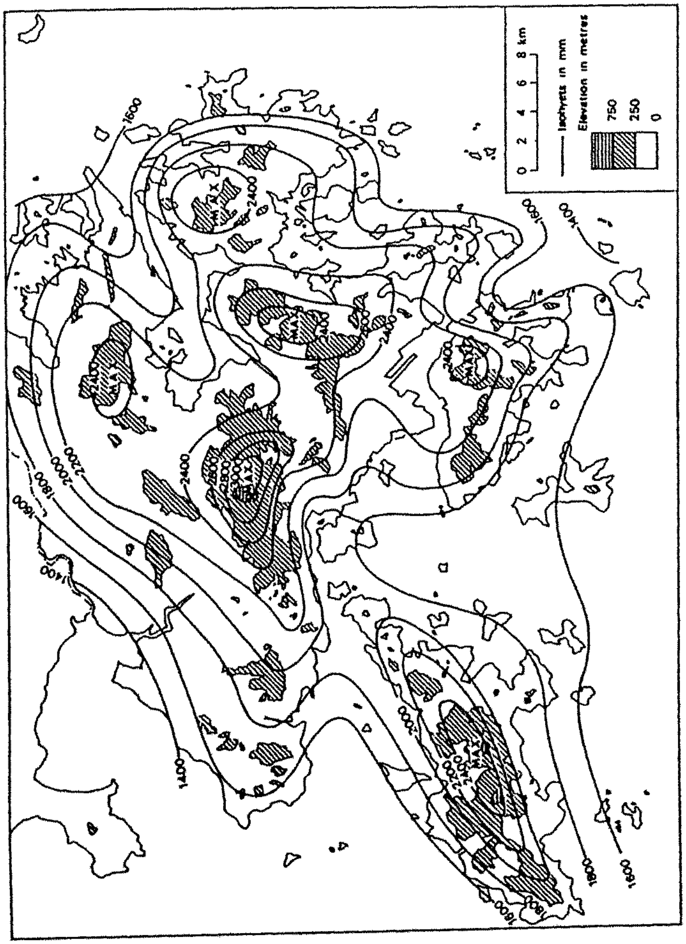
Resource Sheet 16

Cross-section of the Variation of Precipitation, Evaporation and Runoff in China



Resource Sheet 17

Mean Annual Rainfall over Hong Kong
1953-1982



Resource Sheet 18

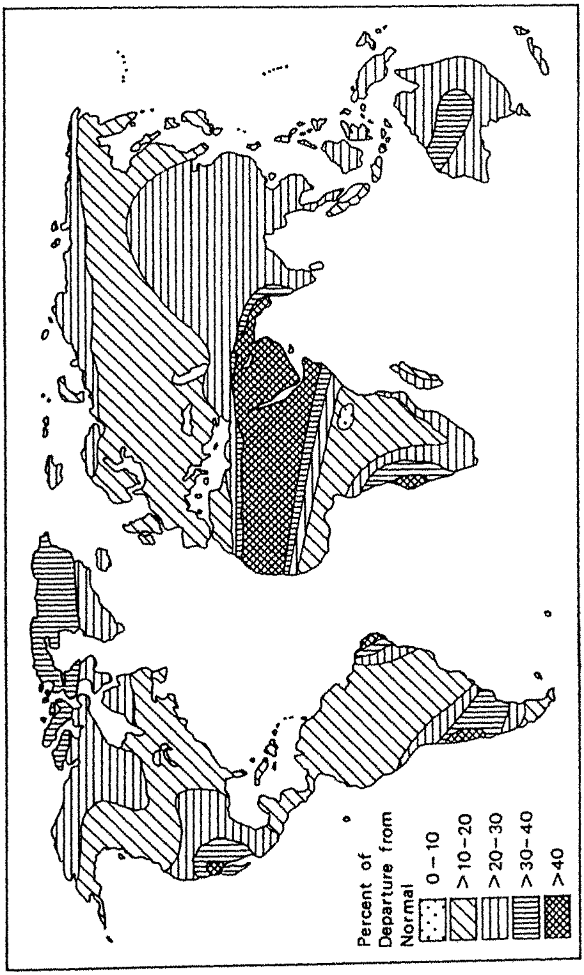
Rainfall and Relief in Hong Kong

30-year mean annual precipitation at stations in Hong Kong 1953-1982

Station	'Height above mean sea level	30-year mean annual precipitation
1 Yuen Long	90	1,725.3
2 Fanling Army Depot	20	2,221.5
3 Ma On Shan: St. Josephs Primary school	20	2,463.6
4 Sam Yuk Middle School	105	2,324.7
5 Shek Kong Village	115	2,483.0
6 Jubilee Reservoir	200	2,481.7
7 Aberdeen Upper Reservoir	120	2,116.7
8 Airport Met. Office	5	2,243.2
9 Cape d'Aguillar Wireless Station	50	1,772.1
10 Pokfulam Reservoir	175	1,951.8
11 Royal Observatory	30	2,223.2
12 Wong Nai Chung Reservoir	240	2,140.4
13 Happy Valley Race Course	35	2,256.1
14 Mui Wo	50	2,130.8
15 Chuen Lung Country Park	330	2,347.8
16 Cheung Chau Met. Station	70	1,756.8
17 Sze Lok Yuen	640	2,967.5
18 Tai Mo Shan	950	3,126.4
19 Tate Cairn Met Stat.	575	2,647.2
20 Cheung Sheung	300	2,494.8
21 Peak police station	400	2,120.8
22 Beacon Hill	150	2,527.6
23 Kadoorie Farm	305	2,415.5
24 Shek Lei Pui reservoir	130	2,288.4
25 Tai Lam forest reserve	110	2,234.6

Resource Sheet 19

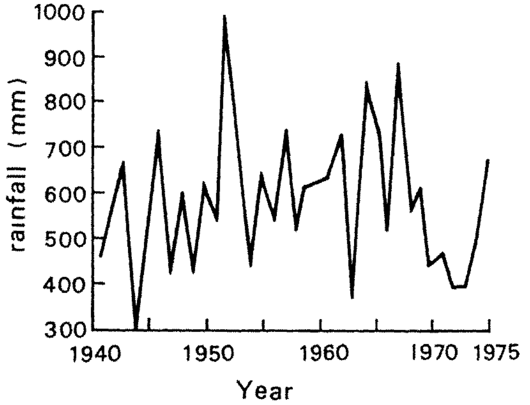
Variation of Global Precipitation

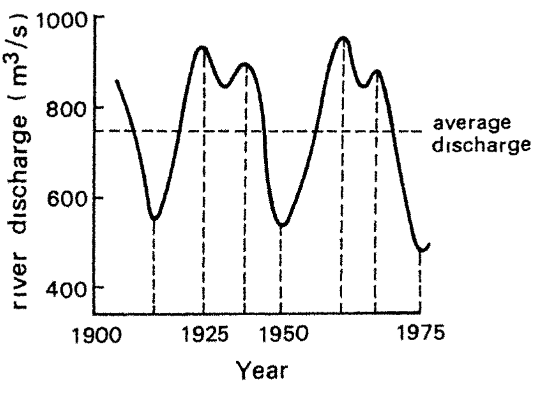


Resource Sheet 20

Long Term variation of rainfall and runoff in the Sahel region of Africa

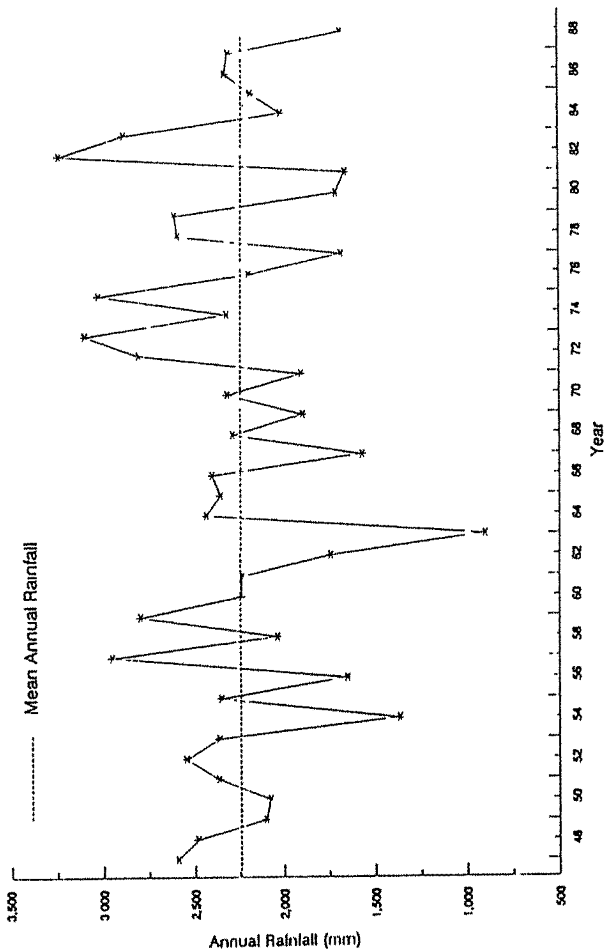
(After Ferguson and Clark, 1984)



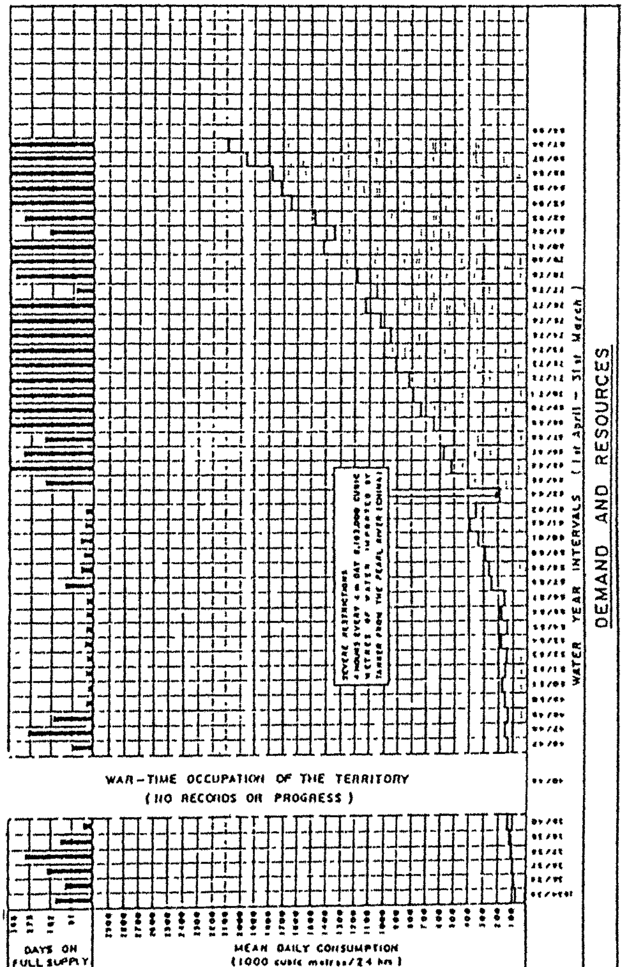


Resource Sheet 21

(a) Variation in mean annual rainfall in Hong Kong

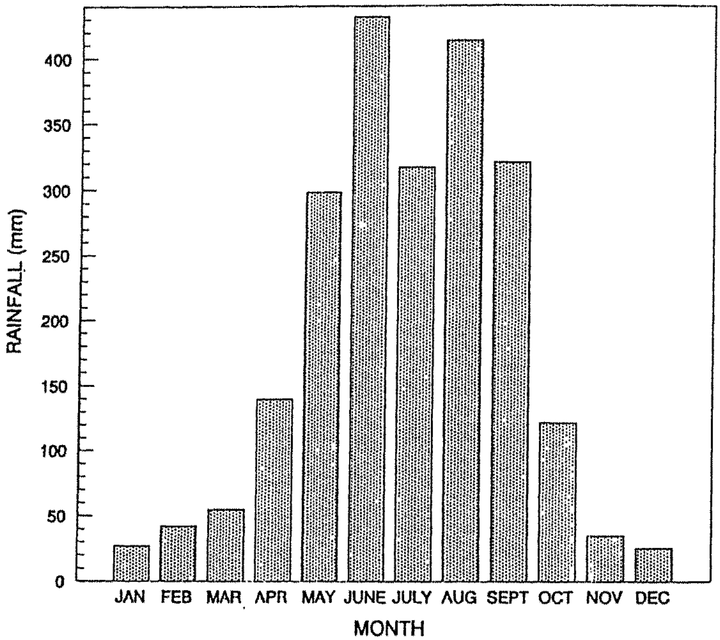


(b) Water demand and water supply in Hong Kong



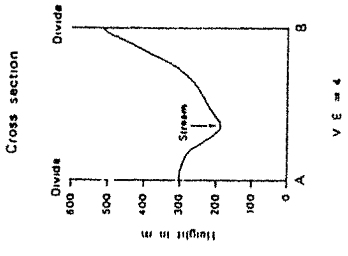
Resource Sheet 22

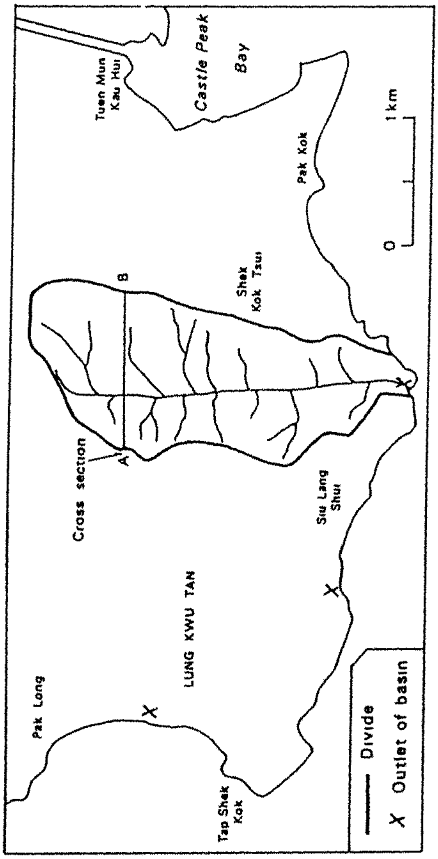
Mean monthly rainfall for Hong Kong (1951-80)



Resource Sheet 23

Shek Kok Tsui Catchment





Resource Sheet 24

Streamflow from Hong Kong Drainage Basins

Basin	Area (km^2)	Runoff (m^3x1000)	Runoff (mm)	Precipitation (mm)
Shek Pi Tau	27.9	26,528	950	1,817
Tai Lam Chung 'A'	0.8	628	785	1,413
Yuen Long Flood Channel B	1.3	4,012	3,134	1,484
Siu Lek Yuen Upper	1.9	2,526	1,336	2,193
Sham Wat	1.0	744	722	1,490
Kam Tin	11.7	22,359	1,908	1,909
Chung Mei Upper	6.1	5,513	903	1,694
Tai Lam Chung 'B'	1.2	933	804	1,413
Nim Wan	5.4	4,842	903	1,458
Lo Shu Ling	10.8	7,244	672	1,467

RESOURCE SHEET 25

Data for 25 British drainage basins for 1981

River	Rainfall (mm)	Runoff (mm)	Mean annual flow m^3s^{-1} km^2	Catch -ment in basin m.	Maximum height	Runoff m^3x10^6
Teviot	1,421	1,070	11.0	323.0	608	345.6
Leven	895	520	1.2	74.9	531	38 9
Nunnigham Strm	842	427	0.2	16.9	137	7.2
ymington	986	377	1.2	98.9	114	37 2
Taf	1,681	1,272	8.8	217.3	385	276 4
Dovey	2,111	1,720	25.7	471.3	905	810 6
Inver	2,282	1,826	7.8	137.5	988	251 0
Blackwater	1,044	654	19.7	951.4	362	622 2
Oykel	2,061	1,707	17.9	330.7	998	564.5
Dee	1,417	1,129	49.1	1,370 0	1,310	1,546 7
Coquet	832	480	8.7	569.8	776	273.5
Canons Brook	766	373	0.3	21.4	110	8.0
Tone	1,102	616	4 0	202.0	409	124.4
Fallocu	3,258	2,543	6 5	80.3	1,130	204.2
Harpers Brook	688	211	0.5	74.3	146	15.7
Yeo	1,036	473	3.2	213.1	252	100.8
Wye	2,403	1,990	0.7	10.4	752	20.7
Bela	1,450	901	3.7	131.0	338	118.0
Findhorn	1,366	902	22.3	781.9	941	705.3
Otter	1,090	584	3.7	202.5	299	118.3
Yealm	1,726	1,091	1.9	54.9	492	59.9
Colne	616	155	1.2	238.2	114	36.9
Yare	724	246	1.8	231.8	69	57.0
Cam	663	159	1.0	194.0	137	30.8
Tyne	701	253	2.5	307.0	528	77.7

Teviot at Hawick; Leven at Easby; Nunnigham Strm at T. Bridge, Lymington at Brockhurst Pk.;Taf at Clog-Y-Fran; Dovey at Dovey Bridge; Inver at Little Assynt; Blackwater at Maydown; Oykel at Easter Turnaig; Dee at Woodend; Coquet at Morwick; Canons Brook at East Way; Tone at Bishops Hull; Fallocu at G. Falloch; Harpers Brook at O.M.B.; Yeo at Pen Mill; Wye at Cefn; Brwyn Bela at Beetham; Findhorn at Forres; Otter at Dotton; Yealm at Puslinch; Colne at Lexden; Yare at Colney; Cam at Dernforth; Tyne at East Linton

Resource Sheet 26

Percent of precipitation intercepted and evaporated back to the atmosphere

vegetation	Interception loss % of precipiation average	range
conifers	33	25-43
temperate deciduous forest	18.5	14-30
Tropical rain forest	25	17-34
grass	9-27	13
acacia catechu plantation		28.5-39.1
Acacia harpophyllia	15.2	

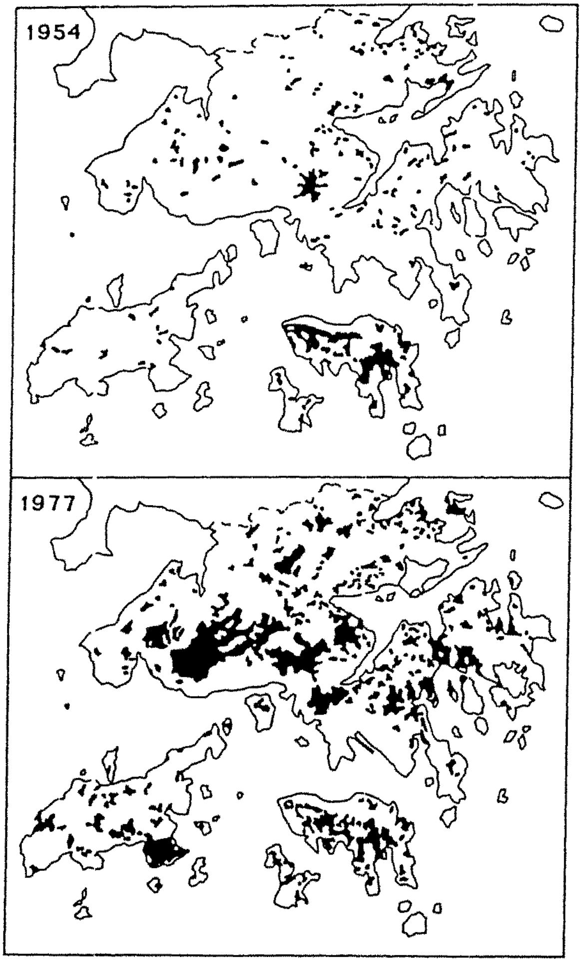
Resource Sheet 27

Results of a modelling study of the redistribution of water in a small catchment in England for a precipitation input of 715mm under 4 different vegetation covers

vegetation	runoff (mm)	interception loss + soil evaporation (mm)	transpiration
wheat	417	158	134
pine	152	253	309
oak	279	172	263
grass	318	62	335

Resource Sheet 28

Distribution of Forests - A Comparison of 1954 and 1977



Source: Prepared by W J. Kyle from land-use maps for the relevant years.

(After Catt, 1983)

Resource Sheet 29

(a) The effect of grain size in initially wet soils without vegetation cover

Grain size class	Infiltration rates (mm/hr)
Clays	0-4
Silts	2-8
Sands	3-12

(b) The influence of moisture content for Illinoise clay-pan soils (after Musgrave and Holtan, 1964)

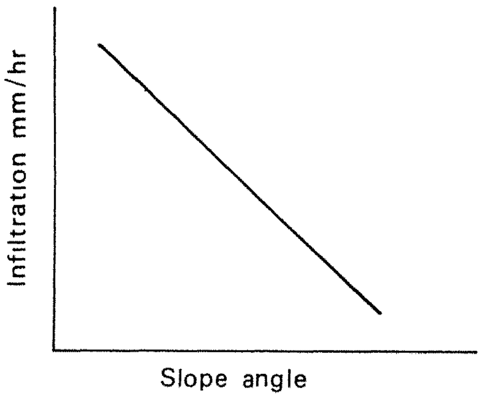
Initial moisture content (%)	Infiltration rates (mm/hr) Good grass cover	Poor weed cover
0-14	18	6
14-24	7	4
24 +	4	3

Resource Sheet 29
-continued

(c) The influence of ground cover for Cecil, Madison, and Durham soils (after Musgrave and Holtan, 1964)

Ground cover	Infiltration rate (mm/hr)
Old permanent pasture	57
Permanent pasture; moderately grazed	19
Permanent pasture; heavily grazed	13
Strip-cropped	10
Weeds or grain	9
Clean tilled	7
Bare ground crusted	6

(d) The effect of slope upon infiltration



Resource Sheet 30

1. DEFINITION OF A PLOT STUDY: a plot study is a smaller scale investigation than a drainage basin. A small area on a hillslope is isolated and the rainfall input is monitored and all surface runoff is collected and measured. The advantage of plot studies is they permit more control of such factors as vegetation cover, slope angle and so forth than is possible in drainage basin studies.

2. HSU, S.I. et al. (1983)
During the period June 1981 to October 1982 52 rainfall events were sampled and the following results were obtained for two small plots:

PRECIPITATION (mm)	RUNOFF (mm)	
	GRASS SLOPE	CHUNAM SLOPE
785.25	167.32	486.64

3. PREMSCHITT et al. (1986)
On two cut slopes small instrumented plots were established. For 42 storms between 1st September 1984 and 20th September 1985 the following results were obtained:

PRECIPITATION (mm)	RUNOFF (mm)	
	GRASS SLOPE	CHUNAM SLOPE
1,393.50	284.10	1,183.50

4. LAM (1969)
Data from plot studies, which was collected during the period 1959 to 1962 by the Forestry section of Hong Kong Government was used to construct monthly rainfall/runoff relationships for a slope covered with Pine trees and a bare slope. The relationships are shown below and they indicate that for a given volume of precipitation the vegetated slope generates less runoff in comparison to the barren slope.

RESOURCE SHEET 31

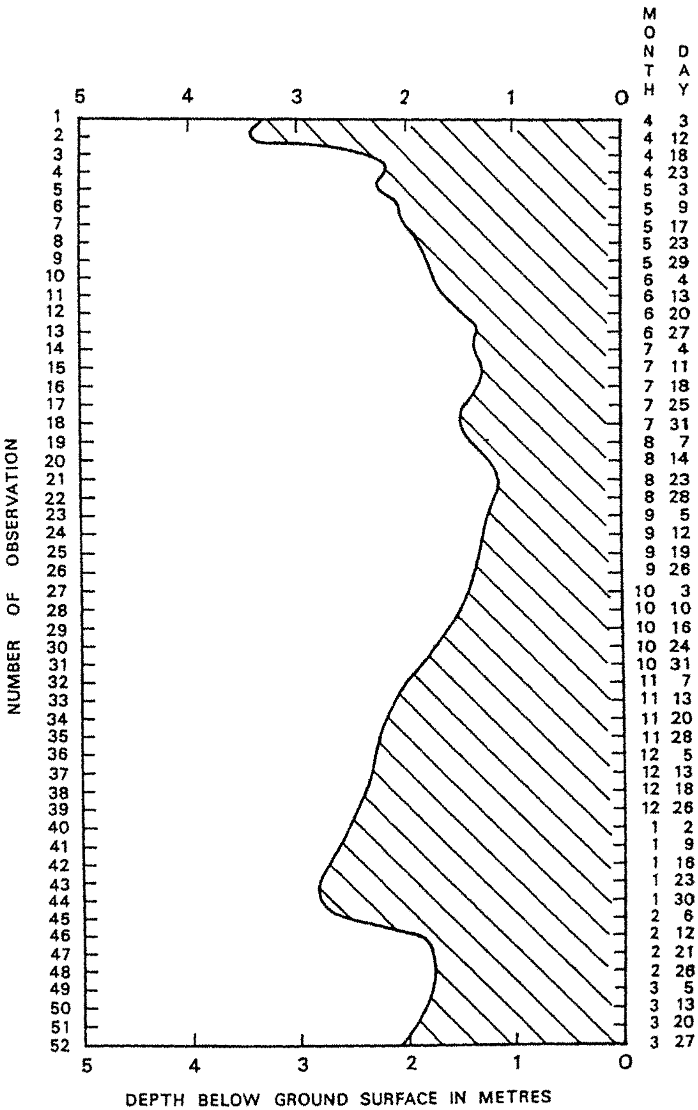
Rainfall and runoff at the Tai Lam Chung 'A' Basin (interpolated data)

Water Year	Rainfall (mm)	Runoff (mm)
1984	1978.70	1122.20
1983	1802.60	1500.40
1982	3883.60	2600.50
1981	1424.70	785.30
1980	1494.30	965.90
1979	1885.00	1343.10
1978	2345.70	1196.20
1977	1462.80	583.40
1976	2079.60	1221.40
1975	2979.10	1990.30
1974	2511.00	1052.30
1973	2469.00	1554.20
1972	2159.10	1173.30
1971	1710.90	807.70
1970	2353.30	1329.70
1969	1613.30	960.40
1968	1752.80	1125.20
1967	1881.20	772.80
1966	1989.20	1278.60
1965	1959.90	1057.10

RESOURCE SHEET 32

High Island Water Scheme - observation well

STATION NO. 106 MUI TSZ LAM NO. 1
WATER YEAR 1984



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