Curricula and syllabi in hydrology

A contribution
to the International
Hydrological
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Second edition

Chief editors:
Satish Chandra and
L. J. Mostertman

Unesco

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Preface

Although the total amount of water on earth is generally assumed to have remained virtually constant, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, are stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" philosophy—either with water resources or any other natural resource. As a result, the need for a consistent policy of rational management of water resources has become evident.

Rational water management, however, should be founded upon a thorough understanding of water availability and movement. Thus, as a contribution to the solution of the world's water problems, Unesco, in 1965, began the first world-wide programme of studies of the hydrological cycle—the International Hydrological Decade (IHD). The research programme was complemented by a major effort in the field of hydrological education and training. The activities undertaken during the Decade proved to be of great interest and value to Member States. By the end of that period, a majority of Unesco's Member States had formed IHD National Committees to carry out relevant national activities and to participate in regional and international co-operation within the IHD programme. The knowledge of the world's water resources had substantially improved. Hydrology became widely recognized as an independent professional option and facilities for the training of hydrologists had been developed.

Conscious of the need to expand upon the efforts initiated during the International Hydrological Decade and, following the recommendations of Member States, Unesco, in 1975, launched a new long-term intergovernmental programme, the International Hydrological Programme (IHP), to follow the Decade.

Although the IHP is basically a scientific and educational programme, Unesco has been aware from the beginning of a need to direct its activities toward the practical solutions of the world's very real water resources problems. Accordingly, and in line with the recommendations of the 1977 United Nations Water Conference, the objectives of the International Hydrological Programme have been gradually expanded in order to cover not only hydrological processes considered in interrelationship with the environment and human activities, but also the scientific aspects of multi-purpose utilization and conservation of water resources to meet the needs of economic and social development. Thus, while maintaining IHP's scientific concept, the objectives have shifted perceptibly towards a multidisciplinary approach to the assessment, planning, and rational management of water resources.

As part of Unesco's contribution to the objectives of the IHP, two publication series are issued: "Studies and Reports in Hydrology" and "Technical Papers in Hydrology". In addition to these publications, and in order to expedite exchange of information in the areas in which it is most needed, works of a preliminary nature are issued in the form of Technical Documents.

The "Technical Papers in hydrology" series, to which this volume belongs, is intended to provide a means for the exchange of information on hydrological techniques and for the coordination of research and data collection. Unesco uses this series as a means of bringing together and making known the experience accumulated by hydrologists throughout the world.

Contents

Foreword

The former IHD Working Group on Hydrological Education prepared a report on 'Curricula and Syllabi in Hydrology' which Unesco published in 1972 in its series 'Technical Papers in Hydrology' (No. 10). This report became out-of-date and the Intergovernmental Council of the IHP, at its second session in 1977, requested the IHP Working Group on the Training of Experts in Hydrology and Water Sciences (Project ED1) to review this publication on the advanced training of hydrologists, taking into account the need to incorporate in it changes resulting from the latest developments and new trends in hydrology. The Council further requested that this work be carried out with the assistance of the directors of the Unesco sponsored post-graduate hydrology courses.

When reviewing the 1972 version, the Working Group felt that not only should it be up-dated but also that essential sections should be redrafted. The Working Group prepared a new outline and a member of the Group, Mr. Satish Chandra, was given the responsibility of co-ordinating the compilation of the new publication. It was also decided that the co-operation of the WMO should be invited.

The Working Group provided the following guidelines:

a. The publication should be entirely devoted to undergraduate and post-graduate studies; technician training should be excluded and treated separately.

b. The general approach of the publication should be maintained.

c. The Intergovernmental Council of the IHP should invite IHP National Committees to submit new material on university programmes conducted in their countries, so as to provide the Working Group with the latest information.

d. The publication should advise potential course organizers on possible ways of effectively setting up new courses and on methods of introducing hydrology into other related scientific or engineering study programmes.

e. The model syllabus developed by the former IHD Working Group should be up-dated; in particular, the imbalance between surface and groundwater should be remedied.

f. The syllabus prepared by the former WMO Working Group on Training in Hydrometeorology should be replaced by the up-dated syllabus published in the WMO 'Guidelines for the education and training of personnel in meteorology and operational hydrology' (WMO No. 258).

g. New, modern topics should be introduced and the scope may be enlarged so as to include certain aspects of water resources assessment.

In order to support Mr. Satish Chandra a Team of Authors was established and it held its initial session at Unesco House, Paris, from 3-7 March 1980. The members of the team were Messrs. L.J. Mosterman (Netherlands), J.E. Nash (Ireland), J. Nemec (WMO), T. Peczely (Hungary) and Satish Chandra (India). Mr. W.H. Gilbrich (Unesco) acted as secretary of the meeting.

In accordance with the Council's deliberations, the Team of Authors noted the differences in syllabi for undergraduate and post-graduate studies and decided that examples of each should be included. The variety of educational systems was emphasized and it was recommended that, in developing new syllabi, due attention should be given to feasibility, endogenous capacities and appropriate evaluation of training objectives. In this connection, the need for practical exercises and on-the-job training was underlined.

The authors decided (a) to make use of the basic themes of the Unesco publication 'The Teaching of Hydrology' (which is now out of print) and (b) to differentiate between undergraduate courses in hydrology and undergraduate courses with an option in hydrology, and between post-graduate courses in general hydrology and post-graduate courses concentrating on selected subjects. The need for special syllabi for courses designed for specific climatological or geographical conditions was emphasized. The authors also considered that the publication might be used for the development of a system of hydrology courses which would ensure that all hydrological subjects were covered. When discussing the character of the publication, the authors recalled that the book was designed as a casebook which would also contain model or reference syllabi. The usefulness of this approach was underlined. The authors based their work largely on the material provided by the National Committees for the IHP and they realized that this material was uneven in terms of presentation, completeness and approach. Thus, inevitably, some courses have been reflected in greater depth while others have been made use of only in an abridged form. Later issues of this publication may be designed with a better balance of presentation.

As in the 1972 publication, an introductory text precedes the syllabi and curricula. The new text places more emphasis on the present status and future trends of hydrological education. Like the Unesco-sponsored courses during the seventies, this publication follows the general development in including aspects of water quality, environmental issues and water resources assessment for the rational utilization of water within national planning schemes.

1. OBJECTIVES OF HYDROLOGICAL EDUCATION

Hydrology may be defined as "the science that deals with the waters of the earth , their occurrence, circulation and distribution, their chemical and physical properties, and their reaction with their environment, including their relation to living beings" (Unesco/WMO International Glossary of Hydrology). As such, hydrology is an indispensable requirement for planning in the field of water resources. Owing to its rapid development during the last decade, hydrology has become a fundamental science for water resources management. Hydrological investigations, including the collection and interpretation of data on precipitation, evapotranspiration, discharge etc., are essential for the practical planning and design of water development schemes.

Civil and sanitary engineers, who traditionally are engaged in water resources studies and design, are enabled by including hydrological courses in their education to improve the quality and efficiency of their designs. In the last few years, new methods for the assessment of surface and groundwater resources have become available as have more sophisticated tools for studies of optimal water use. Application of these more specialized methods requires a training that is more specialized than is normally offered in undergraduate engineering programmes. This determines the need for professionals with hydrology as their main area of competence.

The increase in population and the growth of economic activities in most countries results in a greater demand for water. The consequent water scarcity already forms a limiting factor for development in many regions. The quality of water resources planning and management must therefore be as high as possible. This in turn requires a good data base which can be provided only through having a sufficiency of well trained hydrologists. The training of hydrologists therefore forms an important contribution to economic development.

The main objective of hydrological education is to develop competence for the measuring, handling and analysis of hydrological data, as well as proficiency in the application of such information for the planning and design of water resources projects. The level of competence and proficiency developed varies with the type of education provided. It ranges from the ability to follow standard procedures by geographers and engineers who study hydrology as a small part of a much wider programme, to the use of advanced and original methods of analysis by specialists in water resources for whom hydrology forms a major portion of their professional education.

The level at which hydrology may be taught and the aim that this teaching has in view will be very varied. The extent of this variety basically depends on the system of education prevalent in the country, regardless of whether it is industrially developed or not. In the main, there are four educational activities in hydrology available at the university level: complete undergraduate education of professional hydrologists; hydrology as a subject of study in an education for such fields as civil, sanitary, water resources, environmental and agricultural engineering, geology, geography and geophysics; hydrology as a major option in undergraduate or post-graduate curricula; post-graduate education to train professional hydrologists.

The "International Hydrological Decade" (IHD) (1965-1974) and the first phase of the "International Hydrological Programme" (IHP) which followed, have had considerable impact on all activities in hydrology. Whereas before 1965 hydrology was being taught only at a few places, during the Decade it was introduced into many university and college programmes. Many textbooks on hydrology and related subjects have been published since 1965. A series of special post-graduate courses on water sciences, directed at the needs of developing countries, were set up with the assistance of Unesco.

The aim of this technical paper is to offer sets of examples of the contents of teaching programmes in hydrology. The reader may find that these pages offer useful ideas in drafting curricula and syllabi for specific programmes. The proper programme for a given case will depend on the local needs and facilities, the system and level of education and the local social, economic and physiographic conditions.

2. SPECTRUM OF HYDROLOGICAL EDUCATION

By the nature of its definition, hydrology comprises the description and study of many diverse natural phenomena. Applied hydrology encompasses a variety of methods for the analysis and treatment of hydrological data. Despite this diversity, which is also reflected in textbooks and handbooks on the subject, hydrology is recognized as a distinct single discipline. Its basic principles and methods of analysis are usually taught in one or two courses, which appear under various names but contain essentially the same subject matter. Other, more advanced courses are usually offered in addition to the basic courses. These advanced courses concentrate on specific aspects of hydrological processes, or on special methods of an analysis, or on some specified approaches in hydrological design. Different combinations of the basic course and the advanced courses produce a large variety of educational programmes in hydrology.

Analysis of the professional activities of a hydrologist brings to light the manifold aspects of hydrology and these are of course reflected in the various programmes of hydrological education. The diversity in educational programmes is even greater than in the subject matter itself due to differences in local conditions. The different systems for teaching hydrology follow the pattern of the existing facilities from which they emerge and also reflect the specific natural, economic, social and administrative conditions of a given country. The achievements of scientific research and the results of international programmes such as the International Hydrological Decade have also influenced the development of hydrological education.

The necessity of adapting hydrological education to the particular needs and to the socio-political structure of a country is characteristic, and distinguishes hydrology from other closely related fields such as meteorology, for which teaching follows more closely internationally accepted guidelines. The absence of a universal programme for hydrology may be advantageous in allowing the educational process to adjust more quickly to changing needs and available facilities; however it does make it more difficult to compare different teaching programmes.

Considering the curricula of a number of universities and other institutes or centres for the teaching of hydrology, and the syllabi of the subjects taught, it appears that there are two levels of diversity. One relates to the list of topics included in the basic course or courses in hydrology. The second refers to the list of courses included either as required or optional continuation of the basic course. The latter depends, of course, on the type of education undertaken but even for one definite level of competence, the curriculum offered at various institutes is different.

There are also variations in the syllabi of advanced courses bearing the same title at different institutes. Such variation is relatively small and may reflect the personality and preferences of the teacher as well as the influence of local conditions and the local importance of various aspects of the subject. It should be added that even where syllabi are identical, the teaching may be different depending on the background and personality of the teacher and the availability of teaching aids and experimental facilities.

One more source of variability is in the requirements of the various institutes for background and peripheral courses. These requirements may reflect the basic approach to learning of the institutions but in many cases it is also a result of the framework and the development of the hydrology programme concerned.

Despite the diversity in programmes and in course contents, the general pattern of hydrological education at present is as described in the previous chapter. There are four alternatives for gaining hydrological education at a university level:

a. Complete undergraduate training as professional hydrologists.
b. Participation in a post-graduate programme for training of professional hydrologists.
c. Taking hydrology as a major option in an undergraduate or a post-graduate programme of studies.
d. Studying the basic courses, possibly with one or two optional advanced courses, in a programme leading to a degree in engineering, geography, etc.

Ideally, professional training in hydrology should be provided over a full undergraduate course but the relatively small number of positions available to hydrologists renders this early specialization impractical except in the largest countries or those with special interest in or dependence on water resources. An alternative which might prove feasible would be to modify a civil engineering curriculum to constitute a water resources option without losing the essential civil engineering component. This could be done by replacing some of the structural engineering components of the traditional curriculum by additional courses in water resources and related topics. The traditional courses on water supply, sewage disposal, surveying and even construction would, however, be maintained. Where it is considered desirable to do so, water resources engineering could be combined with other subjects such as road planning under the title of 'civil engineering (environmental)'.

For the immediate future, however, and in many countries for the foreseeable future, the normal method of training professional hydrologists will continue to be by way of post-graduate courses designed to 'top up' existing training usually in an appropriate branch of engineering or to convert a science graduate. The main advantage of this method lies in the fact that students taking such courses will, in most cases, have reached a mature decision to pursue a career in hydrology and often will already be employed in that area. The disadvantages are derived from an impatience in mature students towards the study of a broad course and the difficulty of obtaining a commitment to study over a sufficiently long period. Most such courses require up to one year of study. A further difficulty is that universities consider post-graduate study as the prerogative of only the (academically) best graduates. Post-graduate courses thus tend to become academically biased and to create an elite of academically excellent graduates, rather than providing the spectrum of personnel with practical to theoretical skills which a stable professional community needs. To overcome this difficulty, universities might be encouraged to recognize such continued education (or 'topping up') courses for what they are and to distinguish between these and higher level specialist courses, usually academically excellent, which they could continue to provide for suitably qualified personnel.

3. TOPICS FOR EDUCATION IN HYDROLOGY

Because of differences in the educational systems, the natural circumstances and the needs of various countries, it is impractical to recommend one standard curriculum with world-wide validity. The alternative is to draw up a list of topics which should be included in the educational programme of the future hydrologist. This list can give some guidance to those engaged in the preparation of a curriculum for hydrological education. In preparing such a curriculum, the aim should be to try and provide a proper scientific basic training in hydrology which would, insofar as it was scientific, be common to all circumstances.

The IHD Working Group on Education and the IHP Working Group on Training Experts in Hydrology and Water Sciences have recommended a series of topics that must be taught to ensure that the student receives the minimum of necessary theoretical knowledge and adequate practical training. These topics should be taught in a manner consistent with a specified minimum level of proficiency in mathematics and science which the student must have achieved. The list of topics can be considered as a minimum theoretical knowledge that a person should have in order to be considered a professional hydrologist. This knowledge should of course be supported and amplified by practical training.

The list of topics recommended by the two Working Groups is given below in sections 3.1 and 3.2. Detailed syllabi for the various topics are given in Annex IA. This curriculum may be used as a reference by those who have to design or adapt a training programme on this level. It is not intended as a model to be followed, because each institute of education offering hydrology training will have to adapt its curricula to its own facilities and to the local circumstances.

In addition to the courses considered to be essential, the programme for education in hydrology should contain a number of additional advanced courses. The number of courses depends on the level of training. It may be one or two for students majoring in engineering or geography or it may be ten to twenty for students doing a complete undergraduate or graduate training in hydrology. A list of topics which can be included in these specific or advanced courses is given below in section 3.3. Some of these topics can form a complete course of studies, others represent only sections of courses which can be grouped to form a complete course. Syllabi for some of these advanced courses are given in Annex IB. The selection of the topics to be included in any programme depends, of course, on local conditions and interests.

"An additional source of topics for courses in hydrological education and an example of a curriculum for such education is published in Part II of the second edition of the WMO Publication "Addendum to Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology" (WMO Publication No. 258). This publication includes, among others, curricula and syllabi for the education and training of professional personnel in operational hydrology, prepared by the WMO Commission for Hydrology (CHy). These curricula are reproduced in Annex IC and should serve as useful guidelines for the organizers of special or post-graduate training programmes in the field of operational hydrology. The main topics included in these curricula are listed in section 3.4 below."

3.1 <u>Topics from other disciplines that are basic requirements for the study of hydrology at the professional level</u>

1. General mathematics.
2. Analytical geometry.

3. Differential and integral calculus.
4. Computer programming.
5. Probability and statistics.
6. Engineering drawing and graphics.
7. Elementary physics.
8. Elementary chemistry.
9. Elementary geology and geomorphology.
10. Surveying and cartography.
11. Interpretation of aerial photographs.
12. Fluid mechanics.
13. Hydraulics.
14. Theory of sediment transport.
15. Flow through porous media.
16. Soil science.
17. Ecology, forest types and farm crops.
18. Elements of water resources engineering.
19. Elements of economics of water resources.
20. Water pollution.
21. Meteorology and climatology.

3.2 <u>Essential hydrological topics for all hydrologists</u>

1. Introduction to hydrology.
2. Precipitation.
3. Evaporation and evapotranspiration.
4. Infiltration.
5. Groundwater.
6. Flow in open channels and streams.
7. Surface runoff.
8. Rivers and lakes.
9. Water balance.
10. Hydrological measurements.
11. Quality of water.
12. Hydrological data handling.
13. Hydrological analysis.

3.3 <u>Topics of courses or sections of courses which can be used for advanced programmes in hydrology</u>

1. Stochastic and parametric hydrology.
2. Urban hydrology.
3. Agricultural hydrology.
4. Groundwater development.
5. Geology and hydrogeology.
6. Groundwater systems modelling.
7. Geomorphology, sediment transport.
8. Meteorology and hydrometeorology.
9. Forest hydrology.
10. Hydrology of coastal and estuarine areas.
11. Hydrology of lakes and reservoirs.
12. Hydrology of marshes and swamps.
13. Hydrology of tropical zones.
14. Hydrology of arid and semi-arid zones.
15. Snow and glacier hydrology.
16. Man's influence on the hydrological cycle.
17. Experimental and representative basins.
18. Hydrological forecasting.
19. Nuclear and tracer techniques in hydrology.
20. Photo-interpretation and remote-sensing for hydrology.
21. Computer programming and data processing.
22. Watershed management.
23. Water resources planning and management.
24. Water resources systems analysis.
25. Legal and environmental problems in hydrology.
26. Water quality.

3.4 Topics of courses included in the curriculum for the training of professional personnel in operational hydrology

a. Education in the basic sciences

1. Algebra.
2. Differential and integral calculus.
3. Partial differential and integral equations.
4. Probability theory and statistics.
5. Numerical and graphical calculation.
6. Machine computation.
7. Particle dynamics.
8. Rigid body dynamics.
9. Elastic media.
10. Hydrodynamics.
11. Thermodynamics.
12. Electromagnetism.
13. Electromagnetic radiation.
14. Atomic and molecular physics.

b. Education in operational hydrology and related subjects

1. Principles of descriptive geometry and technical drawing.
2. Theoretical mechanics and fluid mechanics.
3. General chemistry and hydrochemistry.
4. Principles of geophysics, geology, geomorphology and soil science.
5. Surveying.
6. Hydraulics: open channel flow dynamics and channel processes.
7. General meteorology and climatology.
8. Synoptic meteorology.
9. Hydrological instruments and methods of observation.
10. Design of networks.
11. Collection, processing and publication of data.
12. Hydrological analysis.
13. Hydrological forecasting.
14. Applications to water management.
15. Organization of hydrological services.

4. PRESENT STATE OF EDUCATIONAL PROGRAMMES

4.1 Complete undergraduate training as professional hydrologists

The specialized undergraduate university education of hydrologists seems to be typical for large countries with adequate employment possibilities for the graduates of such specialized institutes. Complete undergraduate programmes in hydrology exist at present only in very few countries. The curricula and syllabi of existing programmes in the USA, in the USSR and in Sweden are included in Annex II.

The availability of complete undergraduate programmes for hydrologists will probably continue to be limited to a few countries. The organization of such complete programmes in other countries, or other regions of the world, will be justified only if there were sufficient opportunities of suitable employment for their graduates.

The duration of the complete courses are between 4 and 5 years. In some places it is possible to participate in the programme on a part-time basis which prolongs the durations of the programmes. The programmes usually include some field work and practical training as an essential part. The objectives of the complete undergraduate programmes are to teach the participants a variety of techniques of measuring, handling and reduction of hydrological data, to give them competence in various methods of analysis of data and their use for water resources planning and, for some of the participants, to provide them with a good basis for further study and independent research in advanced problems of hydrology.

4.2 Post-graduate programmes for training as hydrologists

Generally, there are two types of post-graduate training and education programmes in hydrology:

(i) integrated post-graduate programmes of long duration, leading to a post-graduate degree or diploma as a professional hydrologist;

(ii) programmes of short duration on specialized topics leading to increased competence in special subjects or to widening the participant's information.

In the integrated post-graduate programmes, a student follows a more or less fixed curriculum for periods of between six months and two years leading to a post-graduate certificate, diploma or degree in hydrology. These programmes are directed, as far as possible, towards providing education in the wide spectrum of hydrology and equipping students to handle hydrological problems with limited or no guidance. A number of such programmes have been developed as Unesco-sponsored and other international post-graduate courses. Universities in some countries also organize integrated post-graduate hydrology courses leading to a Master's degree. Examples of the curricula and syllabi of some Unesco sponsored post-graduate programmes are given in Annex IIIA. Examples of some integrated post-graduate programmes leading to a Master's degree are given in Annex IIIB.

The short duration specialized programmes considered in this section are those intended for hydrologists who have already gained a more or less complete professional training. Developments in hydrology are taking place at such a rate that the hydrologist must refresh his education and become acquainted with the recent developments and newer techniques for hydrological work. This may include informal seminars organized with research workers and hydrology professors from well established institutions on the one hand and, on the other hand, formal training courses on specialized topics to provide the hydrologist with an opportunity to up-date his knowledge so that he may carry out his duties more effectively. Such seminars and courses will usually be of short duration from a few days to one or two months.

These specialized short programmes could be organized as regional courses or as roving seminars with course material prepared beforehand and made available to the participants. Topics of courses to be included in such programmes can be selected from the list of advanced topics given above in section 3.3. The structure of each programme would depend on the specific aims of the organizers and the students involved, on the educational background of the students, on the availability of teaching personnel, and on the facilities at which the training takes place. Examples of short duration programmes given in recent years are given in Annex IIIC.

4.3 Hydrology as an option in university programmes leading to another degree

In general, university education has not been directed towards highly specialized undergraduate study. In these circumstances, fairly extensive hydrological education can still occur in two types of programmes. In the elective curricula type, a student having chosen his field of study follows a hydrology option during the last one or two years of his course, obtaining his degree in his main field of study. In other circumstances, it is not uncommon for students to follow a general course in another field of study with one or two subjects in hydrology as part of the fixed programme or elective subjects in the programme chosen by the student himself. Civil, environmental and agricultural engineers thus obtain some familiarisation with hydrological methods without becoming specialists in the subject. Agronomists and foresters, geologists and geographers have also become aware of the job opportunities which hydrology offers and this has led to the introduction of this subject in several faculties of agriculture, geology and geography. Examples of curricula and syllabi of hydrology options in undergraduate courses are given in Annex IV.

At some institutions it is possible to follow a hydrology option as part of the programme of studies towards a Master's degree in such fields as civil engineering, water resources management, agricultural engineering, or some non-engineering fields. It should be added that the hydrology option of many graduate study programmes or even the hydrology option to some undergraduate engineering or science courses, can lead to competence as a professional hydrologist if the programme is of sufficient scope and depth. Examples of graduate study options in hydrology leading to a Master's programme in a non-hydrology field are also included in Annex IV.

4.4 General background programmes in hydrology

Hydrology constitutes a part of the educational programmes both at the undergraduate and post-graduate levels in a large number of disciplines. Among these one may mention civil engineering, agricultural engineering, environmental engineering, water resources engineering, geology, geography, forestry, agronomy. Those programmes are not aimed at training hydrologists. However, those taking a number of courses in hydrological subjects may afford a sufficient base for working in hydrology.

A great number of universities include one or two courses in general hydrology in the programme of studies towards degrees that are not hydrology or water resources degrees. Examples of such courses which provide a general background of hydrology and their syllabi are included in Annex V. The aims of these courses are generally to face the student with the importance of the hydrological aspect of his chosen profession and to familiarize him with the standard methods of data gathering and analysis and of hydrological design.

Further discussion of the programmes of hydrological education in some countries is available in the proceedings of a few international meetings held in recent years. A list of some of these meetings is given in the bibliography. Some remarks about and references to articles dealing with hydrological education are also included in many of the standard textbooks and handbooks on hydrology. The bibliography also contains a list of Unesco and WMO publications related to the curricula and syllabi in hydrology.

5. FUTURE TRENDS IN HYDROLOGICAL EDUCATION

Generally, it is very difficult to predict future developments and needs in hydrology. Since programmes for hydrological education tend to respond to the demands for practical or applied hydrologists, this uncertainty also applies to a prediction of future trends in hydrological education. The task is, however, somewhat easier since there are some basic trends, observed since the beginning of the International Hydrological Decade in 1965, which may be expected to continue, at least in the near future.

These basic trends include: (a) the continued and growing demands for hydrologists at all levels of education; (b) the increasing mathematical and scientific level at which the various topics in hydrology are treated; (c) the involvement and growing use of computers in the teaching of various aspects of hydrology; (d) the continued need for specialization within the spectrum of topics contained in hydrological education; (e) the growing importance of water quality aspects of water resources and its impact on hydrology; (f) the development of new techniques for observation and handling of data.

While these trends are reflected in all parts of the hydrological education programme, their impact is less pronounced in the basic or core courses. Their influence is greater in the specialized advanced courses, both in the topics of the proposed advanced courses and the material included in their syllabi. It is expected that this situation will continue over the next few years. The curricula of the basic courses will continue to list the familiar topics of the hydrological cycle, precipitation, infiltration, evapotranspiration, runoff, groundwater flow, etc. However, the course contents represented by these topics will slowly change as new techniques and technologies are introduced. The specialized advanced courses will continue to be the media for introducing new ideas and results from the advanced hydrological research into the curricula for hydrological education. In this respect, it is important to stress the need for continued education programmes for practising hydrologists. There are no doubts that the demand and the need for such courses will continue to grow in parallel with the numbers of people engaged in hydrology and with the introduction of new ideas and new techniques in hydrological practice.

In the discussion of future trends in hydrological education, it is useful to include also some comments on a number of subjects which are and will continue to be important parts of relevant courses.

The hydrological cycle will continue to be the main frame and background against which the various hydrological processes are studied. A quantitative knowledge of the cycle requires measurements and recording, and demands the study of the principles and methods used. It is difficult to forecast the types of instruments and the design of networks that will appear in the next stage. Measurements will, however, continue to play an important role in hydrology, in water resources inventories and in water management. The instruments and the methods of their use will become more accurate, more robust and less dependent on field observers. The collection, transmittal, processing, analysis, storage and retrieval of data over large regions will be performed by automatic equipment. Remote sensing will become a low-cost and effective instrument for water resources inventories. Aerial photography and other remote sensing imagery already form an important tool in the practice and the teaching of hydrology. This will increasingly become the case in the future.

Modern hydrology increasingly turns to a quantitative approach to the various elements of the hydrological cycle and to their interrelation and this tendency will continue to be emphasized in education. The mathematical models representing hydrological concepts and processes are still grossly simplified, partly because of our scientific ignorance and partly because the large amounts of data have proved to be unmanageable. These difficulties may be expected to yield, to some extent, to the increasing research effort and to the power of modern calculation devices. All hydrology and related courses should leave students with a clear understanding of the limitations of existing models and the meaning of the results of new research.

It is also important that practising hydrologists appreciate the quantitative implications of any simplifications inherent in their models of the hydrological cycle. There is a temptation to adopt refinements, as they are published, in one phase of the cycle which may already be better understood than others, without searching for the remedies for much larger errors in the other phases. Hence, the students need a fundamental understanding of the whole cycle and of the sensitivity of their results to any errors in their assessment of any one phase or part of the hydrological cycle.

The use of the digital computer has had a deep influence on hydrological studies in practice. Educational programmes cannot stay behind. Many subjects will be taught in a different way once the students have easier access to computers. However, the use of computers in hydrological education will be treated in a separate study assigned by the Intergovernmental Council of the IHP.

The growing importance of water quality aspects of the hydrological cycle will continue to influence hydrological education. In general, hydrologists in the past were primarily concerned only with the quantity of water in each phase of the hydrological cycle, but there will be a growing need for the study of physical, chemical and biological aspects of water quality as a result of the more extensive use of water resources in all countries. A sufficient mastery of the qualitative aspects of water resources and of the biological and chemical laws underlying the study of water treatment constitutes a vast field of study in itself. It is hardly possible for a hydrologist or for an engineer to master the control of water quality together with advanced methods of predicting water quantities and analysis. For schemes of any significance, the hydrologist, the engineer and the water quality specialist must work together with other professionals in an interdisciplinary team. In order to be effective here, the hydrologist will need a sound knowledge of water quality, including some practical laboratory experience. Programmes of field work on hydrometry should be amplified by the practical determination of simple water quality variables. One can expect that, in future, hydrological education will, to an increasing extent, imply also a study of the quality aspects of water.

Specialization in hydrological education is at present mostly on the basis of specific phenomena involved, which is related largely to the physical location of the water. There is a possibility that, due to the complexity and advanced nature of the procedures being used, new types of specialization will develop according to skills and basic training involved. Thus, specialization might be based on a fourfold division of mathematics, physics, chemistry and engineering. The mathematics specialization would be the most comprehensive and could cover all topics of surface water hydrology, the mathematics of groundwater and all analytical hydrology. The physics related specialization would include the physical and geological aspects of groundwater, as well as the processes of evaporation and climatology. The chemistry specialization would include the chemical and biological aspects of water quality, treatment and pollution. The engineering specialization might concentrate on the engineering works aspects.

Finally, there are some comments on the extent to which it will be necessary for a hydrologist to engage in wider studies of water resources planning. This will depend to a large extent on the organization for which he works. Many organizations will not be satisfied with studies resulting only in a prediction of water yield. They will require an indication of which duties this water can perform. Their hydrologists will, therefore, need a sound knowledge of the quantities of water needed for various uses as well as of the quality standards of the water for each use. They should also know how water demand for various uses is also related to economic factors. The use of water in conjunction with land and other factors of production should be planned to give an optimal contribution to national welfare. Such optimal solutions can best be studied by considering water and related resources as one system. Systems analysis for water resources planning is thus becoming more and more important. The hydrologists will be called to an increasing extent to take a share in the work of multidisciplinary teams, engaged in water resources systems analysis. This tendency dictates the need to include systems analysis topics as part of the hydrology education, probably at the post-graduate specialization level. There is further a need to give some hydrological training on an advanced level for water resources planners well versed in systems analysis. As this analyst should have a sound knowledge of hydrology, one can anticipate the need for special post-graduate programmes in hydrology for engineers whose main field is systems analysis.

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Annex IA

Reference syllabi for topics recommended by the IHP Working Group on Training Experts in Hydrology and Related Water Sciences

Introduction

Because of differences in the educational systems and in the levels of education in various countries, it is impractical to recommend specific curricula for hydrological education. One institution may be able to develop an undergraduate programme of four or five years' duration designed exclusively for the training of hydrologists, while another may find it desirable to provide hydrological education as part of an existing undergraduate programme, such as civil engineering. Still other institutions may wish to restrict hydrological education to a post-graduate programme. Thus, rather than a series of courses, the former IHD Working Group on Education and the IHP Working Group on Training Experts in Hydrology and Related Water Sciences have recommended a series of topics that must be taught to ensure that the student receives the necessary theoretical knowledge and adequate practical training. These topics may be presented as a complete undergraduate programme for the education of professional hydrologists or they may be taken at the post-graduate level as necessary to supplement an existing training in science or engineering. The list of topics recommended is given in Sections 3.1 and 3.2 in the preceding text. This annex gives the syllabi to the various topics although the arrangement of topics in this annex does not correspond exactly to the list.

1. Mathematical methods

General mathematics up to and including linear algebra, determinants, matrices, eigenvalues. Analytical geometry. Calculus including linear differential equations and partial differential equations. Laplace transforms and spectrum analysis, Laplace's equation and boundary value problems. Numerical analysis including systems of linear algebraic equations. Numerical solution of differential equations. Difference equations. z-transform. Solution of partial differential equations.

2. Probability and statistics

Applied statistics. Probability. Distribution theory. Likelihood, hypothesis testing. Regression and correlation. Theory of extreme values. Estimation and stochastic processes.

3. Elements of system analysis

Systems analysis. Analysis of linear input-output systems. Linear and dynamic programming, Optimization, Lagrange multipliers.

4. Elementary physics

Elementary physics, including heat, light and electricity. Molecular structure, Kinematic theory of gases. Elements of nuclear physics. Heat transfer, radiation. Elementary thermodynamics. Physical properties of water including surface tension, viscosity, hydrogen bond. Physics of flow in porous media.

5. Elementary chemistry

General chemistry. Atomic-molecular theory. The periodic system of elements. Chemical combination and the structure of molecules. Kinetics and chemical equilibrium, Theory of solutions. Basic principles of electrochemistry. Hydrochemistry: water as a solvent, its properties, electrolyte solutions. Principles of physico-chemical analysis. Surface phenomena and absorption. Basic problems of colloidal chemistry. Chemical composition of natural waters.

6. Theoretical Mechanics

Statics (including hydrostatics), forces and moments, equilibrium. Dynamics, forces, work energy, Newton's laws of motion. Coriolis force.

7. Fluid mechanics

Flow fields, graphical descriptors, mathematical descriptors, partial differentiation, vectors, gradients, divergence, rotation, circulation. Theorems of Green and Stokes. Mechanics of ideal fluids. Potential flow, flow nets. Laplace's equation. Conformal representation, sources, sinks, etc. Mechanics of viscous flow, Newtonian fluids. Navier-Stokes equations. Laminar and turbulent flow. Reynolds' stresses and Reynolds' equations. Boundary layer theory. Semi-empirical treatment leading to the logarithmic velocity distribution.

8. Hydraulics

Bulk flow. Momentum principle. Flows over weirs and through orifices and flumes. Flow in pipes. The universal resistance diagram. Uniform flow in open channels. Unsteady flow in pipes, water hammer. Principles of similitude and theory of models.

9. Geology

Composition of earth's crust, rock cycle classification of rocks, texture and structure, karst phenomena. Geomorphology, cycles and erosional processes, drainage patterns.

10. Hydrogeology (introduction)

Geological factors in water regime. Origin and occurrence of groundwater in different types of aquifers. Geomorphological and geological investigations for groundwater. Groundwater in rock fissures and karstic rocks. Springs, mineral water, thermal water. Geophysical prospecting for groundwater, well logging.

11. Soil science

Origin and classification of soil. Physics and chemistry of soils. Life processes in plants. Soil-water-plant relationship.

12. Climatology

General properties of the atmosphere. Composition and structure of the atmosphere. Basic gas laws applicable to the atmosphere. Principle of atmospheric statics. Radiant energy in the atmosphere. Heat exchange in the soil and transfer to atmosphere. Air humidity. Precipitation processes. Evaporation. Climate formation and classification. Local climate and microclimate.

13. Surveying and photo-interpretation

Plane surveying and cartography. Aerial surveying and remote sensing. Interpretation of aerial photographs and other imagery for hydrological processes.

14. Introduction to hydrology

Definitions and relation of hydrology to other sciences. The hydrological cycle. Physical characteristics of the watershed. Importance of data. Variability and randomness of hydrological phenomena.

15. Hydrological processes

Surface water, the run-off process, influence of surface conditions and soil cover, drainage pattern. Water in the unsaturated zone: water retention in the soil, tension, wetting and drying, flow processes, equations of motion, infiltration. Water in the saturated zone, Darcy's law, equation of continuity, steady and unsteady flow, the Dupuit-Forchheimer assumptions, flow-net analysis. Snow and ice.

16. Precipitation

Forms and mechanisms of precipitation. Determination of amounts, intensity and duration and spatial and temporal distribution of precipitation. Measurements of precipitation and their accuracy. Snow. Estimation of missing data.

17. Evaporation and evapotranspiration

Definitions. Determination by measurement and by computations. The energy and mass transfer approaches. Evaporation from water surfaces, soil, snow and ice. Transpiration. Total evaporation and total losses. Evaporation control.

18. Infiltration

Soil moisture. Laws governing infiltration. Measurement. Infiltrometers. Empirical formulae.

19. Groundwater

The origins and occurrence of groundwater. Types of aquifer. Hydrological properties of various pervious materials. Interrelation between groundwater and surface water. Depletion. Springs and wells. Water-table fluctuations. Movement of groundwater. Recharge of groundwater reservoir. Simulation by physical or electrical models. Quality of water.

20. Flow in open channels and streams

Energy relations. Uniform flow in prismatic channels. Gradually varied flow in channels and streams. Surface profiles. Unsteady flow and flood routing. St. Venant's equations, methods of solution; convergence. Flow in erodible channels. Theories of sediment transport. Channel morphology. Design of river regulation structures.

21. Surface run-off

Elementary hydrograph, separation of depletion flow and surface flow. Minimum flow. Types of run-off. Depression storage, overland flow, surface detention. Unit hydrograph techniques. Properties of the drainage basin. Synthetic hydrograph. Flood and droughts. Use of the unit hydrograph. Measurements. Statistical and other methods.

22. Rivers and lakes

The natural river as a medium of transport of water and sediments. The river as changed by man's influence. Morphology of river-beds. Natural and artificial lakes.

23. Water balance

Calculation of yield. Short-term and long-term variations. Water balance of lakes, swamps, watersheds and regions. Experimental drainage basins and representative basins.

24. Hydrometry

Collecting hydrological data as a technical and organizational problem. Decision on duration and frequency of observations and on their required accuracy. Various methods of measuring water-levels, velocities and solid and liquid discharges. Storage and processing of data. Cost of measurements. General principles for design of networks, general requirements, optimum network, minimum network.

25. Hydrological measurements

Precipitation, gauge location, recording and non-recording gauges, observations by radar and satellite. Water equivalent of snow, depth and extent of snow cover, ground surveys, radioisotope snowgauges, snow pillows, natural gamma radiation. Ice on rivers, lakes and reservoirs, methods of observation. Synoptic climatological measurements, humidity, temperature, wind speed. Water temperature, observational procedure, infra-red radiation thermometer. Measurement of water surface temperature for lake and reservoir evaporation. Evaporation and evapotranspiration, pan evaporation, soil evaporimeters and lysimeters, snow evaporimeters, indirect methods. Water levels of rivers, lakes and reservoirs. Discharge measurements by current meters, other methods for flow measurement, measurement under ice cover. Stream gauging stations, purposes, selection of site, control sections, artificial controls, stage-discharge relationships. Sediment discharge, suspended and bed load. Soil moisture, weight method, electrical-resistance method, tensiometric method, neutron method, gamma-ray method. Infiltration, infiltrometers, field plots, lysimeters. Groundwater levels, measurement, selection of observation wells.

26. Hydrological data handling

Collection, observational procedures, transmission of hydrological observations. Storage and retrieval of hydrological data. Processing and publication of hydrological data. Hydrological maps - hydrometeorological, surface water, groundwater, water balance, water quality and water management.

27. Hydrological analysis

Interpretation of precipitation data, adjustment of data, double-mass curve analysis, spatial distribution, evaluation of physiographic effects. Storm rainfall studies, depth-area-duration analysis, probable maximum precipitation (PMP). Rainfall intensities and frequencies, drought severity. Interpretation of snow fall, snowpack and snowmelt data. Interpretation of streamflow data, adjustment of data, spatial distribution. Maps of average annual run-off. Temporal distribution of run-off volume and yield. Relation of streamflow to rainfall, volumetric relations. Hydrograph analysis, unit hydrograph, linear and non-linear systems, total response modelling. Flow routing. Statistical relationships, flow duration curves, frequency analysis of floods and droughts. Regional analysis. Stochastic processes, modelling and simulation.

28. Water quality

Physical and chemical properties of natural waters. Changes in these properties by evolutions in land use, power generation, agriculture, industry and habitation. Chemical analysis of water. Water quality monitoring. Biological quality of water. Main principles of aquatic biology. Oxygen depletion and reoxygenation. Analysis of biological water quality. The excess of nutrients in water. Eutrophication of lakes and reservoirs. Prevention and control of water pollution. Quality requirements and standards for various types of water use. Water quality modelling.

Annex IB

Syllabi for topics for advanced study in hydrology

Introduction

The syllabi presented in this annex were collected from various sources, including the previous version of this publication. They are given as examples of possible syllabi for some of the topics listed in section 3.3, but variations can of course be introduced according to local needs and new technical developments. For ease of reference, the numbers given to the various syllabi correspond to the numbers identifying the topic in the above list.

1. Stochastic and parametric hydrology

Hydrological time series; deterministic and stochastic components; stationarity; trend and periodicity; inconsistency and non-homogeneity.

Autocorrelation analysis and the correlogram; spectral analysis and the power spectrum; model building; autoregressive integrated moving average processes; diagnostic checking; the generation of random variates; data synthesis. Short and long-memory models; modelling of seasonality; the Shot Noise process; the Hurst phenomenon; Fractional Gaussian Noise and Broken Line models; multi-site models and disaggregation processes.

Parametric methods in hydrology: the systems viewpoint; nature of hydrological systems; some systems mathematics; state variables and parameters; blackbox analysis; objective functions and optimization; linear conceptual models; linear methods of flood routing; non-linear conceptual models; the role of systems and parametric hydrology.

2. Urban hydrology

Various types of urban run-off; storm run-off, domestic waste water and industrial waste water. Piped and open-channel drainage. Combined or mixed transport of storm water and waste water.

Precipitation and run-off from small areas. Various computation methods. Rational formula, Izzard's method for computation of overland flow; soil conservation service procedure (United States), unit hydrograph, Road Research Laboratory hydrograph method (Great Britain), Chicago method with emphasis on construction of hyetographs, computation of depression storage, flood routings above the surface, gutter, lateral and main canals. Use of the standard graphs of the Chicago method.

Storage inside urban areas. In natural and artificial reservoirs.

Influence of upstream run-off on the urban area.

Groundwater in the urban area. Influence of underground discharge and of withdrawal. Land subsidence in the urban area.

Water quality of run-off from streets, markets, sports fields, roofs and of domestic and industrial wastes.

Quality of urban groundwater. Disposal of waste water in the underground and its consequences.

3. Agricultural hydrology

Soil classification. Agricultural evaluation of the soil. Soil and water. Different conditions of the water in soil. General computation of dotations for irrigation. Establishment of irrigation water requirements for cultivated plants. Measurements of humidity rates and humidity tension in the soils. Water circulation in the soil. Irrigation methods.

4. Groundwater flow and development

Types of aquifers, storage and distribution. Hydraulics of wells, well interference, well and free surface interaction.

Steady flow in confined, semi-confined and unconfined aquifers. Principle of superposition and images. Application of complex variables. Graphical method, numerical methods and analogue models. Flow net analysis.

Non-steady groundwater flow. Compressibility of water and soil, phreatic storage. Derivation of important flow equations. Analytical and numerical solution methods. Unsteady flow to wells and galleries.

Geophysical aspects

Introduction; occurrences of groundwater; practical importance of groundwater; objectives of study in groundwater projects; terminology.

Recapitulation of geology; importance, some terms, effects on porosity and permeability.

Aquifers, different types of aquifers (recharge and flow), semipervious and impervious layers, some figures and formulae for porosity, permeability and specific yield, determination of geohydrological constants for large areas.

Fresh and saline groundwater; origin and migration of salt. Principle of Badon Ghyben - Herzberg and its application to different types of aquifers.

Seepage; prediction of the amount of seepage. Practical consequences of seepage.

Exploitation of groundwater resources; natural recharge of groundwater; consequences of groundwater abstraction; concept of safe yield; artificial recharge, other aspects of groundwater control, groundwater mapping. Salt water intrusion.

Technical aspects

Introduction; formulae for the drawdown curves of galleries, single wells and well systems with confined or unconfined flow under different geo-hydrological and boundary conditions.

Design of galleries, wells and well systems. Test pumping analysis.

Methods of well construction. Construction of well casing and well screen. Well completion and well maintenance. Development and testing of wells.

Pumping equipment for wells.

Radial collector wells.

5. Geology and hydrogeology

Composition of earth's crust. Classification of rocks. Composition and texture of rocks in relation to the processes which lead to their origin, transformation and destruction. Description of the various types of igneous rocks, sedimentary rocks and metamorphic rocks. Review of the main exogenous and endogenous processes: action of wind, water, climate in terms of weathering, erosion, transport and sedimentation, volcanism and intrusions, tectonic movements, folding, faulting, jointing. Influence of various processes on strength and permeability of rocks. Land forms. Karst phenomena. Geomorphology, cycles and erosional process. Geological factors in water regime, origin and occurrence of groundwater in different rock types. Geomorphological and geological investigations for groundwater. Groundwater in rock fissures and karst. Springs, mineral water, thermal water. Geophysical prospecting for groundwater, well logging.

6. Groundwater systems modelling

General. Scaling procedure. Development of model laws and analogies; techniques for modelling groundwater systems; limitations of methods and theories. The sand box. The Hele-Shaw analogue. The electrolytic tank analogue. The RC-network analogue. Applicability of the various models and analogues. Applications of results to prototype conditions.

Development and use of computer models for groundwater systems. Calibration and testing of models. Applications to complex aquifers.

7. Geomorphology and sediment transport

Evolution of land form; weathering processes; slopes and their development; land forms created by river work. Geomorphology of limestone areas; land forms developed under arid conditions; the use of geomorphological maps; principle of geomorphological and geological photo interpretation. Soil erosion, soil deterioration and soil conservation. Classification of erosion processes. Factors affecting surface erosion. Sediment yield. Surface erosion control. Linear erosion. Sediment balance. Routing. Quantitative approaches.

Sediment properties, initiation of motion.

Sediment transport, bed forms, alluvial roughness.

Stable channels, deposition and erosion, local scour.

Sediment transport measurement procedures.

Characteristics of rivers.

River dynamics. Characteristics of natural rivers. Effect of river engineering works.

River models. Mathematical and scale models.

8. Meteorology and hydrometeorology

Atmosphere physics: general introduction, atmospheric gas laws, phase changes of water, psychrometer formula, moisture variables, thermodynamics of vertical atmospheric motion, radiation.

Micrometeorology: vertical turbulent transport, advection and exposure, mass transfer and energy balance evaporation theories.

Meteorological observation: general problems, requirements for stations.

General meteorology: vertical stability, precipitation formation, artificial control of precipitation, general circulation, large-scale weather systems, meteorological forecasting possibilities.

Climatology: synthetic parameters and classification, moisture indices, seasonal circulation patterns, local winds, diurnal and annual courses, influences of latitude and topography, climatic periodicities and changes.

Meteorological instruments: response theory, thermometers, radiation meters, hygrometers, snow and dew measurement, wind meters, radar, radiosonde. Principles of observation and recording for attended and unattended stations.

Observation methods: measurements of temperature, humidity, solar radiation and wind. Keeping, checking and adjustment of records.

Applied hydrometeorology: major weather types producing precipitation. Physics of evaporation: radiation; transport mechanisms; formulae. Measurement of precipitation, design of precipitation networks, precipitation data processing, total precipitation on an area. Intensity-duration-frequency relationships; depth-area-duration analyses, storm maximization.

9. Forest hydrology

Forest hydrology. Study of the erosion. Soil and erosion. Means of transportation. Study of carriages and suspensions. Measurement of solid flow in watercourses. Sample take-off. Conservation of reservoir capacity. Influence of vegetation on the amount of water which reaches the soil surface. Effects of the vegetation on surface run-over.

10. Hydrology of coastal and estuarine areas

Coastal morphology. Sources of salt. Measures to combat salt intrusion. Reservoirs in coastal areas; water and salt balance. Estuarine morphology. Mixing of fresh and salt water. Tidal effects. Water quality aspects of estuarine mixing. Siltation in coastal and estuarine areas.

11. Hydrology of lakes and reservoirs

Various types of lakes, related to their origin and land forms. Evaporation from lakes. Water balance of a lake, relation to the surrounding ground and surface waters. Physical properties of the water, temperature and density. Lake stratification.

Chemical water quality, salinity. Biology of lakes, nutrients, content of the water. Eutrophication of lakes. Sediments from the surrounding areas. Precipitation of silt in the lake, sediment control.

Oscillation of the lake water, causes and consequences, wind set-up and wind waves.

Very high and very low lake levels, drying up of lake bottom.

Management of the lake water quality, aeration.

Operation of lakes for water use, control of water level.

12. Hydrology of marshes and swamps

Various types of marshes, stagnant waters and swamps, their origin and history. Temperature and dynamics phenomena in bodies of standing water.

Water balance of a wetland area, relation to surrounding ground and surface waters, seasonal fluctuations.

Physical properties of water in ponds, marshes and swamps.

Chemical water quality in marshes and swamps, salinity, acidity and alkalinity.

Biology of marshes and swamps, evolution in the available biomass, formation of peat, siltation in the marsh and swamp area.

Coastal swamp areas, tidal flats, mangrove forests.

Consequences of drainage of marsh and swamp area, corrosion of the surface, subsidence, quality of drainage water.

Management of marsh and swamp areas for human uses and as natural area.

13. Man's influence on the hydrological cycle

Principal factors of the hydrological cycle that can be influenced by man. Human activity and its effects along the watercourses in connection with their training and utilization. Effect of human activity on the catchment area. Evaluation of the efficiency and development of water management.

14. Hydrological forecasting

Hydrological forecasts and warnings: types, classification including elements of the regime, period covered, forecasting methods, purpose, time advance.

Forecast methods: rainfall-runoff computation, seasonal and annual forecasts, hydrometeorological forecasts, conceptual catchment models, streamflow simulations, forecasting runoff from snowmelt, river ice formation and break-up forecasting.

Formulation, evaluation and verification of hydrological forecasts: evaluation of methods, verification of operational forecasts, relation between meteorological and hydrological forecasting, cost-benefit analyses.

Forecast of lake level: classification, natural changes and interferences in the regime, short-term and long-term forecasts, methods and selection.

Groundwater level forecasts: natural and man-made changes in the regime of groundwater, classification of forecasts, short- and long-term forecasts, methods and selections.

Water quality forecasts and warnings: chemical, toxical components and their parameters to be forecast, organization, data acquisition and transmission, time advance requirements in quality forecasting, technical equipment, issue of forecast warnings, short- and long-term forecasts, methods, selection of methods.

Hydrological forecast services: operation, organizations, data acquisition and transmission, issue of forecast and warnings, technical equipment.

15. Nuclear and tracer techniques in hydrology

Principles of tracer methods. Advantages and limitations of radioactive tracers. The use of artificial tracers in investigations of surface and groundwater. Radiotracer investigations of surface and groundwater flow and transport. Instrumental methods (snow gauging and survey, soil moisture logging). Occurrence and distribution of environmental isotope data in surface and groundwater investigations. The use of salts and other tracers. Applications of nuclear methodology and techniques to hydrologic investigations and measurement devices in hydrology.

16. Aerial photography and remote sensing for hydrology

Methods of covering an area by aerial photographs. Types of photographs. Geometrical properties of photographs. Difference between a vertical photograph and a map. Binocular vision. Different ways of observing photographs, parallaxes, floating marks. Necessity of ground-control. Slotted template method. Plotting with simple instruments. Principle of the reconstruction of bundles of rays.

The interpretation of aerial photographs. Qualitative and quantitative methods. Importance of photo-scale, emulsion type etc. Simple photogrammetric features; influence of distortion of the photomodel on the interpretation. Demonstration of main geomorphological types. Case studies demonstrating the use of aerial photography for studies in geohydrology and hydraulic engineering works, soil surveys based on geomorphological approach.

Remote sensing. Definition: remote sensing in nature. Main actual uses of remote sensing. Survey of remote sensing techniques. Interpretation of data. The earth's resources, satellite technology, application of remote sensing to meteorology, oceanography, glaciology of the polar caps, hydrology, environmental protection. Biological applications: crop survey, vegetation mapping, pest and disease spotting. Medical uses.

17. Computer programming and data processing

Use of digital calculators. Types of computers. Structure of a typical computer.

The FORTRAN programming language (or another language).

Development of computer programmes for the solution of hydrological problems.

Collection of data. Type of recording, codes, ways of registration, nature of the process, length of the recording interval.

Processing of data. Error detection, correction, data reduction, actual processing.

Storage of data. Files, data bases of information and of data.

18. Principles of watershed management

Elements of wildland hydrology and influence of forest and range vegetation on environment and water resource. Introduction to management of vegetation and use of small structural measures for watershed benefits. Techniques of managing wildlands for increases in usable water yields, protection of watershed values, and rehabilitation of depleted watershed lands.

19. Integrated water resources planning and management

Scope and basic principles, water needs and stage and types of development.

Evaluation of storage capacity, silting of reservoir and reservoir losses, water uses and conflicts.

Planning of single purpose and multi-purpose projects, data for planning, estimation of water needs, formulation and analysis.

River basin development: appraisal of resources and existing development; selection of optimal development, systems approach to optimization of benefits; engineering economy, financial and economic analysis, cost benefit and rate of turnover criteria; analysis of project returns.

Water balance, effect of development on hydrological regime.

Conjunctive use and management of surface and groundwater.

Reservoir regulation, operation planning, schedules and guides.

20. Water resources systems analysis

General principles of the application of system analysis to problems in water resources engineering. Water resources projects as systems. Identification of objectives, economic benefits, cost and decision variables. Application of micro-economics to design. Analysis of performance and production. Techniques for finding optimal development or minimum cost. Computation periods for problems requiring a combination of economic and engineering analysis. Deterministic and probabilistic analysis of hydrological and water resources systems using mathematical techniques such as simulation, linear and dynamic programming and queuing theory. Conjunctive utilization of surface-water and groundwater systems.

21. Hydrological models

Model - prototype relationship in hydrology, collection of data on prototype catchment, experimental and representative basins.

Physical models: rain simulators, catchment models, registration equipment.

Mathematical models: digital simulation of catchment behaviour - solution of equations of motion and continuity, conceptual modelling of the hydrological cycle; catchment as a system. Analogue simulation - catchment as a routing model (reservoir and channels), conceptual electrical analogy of the cycle. Hybrid simulation - digital and analogue.

22. Statistical analysis in hydrology

Definition of terms used jointly in hydrology and statistics, types of hydrological data, classification and presentation of data for purpose of analysis; elementary theory of probability, permutation and combination; frequency distributions of discrete variables and their application to hydrological variables, binomial, multinomial, hypergeometric. Poisson; frequency distributions of continuous variables and their application to hydrological data, normal, log-normal (two and more parameters), Gamma and Beta (one and more parameters), main types of Pearson distribution and distribution of extreme values; different plotting position formulas, use of probability paper, testing goodness of fit and other hypotheses, the Chi-square distribution, maximum likelihood method; comparison of means and variances, analysis of variance; regression and correlation analysis, simple linear regression, regression relation, multiple linear regression; tests of significance, Student t-test, Fisher F test and tests of significance of correlation coefficient. Sampling theory and its application to large and small samples. Applications of extreme value distributions to floods and droughts.

Annex IC

Curricula and syllabi recommended by WMO for the education and training of professional personnel in operational hydrology

INTRODUCTION

Part II of the second edition of the WMO Publication No. 258 'Addendum to Guidelines for the education and training of personnel in meteorology and operational hydrology' includes curricula and syllabi for training professional hydrologists and hydrological technicians.

The field of 'operational hydrology' (1) is defined as follows:

a. Measurement of basic hydrological elements from networks of meteorological and hydrological stations; collection, transmission, processing, storage, retrieval and publication of basic hydrological data;
b. Hydrological forecasting; and
c. Development and improvement of relevant methods, procedures and techniques in: network design; specification of instruments; standardization of instruments and methods of observation; data transmission and processing; supply of meteorological and hydrological data for design purposes; hydrological forecasting.

The curricula and syllabi presented below have been prepared by the Commission for Hydrology (CHy) of the World Meteorological Organization. They are given as guidance for organizers of courses or university-related training of professional hydrologists and do not represent any formal recommendation of the World Meteorological Organization on the training of the personnel of national services in charge of operational hydrology.

A. EDUCATION IN THE BASIC SCIENCES

1. Mathematics

1.1 Algebra

Classic linear and non-linear algebra with special emphasis on vectors and tensors; elements of modern algebra: fields, rings, groups, lattices.

1.2 Differential and integral calculus and advanced calculus

The classical course in differential and integral calculus including the theorems of Green, Ostrogradsky, Stokes and Gauss; methods of evaluating the asymptotic value of integrals.
Functions of a complex variable.
Classical course in series, including Fourier series and orthogonal functions; Fourier integrals.
Ordinary differential equations including linear and higher order and degree equations; solutions in series and the theory of special functions.
Classical course in differential and integral vector and tensor calculus.
Calculus of variation; optimal control theory.

1.3 Partial differential and integral equations

Boundary value problems in heat conduction.
Special functions.
Eigen functions and Eigen values.

1.4 Probability theory and statistics

Foundations of probability theory.
The statistical method and its scope.
Contingency and correlation.
Time series; random series; trends in time series; harmonic analysis; spectrum analysis (power spectra).
Method of least squares.

(1) Sixth WMO Congress, Annex to Resolution 12 (WMO-No. 292).

1.5 Numerical and graphical calculation

Numerical calculation of an expression involving only arithmetical operations.
Numerical differentiation and integration.
Numerical calculation of series.
Solution of ordinary differential equations; numerical approximation and graphical method.
Simultaneous linear equations.
Partial differential equations; relaxation methods.
Non-linear algebraic equations; numerical solution of cubic equations; graphical methods.
Approximation functions.
Solution of the standard transcendental equations; graphical methods.
Standard integral equations.

1.6 Machine computation

The use of computers in meteorology: computers, working principles; coding; general construction, central unit, in- and output devices (CRT displays, plotters); information carriers (paper tape, magnetic disc, microfilm for machine reading); memories; principles; lineprinters; tapes and cards, tape and punch-card machines; sorting and selection stages; programming principles; flow diagrams; programming languages (ALGOL, BASIC, FORTRAN); compilers; statistics, accounting and information handling machines; application of machine methods in meteorological services; analogue computers; processing of continuous variables; applications.

2. Physics

2.1 Particle dynamics

Kinematics of a particle.
Dynamics of a particle.

2.2 Rigid body dynamics

Kinematics of a rigid body.
Dynamics of a rigid body.

2.3 Elastic media

Equilibrium of elastic bodies.
Elastic waves.

2.4 Hydrodynamics

a. Kinematics
Eulerian and Lagrangian variables; decomposition of a field of motion in the vicinity of one of its points into a field of translation; a field of rotation and a field of deformation and divergence; physical significance of vorticity and divergence; application to plane motion.

b. Statics
Pressure; force due to the pressure gradient; equations of state and of change of state of a fluid; perfect gas equation; surface tension of fluids; capillarity; barotropic and baroclinic fluids; isobarisostere solenoids; Pascal's law; Torricelli's experiment; barometer; Archimedes' principle and buoyancy applications; hydrostatic equation along the vertical; altimetry, application to the atmosphere; Laplace's equation.

c. Dynamics
Eulerian and Lagrangian motion; boundary and initial conditions; continuity equation; case of gases and liquids; compressibility and incompressibility.

Work-energy theorem, balance of mechanical energy (potential and kinetic energy); application to aerodynamics; Bernouilli's theorem.

Vorticity and divergence; rotational form of the equations of motion; irrotational motion and two or three-dimensional rotational motion; irrotational motion in three dimensions due to sources, sinks, doublets and line sources; images; flow around an obstacle.

Circulation and vorticity: absolute and relative circulation and vorticity; case of the barotropic fluid: the Lagrange-Helmholtz theorem; case of the baroclinic fluid: V. Bjerknes' theorem and its interpretations.

Small disturbances and their propagation in a fluid in equilibrium; compressibility waves (sound waves); gravity and inertia waves.

Viscous fluids; coefficient of viscosity; case of gas; case of liquids; Navier-Stokes' tensor; integration of the viscous fluid equations in simple cases; Poiseuille's flow and Couette's flow; resistance of fluids to the motion of immersed bodies; Stokes' formula, limiting velocity, applications.

Turbulent fluids; one and two-dimensional turbulent flow; boundary layer; eddy lines and eddy motions in the wake of an obstacle; Reynolds' number; Reynolds' tensor; turbulent diffusion of heat and momentum, eddy conductivity and eddy viscosity; application to the atmosphere, turbulent diffusion of water vapour in air.

2.5 Thermodynamics

Object of thermodynamics: thermodynamic system; definition; exchanges of energy and matter with the external world; closed and open systems; physical state of a system; variables of state; (p,v) systems; Clapeyron's diagram.

Definition of temperature: temperature scales (Celsius, Fahrenheit, Kelvin); variables of state and the equation of state of a system; homogeneous and non-homogeneous systems; thermal expansion of solids, liquids and gases; case of gases: the laws of Boyle-Mariotte, Gay-Lussac, Avogadro and Dalton (gas mixtures); equation of state of a gas: perfect gas and Van der Waal's gas.

Definition of heat: quantity of heat; calories; thermal conductivity; specific heat; case of gases; heat of change of phase; heat of reaction (chemistry); calorimetry.

First law of thermodynamics: various forms of energy (work, heat, electrical and chemical energy, etc.); principle of the conservation of energy; principle of the equivalency of heat and work (Joule); statement and meaning of the first law in the cases of systems at rest and in motion (atmospheric air); in the cases of closed and open systems (clouds in the case of precipitation); case of systems in motion; consequences of the first law and of the kinetic energy theorem as applied to the system; internal energy; enthalpy; Gibb's system; work accomplished by the expansion of an ideal fluid; reversible exchange of work and heat; calorimetric coefficients of a fluid; adiabatic transformations; case of the perfect gas.

2.6 Electromagnetism

Electrostatics.
Direct current.
Magnetostatics.
Alternating current.
Electromagnetism.

2.7 Electromagnetic radiation

Geometric optics.
Wave optics.
Spectroscopy.
Theory of electromagnetic radiation.

2.8 Atomic and molecular physics

Concept of the composition of matter.
Elements of wave and quantum mechanics, and atomic physics.

B. EDUCATION IN OPERATIONAL HYDROLOGY AND RELATED SUBJECTS

1. Principles of descriptive geometry and technical drawing

Principles of descriptive geometry: point; planes; methods of conversion of projections; axonemetric projections.
Technical drawing: principles of projection and topographic drawing.

2. Theoretical mechanics and fluid mechanics

Statics: composition of forces; parallel forces - theory of couples on a plane surface; plane and general system of forces; centre of parallel forces and of gravity.

Kinematics: kinematics of a point; translation and rotation motion of a solid body; complex motion; plane-parallel motion of a solid body.

Dynamics: differential equations of the motion of a material point; theorems on the amount of motion of a material point and system; theory of shocks; theorems on the moment of the amount of motion of a material point and on the kinematic moment of a system; theorems on the variation in the kinematic energy of a material point and system - general law of energy conservation; d'Alembert's principle and principle of virtual displacements.

Fluid mechanics: kinematics of a liquid; hydrostatics; hydrodynamics of an ideal liquid; wave theory; dynamics of a viscous liquid.

3. General chemistry and hydrochemistry

General chemistry: atomic-molecular theory; structure of the atom and the periodic system of elements; chemical combination and the structure of molecules; kinetics and chemical equilibrium; theory of solutions; basic principles of electrochemistry; general properties of metals; alloys; first group of the periodic system of elements; second group; third group; fourth group; organic combination; fifth group; sixth group; seventh group; eighth group; zero group.

Hydrochemistry: water as a solvent; its properties; electrolyte solutions; principles of physico-chemical analysis; surface phenomena and absorption; basic problems of colloidal chemistry; chemical composition of natural water; chemical composition of atmospheric precipitation; chemistry of rivers, lakes and reservoirs; chemistry of groundwater; chemistry of seas and oceans.

Water pollution.

4. Principles of geophysics, geology, geomorphology and soil science

Principles of geophysics and general information about the globe: shape, dimensions and types of motion of the globe; layers surrounding the globe - atmosphere, hydrosphere, biosphere, lithosphere and bathysphere; their composition, structure, thermo-dynamic conditions and state of aggregation; terrestrial magnetism, density of the earth and distribution of gravity forces over its surface; distribution and relationship of water and land on the earth's surface.

Principles of geology: composition of the earth's crust; distribution of chemical elements in the earth's crust; minerals and rocks; geological processes; tectonics and mountain formation phenomena; historical geology methods.

Principles of geomorphology: classification of types of relief - morphological, orographic and genetic; action of flowing water and erosion; rivers and climate; water-accumulation forms of relief; karst and glacier forms of relief; forms of relief in deserts and mountainous areas.

Principles of soil science: soil formation, soil as polydispersion system; physics of soil; chemistry of soil; classification of soils; soil and water; movement of soil water; hydrological properties of soils; soil water balance.

5. Surveying

Plan and map: principles of theory of errors in measurements; measurement of lines in the field; optical parts of geodetic instruments; theodolite and theodolite survey; levelling; combined planimetric-altimetric surveys; approximation surveys; geodetic network; geodetic applications in stationary and field hydrological surveys; principles of aerial photography; principles of cartography.

6. Hydraulics: open channel flow dynamics and channel processes (river bed formation)

General hydraulics: hydrostatics; principles of hydrodynamics; flow through small and large orifices at constant and variable pressure; steady flow in open channel; pressure flow of a liquid in pipes; non-steady flow; spillways and flow over structures; hydraulic jump and energy dissipators.

River hydraulics: non-uniform flow in channels; flow with a variable discharge; unsteady flow in open channels; hydraulics of bifurcations and estuaries.

Principles of similitude.

Principles of the dynamics of streams with a non-erodable bed: mechanics and structure of two-dimensional channel flow; hydro-mechanical analysis of two-dimensional turbulent flow; non-rectilinear flow and additional resistance of channel to flow.

Physical and hydromechanical basis of the theory of flow in an eroding channel: main mechanical and hydraulic characteristics of river beds and sediments; mechanism of sediment transport.

Channel processes: hydrodynamic and hydromorphological approach to the channel processes theory; basic river bed processes produced by the construction of hydraulic structures.

7. General meteorology and climatology

General properties of the atmosphere; composition of structure of the atmosphere; basic gas laws applicable to the atmosphere; principles of atmospheric statics.

Radiant energy in the atmosphere: solar radiation; effective radiation and radiation balance.

Heat exchange in the soil, water and atmosphere: heat regime of the soil and bodies of water; principle of atmospheric thermodynamics; heat transfer in the atmosphere - air temperature; vertical distribution of air temperatures.

Physical meteorology: cloud formation; the nucleation of water-vapour condensation; the nuclei of atmospheric condensation; the growth of droplets in cloud and fog; initiation of the ice phase in cloud; the formation of snow crystals; the physics of natural precipitation processes.

Artificial modification of clouds and precipitation: suppression of large hail.

Wind measurement methods.

Climatological problems and investigation methods - relationship with meteorology and hydrology: climatological data processing methods; basic factors of climate formation; influence of relief on climate; influence of snow and ice on climate; geographical distribution of climatic elements over the globe; classification of climates; microclimate and local climate; changes in climate and climatic fluctuations; climates of the world.

Network of meteorological stations - observation times and the transmission of information.

8. Synoptic meteorology

General information on synoptic meteorology and short-range weather forecasts: basic synoptic codes - prospects of using meteorological satellite data - elements of World Weather Watch; compilation and analysis of weather charts; analysis of the fields of meteorological elements; air masses - their classification and properties; atmospheric fronts: cyclone activity; analysis and short-range forecasts of the synoptic position and weather conditions; quantitative precipitation forecasting.

Macro-synoptic processes and long-range weather forecasts: laws of general atmospheric circulation; peculiarities of circulation in various areas of the globe and types of macro-synoptic processes; methods of long-range weather forecasts covering long and short periods.

9. Physical meteorology (cloud microphysics)

Nucleation of the liquid phase from the vapour; condensation nuclei, their properties and distribution; ice nuclei and their properties and distribution in time and space; growth of cloud drops and ice crystals by diffusion, snow-crystal habit; size, number, fall speed of drops and crystals; limit on diffusional growth and need for precipitation mechanisms; Bergeron-Findeisen process; coalescence of cloud drops; growth of warm rain; formation of graupel and hail, growth of precipitation in convective, stratiform and orographic clouds; icing of aircraft; artificial modification of clouds; critical assessment of techniques for stimulation of rain, prevention of hail, dissipation of fog and cloud.

10. Hydrological instruments and methods of observations

Precipitation: gauge location; recording and non-recording gauges; snowfall; observation by radar; dew.

Snow cover: water equivalent; depth and extent of snow cover, ground surveys; radioisotope snowgauges; snow pillows; natural gamma radiation.

Evaporation and evapotranspiration: pan evaporation; soil evaporimeters and lysimeters; snow evaporimeters; short and long-wave radiation; indirect methods.

Water levels of rivers, lakes and reservoirs: gauges and procedures for measurement of state; frequency of gauge measurements.

Discharge measurements: current meters; float method; dilution method; measurement of corresponding stage; moving-boat method; ultrasonic method; electromagnetic method; indirect methods; measurement under ice cover.

Stream gauging stations: purposes; selection of site; control sections; artifical controls; stage-discharge relationships.

Sediment discharge: measurement of suspended sediment discharge; measurement of bed-sediment discharge.

Water temperature; instruments for point-to-point and continuous measurements; observational procedure; infra-red radiation thermometer; measurement of water surface temperature for lake and reservoir evaporation.

Ice on rivers, lakes and reservoirs: elements of ice regime; methods of observation; times and frequency of observations.

Soil moisture: weight method; electrical-resistance method; tensiometric method; neutron method; gamma-ray method.

Groundwater levels: methods of measurement; selection of observation wells.

11. Design of networks

General principles for design of networks: general requirements; optimum network; minimum network; optimum use of existing stations in organizing a minimum network; data to be considered in determining network density; quality of data to be collected.

Density of observation stations for a minimum network; factors affecting the density; minimum density limit of climatological networks; hydrometric network of minimum density.

Integration of bench-mark stations and representative basins in the network.

12. Collection, processing and publication of data

Collection: observational procedures; transmission of hydrological observations; quality control; storage and cataloguing.

Use of satellites in operational hydrology; types of sensor; platforms; hydrological applications; data-transmission systems.

Streamflow computation: computation of average gauge height; computation of average discharge; computation of average discharge under ice cover; quality control of streamflow data.

Special data collection: requirement, 'bucket surveys' of storm rainfall; weather-radar data; extreme river stages and discharges.

Processing: general methods; special applications.

Publication: purpose; requirements of hydrology; frequency of publication; contents and formats.

13. Hydrological analysis

Interpretation of precipitation data: adjustment of data, double-mass curve analysis, interpolation of data; spatial distribution, isohyetal maps, evaluation of physiographic effects; average depth over a catchment; storm rainfall studies, depth-area-duration analysis, probable maximum precipitation (PMP); rainfall frequencies, drought severity; rainfall intensities; snowmelt.

Interpretation of soil-moisture data.

Evaporation and evapotranspiration: derivation of lake and reservoir evaporation, water-budget method, energy-budget method, aerodynamic approach, combination of aerodynamic and energy balance equations, pan-coefficient method; estimates of basin evapotranspiration, water budget, energy-budget method, aerodynamic approach.

Interpretation of streamflow data: adjustment of data; spatial distribution, maps of average annual run-off; temporal distribution of run-off volume, unit hydrograph, isochrone method; streamflow routing; low-flow analysis, flow duration curves, low-flow frequencies, statistical analysis of droughts, recession curve analysis; flood frequencies, statistical analysis of floods, regional generalization of flood characteristics; long-period trends.

Run-off relations- rainfall and snowmelt: regression and analysis; run-off by storm periods, antecedent-moisture index method, initial base flow as index to rainfall run-off, moisture accounting techniques; run-off from short-period snowmelt; monthly, seasonal and annual water-budget.

14. Hydrological forecasting

Hydrological forecasts and warnings: classification of hydrological forecasts.

Hydrological forecasting services: operations; organization; collection of data and issue of forecasts and warnings; data requirements, accuracy and frequency of data measurements, operational data acquisition, use of radar observations for hydrological forecasting, use of snow and ice observations from meteorological satellites, technical equipment for hydrological forecasting services.

Forecast methods: theory of rainfall and snowmelt, floods and methods of their computation, forecasting run-off from snowmelt, seasonal and annual flow forecasts; stages and flows, flood forecasts, rainfall-run-off computations, conceptual catchment models, (numerical run-off models), streamflow simulation; short- and long-term forecasts of ice formation and break-up; updating of forecasts.

Formulation, evaluation and verification of hydrological forecasts: formulation of hydrological forecasts; evaluation of forecasting methods; verification of operational forecasts; relation between meteorological and hydrological forecasting; cost-benefit analyses for hydrological forecasting.

15. Applications to water management

Estimation of available surface water supplies: factors to be evaluated; suitability of available records; synthesis of hydrological data; probabilistic approach; time series approach.

Estimation of water demand and losses: estimation of components of water demand; estimation of water losses from surface water systems.

Estimation of required reservoir storage capacity: data adaptation; probabilistic approach, discharge frequency, volume frequency; time series approach, mass curves, Hurst phenomenon, Markovian process; multipurpose storage requirements; reservoir system design; environmental effects.

Estimation of design floods; definitions; types of design flood; determination of optimum design probabilities of flood discharge and the probability distribution used in hydrological design; data preparation; use of streamflow data in computing flood-frequency curves; techniques for computations of design floods, determination of design floods.

Design of flood control works: design of flood protection reservoirs; operational considerations for design purposes; operation of reservoirs for flood control; further considerations concerning reservoirs; channel modification, levees, flood proofing; other flood protection structures, non-structural measures, flood plain regulation, flood warning.

Design of urban and small rural watershed drainage works: rational method; unit hydrograph and time-area curves; distributed system models; rainfall data required for design of drainage works.

Estimation of maximum reservoir levels: wind set-up; wind generated waves; periodic undulations of water surface.

Sediment transportation: erosion of watersheds; sedimentation.

Influences of hydrological factors on water quality: streamflow; lakes and reservoirs.

General causes of water quality changes, reaction to pollutants; eutrophication; self-purification; absorption and accumulation; rise in water temperature.

16. Organization of hydrological services

Functions of hydrological services: basic data functions; reports on water resources; hydrological forecasts; analysis and design studies; research; training.

Organization of hydrological services: existing patterns; technical considerations in organizational planning.

Annex II

Curricula and syllabi for complete undergraduate training in hydrology

SELECTED SYLLABI FOR COURSES IN HYDROLOGY AND RELATED SUBJECTS IN THE U.S.S.R.

1. Fluid mechanics

1.1 Kinematics

Velocity fields of steady and unsteady flow. Acceleration. Trajectory of movement, stream line. Differential equation of the stream tube. Two-dimensional flow. Flow net. Continuity, etc. Sources, sinks, vortex. Cartesian components. Helmholtz and Stokes laws. Velocity potential. Laplace equation. Concepts of flow function.

Simple fields of potential flows. Flow systems.

Conformal representation. Flow around cylinders and polygonal profiles, separation of boundary layer.

1.2 Hydrodynamics

Derivation of differential equations of viscous flow. Laminar and turbulent flow, theory of hydrodynamic similarity, design of free surface flow according to Bernadski. Wind-induced currents in deep reservoirs, seiches. Hydromechanics and its relation to hydraulics and thermodynamics.

Practical examples in kinematics and hydrodynamics.

2. General and special (open channel) hydraulics

2.1 General hydraulics

Introduction. Hydrostatics. Basic hydrodynamics. Flow through orifices and nozzles. Uniform flow in open channels. Pressure flow in conduits. Non-uniform flow. Flow over and through structures. Hydraulic jump and its connection with upper and lower backwater.

2.2 Special (open channel) hydraulics

Non-uniform flow in channels. Flow with changing discharge. Unsteady flow. Hydraulics of bifurcations and of estuaries. Laboratory work problems.

3. Hydrophysics

Basic data referring to the physics of water and ice.

Hydrothermics: heat balance of soils and hydraulic structures; Laplace equations and practical methods for their solution; solution of thermal problems by means of temperature models; heat balance of reservoirs; differential equation of turbulent-flow temperature fields; heat balance in ice-covered reservoirs; thermal balance of ice melting, etc.

Capillary, film and vapour movement of water in soils and other porous media; laws of motion temperature gradients, heat regime of snow packs, osmotic phenomena in soils, etc.

Hydro-acoustics and hydro-optics; sonic velocity in liquids, ultra-sound, laws of spectral reflection and refraction.

Electrical and magnetic phenomena in liquids. Experiments in laboratory.

4. Chemistry and hydrochemistry

4.1 Chemistry

Basic laws of chemistry; construction of atoms - Mendeleev's periodical system of elements; chemical bond and structure of molecules; crystallic state of the substance; chemical kinetics and equilibrium; solutions; bases of physical and chemical analyses; surface phenomena and adsorption; basic laws of colloidal chemistry; oxidation; general properties of metals; alloys; basic electrochemistry - corrosion of metals and methods of protection; description of the eighth group of the periodical system; organic compounds.

4.2 Hydrochemistry

Methods of hydrochemical research. Chemical composition of natural waters; atmospheric precipitation; groundwater; river waters; lakes and reservoirs; sea water; economic importance of chemical composition of natural waters. Laboratory training.

5. Geophysics, geology, geomorphology

Components of the environment of the globe. Mutual influence of the hydrosphere and lithosphere. Modern geology and geomorphology. The earth's shell, geological processes, volcamism, earthquakes, historical geology and geomorphology, processes of soil formation, etc. Pedology. Field exercises.

6. General climatology and meteorology

General properties of the atmosphere; radiation energy. Winds, heat circulation in the soil, water and atmosphere; water vapour transport in the atmosphere.

Climatology: methods of processing climatological observations; basic climatological factors; influence of the relief on the climate; classification of climates; micro-climate and regional climate; changes in fluctuations of the climate; climates of the globe. Laboratory training.

7. Synoptic meteorology

General information about the weather-service; preparation and analysis of weather-charts; analysis of fields of meteorological elements; atmospheric masses; fronts; cyclones, analysis and short-term forecast of the synoptic situation and weather conditions.

Macro-synoptical processes and long-term weather-forecasts: determination of general atmosphere circulation. Zonal and meridional components of air flows; successive recurrence of cyclones and anticyclones in the Northern Hemisphere. Pressure distribution on the globe. Climatological centres of atmospheric action. Direction and velocity of basic air flows on the ground and in altitudes; situation and intensity of main frontal zones; average characteristics of main intense atmospheric flows; role of basic factors in the formation of general atmospheric circulation; schemes of general atmospheric circulation, criticisms. Methods of long-term weather-forecasts according to B.P. Multanovskij; macro-circulatory method of long-term weather-forecasts according to G.J. Wangenheim. Laboratory training.

8. Hydrometry

8.1 General hydrometry

Measurement of the water regime; discharge computation; sedimentation; winter and other temperature regimes; chemical composition, transparency and colour of water; wave motion; aerial photography in hydrometry; hydrometric stations and gauges; general principles of mechanized and automated observation and processing of data; safety techniques.

8.2 Hydrometric structures and equipment.

9. General and special hydrogeology

9.1 General hydrogeology

Introduction; classification and physical properties of rocks and of groundwater; chemical composition, bacteriological properties and radioactivity of groundwater; origin and classification of groundwater; waters of the aeration zone, soil moisture; swamp water and interflow; groundwater in fissures; mineral waters, wells; groundwater protection.

9.2 Special hydrogeology

Groundwater in the U.S.S.R.; dynamics of groundwater; research and investigation of groundwater. Laboratory training.

10. General hydrology

10.1 Land hydrology

Introduction; meteorological conditions of the regime of continental waters; channel network and watershed; morphology of river channels; origin of river water; regimes of water-level and discharges; river run-off and the water balance; temperature and winter regimes of rivers; energy of rivers and river sediments; hydrology of lakes and reservoirs; river and lake biology; swamp hydrology.

10.2 Oceanography

Introduction; general data on oceans; morphology of the sea-bed; level fluctuations of oceans; chemical composition, physical properties of sea water; mixing processes; currents; waves; sea ice. Laboratory training.

11. Hydrological analysis

Introduction; equation of mass and heat balances; mean annual run-off; fluctuations of annual run-off; seasonal variation of run-off; minimum run-off; run-off of spring floods and storm floods; run-off of bed load and of suspended matter; special problems of hydrological computations. Laboratory training.

12. Water resources management and design

12.1 Water management
Water resources and water management; hydraulic structures in the U.S.S.R.; water requirements of various branches of national economy-standards, consumption and water use; phenomena accompanying the construction of reservoirs; evaluation of economical effectiveness of water management measures.

12.2 Water management computations
Water management installations and reservoirs; basic data for water management; theoretical basis of run-off regulation to meet a defined demand; run-off regulation computations using methods of mathematical statistics for a fixed demand and for a defined variable demand; operation diagrams for reservoirs; statistical methods in various fields of water management; hydropower assessment; regulation of flood run-off; reservoir systems, balancing regulation. Laboratory training.

13. Hydrological forecasting

General bases of hydrological forecasts; short-term run-off forecasts (stage and discharge); long-term run-off forecasts; long-term run-off forecasts for mountain streams; long-term forecasts of annual run-off; forecasts of ice phenomena. Laboratory training.

14. Water balance studies

Investigation of the water balance in catchment areas, lakes and reservoirs with regard to the development of the national economy; analysis of the water balance equation in general, under various conditions and correlation of its components and various time periods; water balance fluctuations due to man's activity; design of hydrological networks and stations; design and location of representative and experimental basins; water balance and hydrological field research; field research of water balance components. Laboratory training.

15. Hydrological data and surveys

Multipurpose management; surveys for various developments in the basin, e.g. irrigation, drainage, highways, navigation. Safety regulations for surveys. Practical training.

16. Dynamics of channel flow and channel erosion

16.1 Dynamics of flow in a rigid-bed channel
Hydromechanical analysis of a shallow turbulent flow; curved flow and additional resistance.

16.2 Hydromechanics of flow in erodable channels
Basic characteristics of river-beds and of sediments; bed load transport.

16.3 Channel processes
Theoretical hydrodynamics, hydromorphology of river channels; basic channel processes, hydraulic structures. Laboratory training.

17. Hydraulic structures

17.1 Bases of hydrotechnical constructions
Constructional work and materials in hydrotechnics; basic hydrotechnical installations.

17.2 Techniques of water resources exploitation and control of damaging water effects
Exploitation of water energy; log driving; irrigation; irrigation of regions and irrigation with local run-off; drainage; water-supply of settlements and industrial plants; measures against soil erosion and gorge formation; hydrotechnics of bridges; notions concerning the design and organization for the construction of hydraulic structures; list of practical and laboratory training.

TABLE II.1 - CURRICULA AND SYLLABI OF HYDROLOGICAL EDUCATION IN THE USSR: TIME SCHEDULE

TYPE OF TRAINING	NUMBER OF WEEKS FOR A FIVE YEAR COURSE					
	1	2	3	4	5	TOTAL
Theoretical lessons	33	33	32	29	14	141
Practical lessons (laboratory training)	6	6	1	2		15
Field work			6	8	10	24
Preparation of diploma project					12	12
Annual examinations	6	6	6	6	3	27
State final examination					2	2
Vacation	7	7	7	7	2	30
TOTAL	52	52	52	52	43	251

TABLE II.2 - CURRICULA AND SYLLABI OF HYDROLOGICAL EDUCATION IN THE USSR: TEACHING SCHEDULE

SUBJECT	NUMBER OF HOURS				NUMBER OF HOURS IN A WEEK PER YEAR AND SEMESTER									
	Total	Lectures	Laboratory Training	Field Work	Year 1		Year 2		Year 3		Year 4		Year 5	
					Semester 1	Semester 2	Semester 3	Semester 4	Semester 5	Semester 6	Semester 7	Semester 8	Semester 9	Semester 10
					WEEKS									
					18	15	18	15	18	14	14	15	14	20
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Political economy	140	70							4	2	3			
Foreign languages	250			250	2	2	3	2	2	4				
Higher mathematics	485	242		243	8	8	6	4	3					
Numerical methods and computer programming	75	45	30					5						
Physics	288	138	100	50	6	6	5							
Theoretical mechanics and hydrodynamics	130	80		50			4	4						
Principles of electronics	72	30	42						4					
Introduction into special subjects	36	36			2									
Control of the environment	42	42											3	

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Principles of geophysics	102	66	36		4	2								
Hydrochemistry	96	50	46			4	2							
Geodesy and geophysical designing	120	50	45	25	4	3								
Meteorology, synoptic meteorology and climatology	162	81	81			4		2	4					
Hydrometry	150	84	66				5	4						
Hydrogeology	117	66	51				4	3						
Hydrophysics	70	42	28							5				
General and river hydraulics	156	96	60					4	3	3				
General hydrology and hydrography	202	110	92						5	4	4			
Hydrological computation	145	87	58								5	5		
Hydrological forecasting	158	72	86									4	7	
Numerical methods in hydrology using computers	70	30	40								5			
Water technical surveys; safety techniques	42	28	14						3					
Water balance research	45	30	15									3		
Water management	101	58	43									3	4	
Hydrometeorological service for the national economy	30	30											2	
Hydrometeorological constructions	98	56	42							3	4			
River channel processes and the dynamics of water flow	116	58	58									4	4	
Sport	130			130	2	2	2	2						
Special courses for hydrological subjects	348				2	9	2	4	7					

CURRICULUM OF THE HYDROLOGICAL EDUCATION PROGRAMME IN THE EAST CHINA INSTITUTE OF HYDRAULIC ENGINEERING, NANJING. DURATION OF PROGRAMME IS FOUR YEARS.

1. List of courses required by all students

Fundamental hydrology; meteorology; principle of runoff formation; groundwater hydrology; probability and statistics; river dynamics; hydrometry and data processing; hydrological forecasting; hydrological computation; water resources design and planning; hydrochemistry; higher mathematics; algorithmic language and programming; physics; theoretical mechanics; surveying; engineering drawing; hydraulic engineering; fundamentals of electronic instrumentation; physiography; political studies. Athletics. Foreign language (English, Russian or Japanese).

2. List of optional courses

Hydrometeorology; watershed hydrological modelling; stochastic hydrology; combined operation of water projects; hydrological experiment and research; water quality monitoring; oceanology and esturial hydrology; application of remote sensing in hydrology; limnology. Second foreign language.

3. Field work and practical experience

During the four-year period of study, some field work is conducted including surveying, hydrometry, and physiographic investigations. Practical training in data processing, hydrological forecasting, hydrological computation and water resources planning is also arranged in different semesters. A thesis on a particular problem will be prepared by each student in the last semester of his studies.

CURRICULA AND SELECTED SYLLABI ON EDUCATION IN HYDROLOGY IN LUND, SWEDEN (1)

1. Water and society

An integrated course that deals with water, man and the environment. Water, food and energy. Socio-economic aspects of water management. Water planning concepts, legal and administrative aspects.

2. Principles of hydrology

Basic principles of modern hydrology. Global energy and water balance principles. Comparative hydrology due to different climatic regions with a special reference to Nordic hydrological conditions.

3. General hydrometry

Basic principles of hydrological information. Methods of observations of precipitation (including snow), evaporation and interception. Methods of discharge computation, as well as groundwater and soil water observations. Hydrometric stations and gauges, their management and operation. Processing of data.

4. Physical hydrology

Physical hydrology including major topics in hydrology such as precipitation, evapotranspiration, soil water and groundwater processes. Watershed hydrology, lake hydrology and quantitative as well as qualitative hydrological aspects.

5. Hydrochemistry

Elementary chemistry. The hydrological cycle of the dissolved substances. Planning of sampling, analysis of data, budget and mass balance equations. Influence of man on the water quality.

(1) These syllabi do not reflect a complete study programme but the entity offered in this field at the University of Lund.

6. Hydrological computations

The characterization of hydrological observations. Hydrological data processing. Hydrological mapping. Hydrological dimensioning including also risk analysis, hydrograph analysis and run-off models. Hydrological prognoses and their practical applications.

7. General hydraulics

Hydrostatics and basic hydrodynamics. Turbulence. Uniform flow in open channels. Pressure flow in conduits. Flow over and through structures. Hydraulic jump and its connection with upper and lower backwater. Groundwater hydraulics.

8. Non stationary hydraulics

Water hammer equations. Pressure waves in conduit nets. Valves and pumps. Method of characteristics. Cavitation. Calculation of mass oscillations for instance in surge shafts. Kinematical and dynamical waves in channels.

9. Hydrogeology

Geology and hydrological factors of importance for the occurrence and development of groundwater. Groundwater exploitations. Geothermic processes.

10. Advanced course in hydrology

Hydrological models: stochastic, deterministic, conceptual, etc. Stochastic hydrology including stochastic processes, correlation analysis, frequency analysis, the structure of hydrological time series. Monte Carlo methodology. Urban hydrological processes: frequency analysis of precipitation, distribution functions for precipitation, methods of calculations of run-off from impermeable surfaces, qualitative and quantitative aspects of urban run-off and the impact of run-off on receiving bodies.

11. Water resources planning

Water resources planning in different countries: legal, administrative and socio-economic aspects. Integrated water resources planning as a concept within the framework of regional or national physical planning.

TABLE II.3 - CURRICULUM FOR EDUCATION IN HYDROLOGY IN THE UNITED STATES

SUBJECT	SEMESTER							
	1	2	3	4	5	6	7	8
Fundamentals of chemistry	4	4						
Freshman composition	3	3						
College algebra and trigonometry	5	-						
Engineering graphics	3	-						
Analytic geometry and calculus		5	5					
Descriptive geometry		3						
Introduction to hydrology		1						
Analytic mechanics			5					
Geology for engineers			3					
Introduction to meteorology and climatology			3					
Fields of static and moving charges				3				
Introduction to optics and acoustics				3				
Historical geology for engineers				3				
General botany				4				
Introduction to analytic chemistry				3				
Calculus and differential equations					5			
Introduction to statistics					3			
Introduction to crystallography and mineralogy					3			
Spectrographical petrology					1			
Contemporary economics					3			
Structure and physical properties of soils					3			
Structural geology						3		
Fluid mechanics						3		
Hydrology						3		
Physical climatology						3		
Introduction to geological surveying methods						3		
Humanistic-social studies						3		
Field geology							3	
Field hydrology							3	
Principles of geomorphology							3	
Photogrammetry							3	
Resource economics							3	
Humanistic social studies							3	6
Electronics							6	3
Geology of groundwater								3
Preparation of geological reports								2
Hydrological systems								3
TOTAL	15	16	16	16	18	18	24	17

Annex IIIA

Curricula and syllabi for some Unesco-sponsored post-graduate programmes in hydrology

INTRODUCTION

The curricula and syllabi listed in this annex are taken from official programmes published by the organizers of each programme. Listed are only programmes that are given regularly every year or every two years and extend over a period of at least six months. The information presented is, in most cases, the latest available at the time of editing this publication.

A. INTERNATIONAL COURSE ON WATER RESOURCES ENGINEERING - "JAROSLAV CERNI" INSTITUTE FOR DEVELOPMENT OF WATER RESOURCES AND THE FACULTY OF CIVIL ENGINEERING, UNIVERSITY OF BELGRADE, BELGRADE

Duration of programme: 3 months. Language: English.

List of courses		Hours
1.	Hydropower development with emphasis on small and medium size projects.	52
2.	Hydraulic structures and dams	71
3.	River engineering	63
4.	Water supply and sewerage	68
5.	Water resources management	47
6.	Groundwater hydrology and hydraulics	48
7.	Sedimentation engineering	32
8.	Scale models in hydraulic engineering	19
9.	Hydrodynamic measurements and data processing	21
10.	Mathematical modelling and computer applications	30
	Total:	451

Syllabi of courses

1. Hydropower development with an emphasis on small and medium projects

The role of hydroelectricity in modern power systems. Review of recent developments in planning, design, construction and operation of hydropower plants. Assessment of hydropower potential on a national or regional scale. Classification of plants by size, type, energy production, etc. Design criteria: selection of sites, energy and power requirements, hydrological conditions, energy production, etc. Market for energy from small and medium plants: industry, domestic use, rural development, etc. Relation to regional or national power networks. Mechanical and electrical equipment. Operation and maintenance and management of power stations and smaller power systems.

2. Hydraulic structures and dams

Objectives of dams and reservoirs. Selection of sites. Environmental impact. Types of dams. Safety considerations. Site investigations. Construction materials. Laboratory studies. Appurtenances. Hydraulic works. Foundation treatment. Equipment. Cost estimates. Operation and maintenance.

Design particularities of different types of dams: earth dams, concrete gravity dams, multiple arch and arch dams.

Hydraulic structures in water resources systems: water intakes, settling basins, canals and canal structures. Water conveyance tunnels: elements of rock mechanics, site investigations, design considerations, construction methods.

Seismicity and hydraulic structures.

3. River engineering

Introduction to alluvial river mechanics. Objectives of river engineering works. Field investigations. Morphological studies and computation. Fluvial hydraulics: steady flow and unsteady flow calculations, prediction of river bed development. Elements and principles of channel improvement works. Dredging. River training structures: influences and loads, materials, typical structures; design problems, construction and maintenance works. Special engineering works: underwater pipeline crossings, cut-offs, protection of bridges against scour, etc. Flood control: structural and non-structural measures. Levees and dykes. Reservoirs and retention basins.

4. Water supply and sewerage

Water borne diseases and toxic substances in natural waters. Parameters of water quality and WHO standards for drinking water. Protection of water resources from pollution and eutrification. Sanitary control of available water resources. Planning for water demand. Surface and groundwater intakes. Water treatment for suspended colloidal and dissolved solids removal: disinfection. Water distribution systems, selection of pipes and construction materials, hydraulics of conveyance systems, construction problems, appurtenances and special structures.

Waste water collection: estimation of quality, collection systems; appurtenances and special structures; waste water treatment; primary, secondary, tertiary, package treatment plants. Waste water and sludge disposal, and re-use. Problems of marine disposal.

Field and laboratory investigations: monitoring of water quality, water and waste water treatment processes.

Specific problems of water supply and sewage disposal in small settlements.

5. Water resources management

Complexity of water resources systems: spatial and temporal distribution of water resources and users, stochasticity and time dependence. Relation to economic and social development and environmental effects. Economy of water resources projects.

Optimization methods and models: objectives, constraints, criteria. Simulation of system performance.

Project management. Financing, tenders, project organization, execution and supervision.

6. Groundwater hydrology and hydraulics

Hydrodynamics of aquifers. Site investigations, mathematical modelling, use of input data, calibration of models and determination of aquifer characteristics.

Patterns of groundwater use. Wells and other intake structures. Clogging of wells and safe yield. Artificial recharge.

Seepage problems at dams, barrages, weirs and levees. Seepage control at engineering structures. Seepage losses from canals and their control. Electrical and other analog methods, laboratory techniques, calibration and analysis.

7. Sedimentation engineering

Review and refreshment of theoretical background to sedimentation mechanics. Practical problems of sediment transport in rivers. Scour and deposition induced by engineering structures. Prediction of reservoir sedimentation. Field measurements and data processing.

Sedimentation control methods. Economic and social aspects of sedimentation and sedimentation control.

8. Scale models and hydraulic measurements

Dimensional analysis and similarity criteria. Models of closed conduits: water ducts, tunnels, regulators. Cavitation problems. Models of hydraulic structures: spillways, tail races, stilling pools, etc. River models: fixed and movable bed models, scale distortion, modelling of sediment transport and of local scour. Coastal models, stability of breakwaters and other structures. Littoral drift and siltation problems.

Measurement of hydraulic phenomena in laboratory and field. Instruments for manual and automatic measurements. Unattended stations. Remote sensing. Planning of laboratory experiments. Measurements of unsteady dynamic quantities: sensors, signal conditioning, data acquisition and storage, data processing, error analysis. Mini and micro processors: their advantages and demerits. Examples and demonstrations in laboratory work: automatic control of experiments, interactive and off-line work.

10. Mathematical modelling and computer applications in water resources design

Introduction to computers: hardware and software, organization of computer centres, programming languages. Programme organization with modular structure. Communication between user and computer, interactive and batch work. Subroutine libraries oriented to hydraulic engineering. Applications: open channel flow in canals and rivers, flood routing in rivers and reservoirs, groundwater flow, urban hydraulic systems. Information systems and data banks, simulation of water resources systems.

Guide to programme packages, applications to selected problems, design problems solved by computer techniques.

B. INTERNATIONAL POST-GRADUATE COURSE ON HYDROLOGY - ORGANIZATION FOR INTERNATIONAL TECHNICAL AND SCIENTIFIC CO-OPERATION (TESCO) - RESEARCH CENTRE FOR WATER RESOURCES (VITUKI), BUDAPEST - HYDROLOGICAL METHODS FOR DEVELOPING WATER RESOURCES MANAGEMENT

Duration of programme: 6 months. Language: English.

List of courses

1. Engineering hydraulics
2. Computer programming I
3. Computer programming II
4. Probability calculus
5. Mathematical statistics
6. Hydrometeorology and water balance
7. Hydrological measurements
8. Network planning
9. Surface water hydrology
10. Stochastic processes in hydrology
11. Nuclear methods
12. Hydrological models
13. Hydrological forecasting
14. Systems hydrology
15. Numerical methods
16. Data collection and processing
17. Groundwater hydrology
18. Hydrology of the soil-moisture zone
19. Hydrology of the shallow groundwater
20. Hydrological processes in large sedimentary basin
21. Hydrology of solid rock terrains
22. Groundwater recovery
23. Hydro-geophysics
24. Soil-physics
25. Water resources planning
26. Water resources regulation
27. Hydrological aspects for the protection of the aquatic environment
28. Quality characteristics of water resources
29. Water supply and waste-water treatment
30. Flood control, flood-plain management
31. Hydrology of land drainage
32. River training
33. Hydrology for irrigation
34. Sediment transportation I
35. Sediment transportation II
36. Organization and administration of hydrological services.

C. INTERNATIONAL COURSE IN GENERAL HYDROLOGY WITH EMPHASIS ON GROUNDWATER HYDROLOGY - NATIONAL COMMITTEE FOR THE INTERNATIONAL HYDROLOGICAL PROGRAMME, BUENOS AIRES

Duration of programme: 5 months. Language: Spanish. The programme is composed of four sections. Lectures and practical training are given in three locations: Santa Fe, Mendosa and San Juan.

List of courses

Section 1 - Basic subjects

1.1 Mathematics
1.2 Statistics
1.3 Computation methods
1.4 Elements of fluid mechanics
1.5 Applications of geology in hydrogeology

Section 2 - Surface hydrology

2.1 The hydrological cycle
2.2 Elements of photogrammetry and photo-interpretation
2.3 Geomorphology
2.4 Soil studies
2.5 Vegetation and physical conditions
2.6 The atmosphere and meteorological variables
2.7 Evaporation from water surfaces
2.8 Precipitation
2.9 Surface detention and infiltration
2.10 Surface run-off
2.11 Systems of information
2.12 Regulation of rivers. Determination of the capacity and operation of reservoirs.
2.13 Hydrological systems
2.14 Analysis of intense precipitation
2.15 Hydrological models for the calculation of peak flows in watersheds of mountain streams
2.16 Hydrological studies of alluvial watersheds and the hydrological effects of forests

Section 3 - Groundwater hydrology

3.1 Groundwater basins. Preparation and interpretation of geological and hydrogeological maps.
3.2 Methods of geophysical investigations as employed in hydrogeological investigations
3.3 Elements of fluid mechanics
3.4 Theory of fluid flow in porous media
3.5 Hydraulics of confined underground flow of water
3.6 Application of tracers and radio-isotope techniques in groundwater hydrology
3.7 Relationship between fresh and salt water
3.8 Mathematical modelling in groundwater hydrology
3.9 Projects and structures for trapping of groundwater
3.10 Artificial recharge of aquifers
3.11 Chemical aspects of groundwater

Section 4 - Practical applications

The integral evaluation of the hydraulic and hydrological properties of a watershed. The preparation of plans for the use of its water.

D. INTERNATIONAL COURSE FOR HYDROLOGISTS - INTERNATIONAL INSTITUTE FOR HYDRAULIC AND ENVIRONMENTAL ENGINEERING, DELFT, NETHERLANDS

Duration: 11 months.

I Compulsory courses

● Hydrology 1
● Hydrology 2
● Statistical analysis
● Groundwater flow 1
● Meteorology 1
o/● Geology
o/● Soil sciences
● River hydraulics 1
o River hydraulics 2
o Computer programming
o Aerial survey
o Geomorphology
o Hydrometry
o Groundwater recovery

Notes

● Compulsory course with examination
o Compulsory course
* Facultative course

- o Water quality
- o Engineering economy
- o Systems analysis 1
- o Mathematics 1
- o Mathematics 2
- o Water law and management
- o Water resources planning

II Facultative courses

* Groundwater flow 2
* Meteorology 2
* Groundwater recovery
* Systems analysis 2
* Reservoir operation
* Data collection and processing
* Erosion control
* Urban hydrology
* Hydrology of coastal areas
* Deterministic hydrology
* Geophysics
* Hydrological models)
* Hydrological forecasting)
* Remote sensing
* Stochastic hydrology
* Analogue computation
* Network design
* Numerical methods
* Water management policy analysis
* Groundwater quality
* Hydrological services

III Laboratory courses

- o Water quality
- o Interpretation of aerial photographs

1. Hydrology 1

a. Introduction; the hydrological cycle; hydrographs; economy and hydrology; international organizations; the International Hydrological Programme.
b. Precipitation; measuring devices; distribution and characteristics of rainfall; "horizontal" precipitation.
c. Evaporation; evaporation from free water surfaces and evapotranspiration; measuring devices; lysimeters; formulae and theories on evaporation; the energy approach; use and application of methods and formulae.
d. Infiltration. The role of infiltration in the hydrological cycle; infiltration as a factor in run-off and infiltration as recharge of groundwater; comparison of methods.

2. Hydrology 2

a. Surface flow: yield; characteristics of drainage basins. Minimum flow and depletion curves; relation with geohydrology.
b. Surface flow: floods; maximum floods and frequency of occurrence; analysis of flood hydrographs; method of the unit hydrograph and other methods for estimating surface run-off; groundwater hydrographs; synthetic hydrographs; long-term and short-term forecasting of yield and floods; flood routing.
c. Physical aspects of erosion; wind erosion.

3. Statistical analysis

Definition of terms used jointly in hydrology and statistics, types of hydrological data, classification and presentation of data for purpose of analysis; elementary theory of probability, permutation and combination; frequency distributions of discrete variables and their application to hydrological variables, binomial, multinomial, hypergeometric.

Poisson; frequency distributions of continuous variables and their application to hydrological data, normal, logonormal (two and more parameters), Gamma and Beta (one and more parameters), main types of Pearson distribution and distribution of extreme values; different plotting position formulas, use of probability paper, testing goodness of fit and other hypotheses, the Chi-square distribution, maximum likelihood method; comparison of means and variances, analysis of variance; regression and correlation analysis, simple linear regression, regression relation, multiple linear regression; tests of significance, student t-test, Fisher F test and tests of significance of correlation coefficient.

4. Groundwater flow 1

Physical phenomenon of viscous flow in porous media.

Mathematical treatment of a number of important flow problems. Confined, semiconfined and unconfined steady flow. Principle of superposition and method of images. Application of complex variables. Graphical method, numerical methods and analogue models.

5. Groundwater flow 2

Non-steady flow. Tidal fluctuations of groundwater levels. Pumping tests. Two fluid flow in coastal aquifers.

6. Meteorology 1

a. Atmosphere physics: general introduction, atmospheric gas laws, phase changes of water, psychrometer formula, moisture variables, thermodynamics of vertical atmospheric motion, radiation.
b. Micrometeorology: vertical turbulent transport, advection and exposure, mass transfer and energy balance evaporation theories.
c. Meteorological observation: general problems, requirements for stations.
d. General meteorology: vertical stability, precipitation formation, artificial control of precipitation, general circulation, large-scale weather systems, meteorological forecasting possibilities.
e. Climatology: synthetic parameters and classification, moisture indices, seasonal circulation patterns, local winds, diurnal and annual courses, influences of latitude and topography, climatic periodicities and changes.

7. Meteorology 2

a. Meteorological instruments: response theory, thermometers, radiation meters, hygrometers, snow and dew measurement, wind meters, radar, radiosonde. Principles of observation and recording for attended and unattended stations.
b. Observation exercises: measurements of temperature, humidity, solar radiation and wind. Keeping, checking and adjustment of records.

8. Geology

a. Composition and texture of rocks in relation to the processes which lead to their origin, transformation and destruction; description of the various types of igneous rocks, sedimentary rocks and metamorphic rocks; review of the main exogenous and endogenous processes; action of wind, water, climate in terms of weathering, erosion, transport and sedimentation; volcanism and intrusions, tectonic movements, folding, faulting, jointing. Influence of various processes on strength and permeability of rocks.
b. Some aspects of hydrogeology are reviewed, in particular with respect to geochemistry. A number of test cases are discussed to illustrate various geological and hydrological features mentioned during the lectures.

9. Soil science

a. Chemical and physical properties of soils; soil organic matter, soil organism, soil moisture relationships, soil structure.
b. Soil formation, soil mapping, soil classification. Land classification.
c. Salty soils.
d. Pedology and agrohydrology.

10. River hydraulics 1

a. Fluid properties. S.I. units.
b. Uniform flow in open channels and pipes. Reynolds number. Velocity distribution. Resistance equations (Chezy, Manning).
c. Equations of continuity and motion in one-dimensional flow.
d. Gradually varied flow. Critical depth. Froude number, backwater curves.
e. Unsteady flow, surge waves, flood waves.
f. Flow over and in hydraulic structures, hydraulic jump, head losses.
g. Sediment properties, initiation of motion.
h. Sediment transport, bed forms, alluvial roughness.
i. Stable channels, deposition and erosion, local scour.

11. River hydraulics 2

a. Introduction - river characteristics, use of rivers.
b. Sediment transport measurement procedures.
c. River dynamics:
- characteristics of natural rivers, depth-width-slope-discharge relation, meandering, river bends.
- effects of river engineering works, dams, weirs, short cuts, canalisation, dredging.
d. Flood control - retarding reservoirs, flood plains, diversion.
e. River models - mathematical and scale models.

12. Computer programming

a. Use of digital calculators.
b. A course on the FORTRAN programming language.
c. Development of computer programmes for the solution of hydrological problems.

13. Aerial survey

How an area is covered by aerial photographs. Types of photographs; geometrical properties of photographs; differences between a vertical photograph and a map; binocular vision; different ways of observing photographs; parallaxes, floating marks.

Necessity of ground control; slotted template method; plotting with simple instruments; principle of the reconstruction of bundles of rays; spatial triangulation principle; flight planning in connection with application of the photographs for civil engineering.

14. Geomorphology

Evolution of land form; weathering processes; slopes and their development; land forms created by river work.

Geomorphology of limestone areas; land forms developed under arid conditions; the use of geomorphological maps; principle of geomorphological and geological photo-interpretation.

The course serves as a reference for practical applications in interpretation work.

15. Hydrometry

Methods and equipment used for measuring stages and discharges. Construction and use of stage - discharge relations. Processing of the measured data. Measuring weirs and flumes. Accuracy and errors inherent to the measurements.

16. Groundwater recovery

a. Geophysical aspects
i. Introduction; occurrence of groundwater; practical importance of groundwater; objectives of study in groundwater projects; terminology.
ii. Recapitulation of geology; importance, some terms, effects on porosity and permeability.
iii. Aquifers, different types of aquifers (recharge and flow), semipervious and impervious layers, some figures and formulae for porosity, permeability and specific yield, determination of geohydrological constants for large areas.
iv. Fresh and saline groundwater; origin and migration of salt. Principle of Badon Ghyben-Herzberg and its application to different types of aquifers.
v. Seepage; prediction of the amount of seepage. Practical consequences of seepage.

vi. Exploitation of groundwater resources; consequences of groundwater abstraction; concept of safe yield purpose of artificial recharge, other aspects of groundwater control, groundwater mapping.

b. Technical aspects
i. Introduction; formulae for the drawdown curves of galleries, single wells and well systems with confined or unconfined flow under different geo-hydrological and boundary conditions.
ii. Design of galleries, wells and well systems. Test pumping analysis.
iii. Methods of well construction. Construction of well casing and well screen. Well completion and well maintenance.
iv. Pumping equipment for wells.
v. Radial collector wells.

17. Water quality

a. Composition of natural waters. Factors determining natural water quality (rainwater, lakes, rivers, groundwater, estuaries).
b. Standards and criteria for various types of water uses (drinking water, cooling water, industrial process water, irrigation water, swimming and recreation).
c. Mechanisms of water pollution caused by water utilisation (chemical, physical, biological).
d. Consequences of water pollution. O_2 balance of rivers, eutrophication of lakes.
e. Principles of water quality control. Water and waste water technology.
Preventive measures (schisto somiasis) and development of waste utilisation methods (biogas, algae ponds).

18. Engineering economy

Principles of engineering economy. Capital, interest and interest rates, time value of money, depreciation, other costs, benefits, rates of return.

19. Systems analysis 1

a. Principles of systems analysis: a systematic approach to decision making. Defining alternative solutions.
b. Simulation models. A search for optimal solutions.
c. Linear programming models. Optimization and sensitivity analysis, L.P. algorithms, use of existing computer programmes.
d. Dynamic programming models. Optimization and sensitivity analysis. Development of a computer programme.
e. Introduction to stochastic optimization models.

20. Systems analysis 2

a. Resources management in a world with limits. Some comments on world models studies. Role of systems analysis in environmental management.
b. Scientific and engineering perspectives on systems. Basic concepts, definitions and terminology. Procedural framework for systems engineering.
c. Systems modelling. Model formulation and use. Mathematical function models. Production functions. Supply and demand models. Commensuration in time. Commensuration in kind.
d. Functional optimization. Criterion function. Marginal analysis in systems design.
e. Applications in water resources engineering using linear and dynamic programming models.
f. Engineering-economic and systems evaluation. Multi-objective systems design.

21. Mathematics 1

a. Main physical quantities in English engineering dimensions and in metric dimensions. Application: conversion of some uniform flow formulas from English units in metric units.
b. Geometric formulas; e.g. area, perimeter, centroid, first moment of an area, second moment of an area or moment of inertia; volume, surface area, centroid, mean height. Application: magnitude of force exerted on a plane area.
c. Definitions of trigonometric functions, double angle and half angle formulas, sum difference and product of trigonometric functions. Definitions of hyperbolic functions, relationship between hyperbolic and trigonometric functions. Application: oscillations of a liquid in a U-tube, wind waves formulas.

d. Basic calculus; binominal formula, quadratic equation, cubic equation, quartic equation, exponential and logarithmic functions, complex numbers.

22. Mathematics 2

a. Matrix algebra. Some definitions. Solving sets of linear equations directly and by matrix inversion using exact and iterative methods. Use of computer.
b. Differential and difference equations. Some exact solutions. Solving simple differential equations using numerical procedures.
c. Fourier and Taylor series.
d. Laplace transforms.

23. Water law and management

The role of water in metabolic processes and in human activities is reviewed. The contribution of water to special, economic and environmental wellbeing and as a key component of development is analysed in terms of the knowledge systems, leading to an understanding of the management of the resource. A number of conceptual approaches are explored and a decision-making model is introduced to situate legislation and administration. Legislation is related to planning and regulatory functions and to the administration of water. The case is made for water legislation in both federal and unitary systems of government. Administration is studied in terms of structure and processes. The notions of stability, coordination and efficiency are considered and tested in the discussion of a number of case studies.

24. Water resources planning

a. Principles of engineering economy; comparative cost, interest and depreciation.
b. Social and economic aims of projects; economic versus financial analysis; analysis of cost and benefits; private and social sphere. Assessment of imponderables; the realization rate.
c. Decision problems as encountered in water resources development; the decision process; sources of finances; the use of simulation techniques.
d. The work of the United Nations and its agencies with respect to water development projects in developing countries. The operations of the World Bank, the United Nations Development Programme, the regional organization and bilateral schemes.

25. Reservoir operation

Assignment, types and main characteristics of reservoirs. General requirements for the design of reservoirs. Analysis of factors affecting the operation of reservoirs. Basic hydrological data for computation of reservoir operation. Water losses from the reservoir. Evaporation and infiltration losses. Numerical and graphical presentation of hydrographs, duration curves and mass inflow and mass outflow curves. Reservoir operation for design purposes by analysis of hydrograph, duration curve and mass curve. Numerical procedure for reservoir operation. Reservoir operation by statistical methods. Probability of water supply and flood protection.

Evaluation of minimum water supply rate and maximum flood protection rate; reservoir capacity, height of dam and rule curves. Conflict of interests.

The interdependence of two purposes and reservoir size. Design of the free board above maximum still water level for design of a dam. Wind waves and set-up in reservoirs.

26. Data collection and processing

a. Collection of data. Type of recording, codes, ways of registration, nature of the process, length of the recording interval.
b. Processing of data. Error detection, correction, data reduction, actual processing.
c. Storage of data. Files, data bases of information and of data.

27. Erosion control

a. Soil erosion affected by human activity: soil deterioration and soil conservation. Allied sciences.

Classification of erosion.
b. Factors affecting surface erosion. Sediment yield. Surface erosion control.
c. Linear erosion. Sediment balance. Rousing. Quantitative approaches. Linear erosion control.

28. Urban hydrology

Rational formula, Izzard's method for computation of overland flow, soil conservation service procedure (U.S.A.), unit hydrograph, Road Research Laboratory hydrograph method (Great Britain), Chicago method with emphasis on construction of hyetographs, computation of depression storage, flood routings above the surface, gutter, lateral and main canals. Use of the standard graphs of the Chicago method.

29. Hydrology of coastal areas

Morphology of coastal areas; sources of salt; measures to combat salt intrusion; reservoirs in coastal areas; water and salt balance.

30. Deterministic hydrology

Deterministic methods in systems hydrology: the systems viewpoint; nature of hydrological systems; some systems mathematics; blackbox analysis; first set of exercises; linear conceptual models; linear methods of flood routing; non-linear conceptual models; second set of exercises; the role of systems hydrology.

31. Geophysics

Review of the various prospective methods. Seismic refraction method; electrical resistivity method, its use and application in groundwater studies.

Groundwater quality and mapping of groundwater reservoirs, mathematical and physical interpretation, case histories, well-logging methods.

32. Hydrological models

a. Model-prototype relationship in hydrology, collection of data on prototype catchment, experimental and representative basins.
b. Physical models: rain simulators, catchment models, registration equipment.
c. Mathematical models: digital simulation of catchment behaviour - solution of equations of motion and continuity, conceptual modelling of the hydrological cycle; catchment as a system. Analogue simulation - catchment as a routing model (reservoir and channels), conceptual electrical analogy of the cycle. Hybrid simulation - digital and analogue.

33. Hydrological forecasting

a. Types of hydrological real-time forecast.
b. Operation of a forecasting service.
c. Data requirements
i. Conventional real-time data acquisition system.
ii. Special systems of data acquisition (radar and satellites).
iii. Data transmission and processing codes.
d. Forecasting of stages and flows.
i. Short-term forecasts of floods.
ii. Medium-term forecasts of floods.
iii. Seasonal and low flow forecasts.
iv. Annual forecasts.
e. Lake level forecasts.
f. River ice information and break-up forecasts.
g. Issuing, evaluation and verification of forecasts.
h. Relationship between meteorological and hydrological forecasts.

34. Remote sensing

Remote sensing. Definition: remote sensing in nature. Main actual uses of remote sensing. Survey of remote sensing techniques. Interpretation of data. The earth's resources, technology satellite, application of remote sensing to meteorology, oceanography, glaciology of the polar caps, hydrology, environmental protection. Biological applications: crop survey, vegetation mapping, pest and disease spotting.

Medical uses.

35. Stochastic hydrology

Various types of hydrological sequences: periodic series, almost periodic series, ergodic and non-ergodic series, stationary random series, noise, first and second order Markov series, moving average schemes.

Use of Fourier methods, cross correlation and auto-correlation calculation; spectral and cross-spectral analysis; separation of time series in deterministic and stochastic components; detecting of trends and discontinuities; application to programming of reservoirs.

36. Analogue computation

Digital and analogue computers: sequential and continuous operations. Types of analogue machine; hybrid machines; basic components: sign changer, summer, integrator, potentiometer multiplier, function generator; control modes, single shot and repetitive working; applications to reservoir lag, surge chamber, flood routing and soil consolidation computation; patch pannel preparation and demonstration of the analogue machine of the International Institute.

37. Network design

a. Objectives of network planning and design.
b. Characteristics of hydrological elements and their influence on network design: precipitation and evaporation, surface run-off, groundwater, water quality.
c. Techniques for network design: systems analysis and design theory, statistical sampling, regionalization.
d. Examples of operating networks.
e. Networks in problem areas.

38. Numerical methods

a. An introduction to the classification of Elliptic, Parabolic and Hyperbolic equation systems; discussion of examples. General approach to obtaining approximate solutions.
b. Explicit schemes: stable and unstable behaviour. A sufficient condition for stability. Implicit schemes: unconditional stability. Truncation errors. The tri-diagonal algorithm.
c. Solution of problems governed by hyperbolic equations. Stability; optimization of stability and the elimination of truncation errors.
d. Solution of problems governed by parabolic equations. Consistency; acceleration of convergence.

39. Water management policy analysis

General description of the water resources management system. Application of the theory of hierarchical multi-level systems. Multi-objective policy analysis in general. Multi-criteria decision model GELPAM (Gelderland Policy Analysis Model). Application of GELPAM on a specific water management problem with multiple decision makers. Evaluation of the results.

40. Groundwater quality

Processes determining groundwater quality (hydrogeological, chemical, physical and biological). Problems concerning field survey and sample handling. Groundwater quality and variations in groundwater quality related to type of soils and human activities. Sources of groundwater pollution and their effects on groundwater quality. Presence and behaviour in groundwater of germs and some other organic and inorganic pollutants (N, P, organic micropollutants). Groundwater quality monitoring; flowlines and residence time of polluted groundwater. Protection of groundwater; sanitation and prevention.

41. Hydrological services

a. Functions of hydrological services.
i. Establishment and operation of networks.
ii. Data collection, processing and publication.
iii. Preparation and dissemination of forecasts.
iv. Analysis of data for design of projects.
v. Research and development.
vi. Training.

b. Organization of hydrological and related services.
i. Existing patterns.
ii. Technical and administrative considerations.
iii. Recommendations.
c. Administration of hydrological and related services.
i. Headquarters activities.
ii. Regional and field activities.
iii. Interagency co-ordination.

E. POST-GRADUATE COURSE IN OPERATIONAL AND APPLIED HYDROLOGY - FEDERAL POLYTECHNICAL SCHOOL OF LAUSANNE, INSTITUTE OF RURAL ENGINEERING, LAUSANNE, SWITZERLAND

Duration of programme: 10 months. Language: French.

List of courses

a. Basic courses

1. Theory of probability.
2. Statistics
3. Computation
4. Fluvial hydraulics

b. Basic and specialized hydrology courses

1. The importance of operational hydrology and of meteorology for the different sectors of the national economy.
2. Planning of observation networks as a function of their rational scientific and economic motivation.
3. Measurement of the meteorological elements in the hydrological cycle.
4. Measurement of water levels and calculation of discharge.
5. Measurement of various other hydrological elements.
6. Automatization of hydrological measurements including their transmission.
7. Observation and prospecting for groundwater.
8. Mechanical means for data treatment.
9. Statistical analysis of data and calculation of risks.
10. Analysis of data as a base for the design of projects in rural engineering.
11. Analysis of data for hydroelectric energy projects.
12. Analysis of data for water distribution and water treatment projects.
13. Hydrological forecasting.
14. Hydrological balance of watersheds for the purpose of complex water exploitation projects.
15. Special research and scientific problems in hydrology.
16. Problems of the organization of hydrological services and the training of their personnel.

c. Practical training and field trips

1. Technical visits to a regional office of hydrological and meteorological services.
2. Study tour to a number of research institutes and water management centres.
3. Practical experience for a period of eight weeks in an institute for research, management or collection of water data.

F. INTERNATIONAL POST-GRADUATE COURSE IN GENERAL AND APPLIED HYDROLOGY - THE INSTITUTE OF HYDROLOGY OF THE HIGH COUNCIL OF SCIENTIFIC INVESTIGATION, MADRID

Duration of programme: 6.5 months. Language: Spanish.

List of courses

1. Climatology.
2. Statistics
3. Photo-interpretation
4. Geophysics
5. Geology
6. Fluvial hydraulics
7. Agricultural hydrology

8. Applied hydrology
9. Forest hydrology
10. Karstic hydrology
11. Subterranean hydrology
12. Surface hydrology
13. Hydrochemistry
14. Instruments
15. Isotopes
16. Meteorology
17. Models
18. Computers
19. Pollution
20. Dams
21. Practical work

Syllabi of courses

1. Climatology

Climate: definitions, elements and factors. Climatological series. Homogenization of series, practical cases. Double masses. Temperature: variations, variation with height. Pluviometry: measures, criteria, distribution. Rainfall: table of precipitation. Classification of climate. Classification of Koppen. Deserts.

2. Statistics

Randomly distributed phenomena. Algebra of occurrence. Conditional probability. Repeated tests with replacement. Variable and randomly distributed statistics. Function of density and function of distribution. Mathematical expectation. Moments with respect to origin and centrals. Relation between them. Mode, median. Generant function of moments. Binomial distribution. Distribution of Poisson. Normal distribution N(0,1) and N(μ,σ). Galton's law. Gamma Variable, $\chi^2 n$ of Pearson, t of Student. Distributions of Gumbel and of Frechet. Bidimensional variables. Function of distribution. Function of density. Moments with respect to origin and centrals. Relation between the two. Straight lines of regression of y/x, of x/y, orthogonal co-efficient of correlation. Contrast of hypothesis. Pearson's test for χ^2. Kolmogoroff test. Applications. Ven Te Chow method. Poisson process. Shane method for flood calculation.

3. Photo-interpretation

Aerial photography: introduction and methodology. Photo-interpretation: definition and characteristics. Basic elements of photo-interpretation. Photo-interpretation: general method and application. Photo-interpretation in hydrology: introduction. Evaluation of the hydrological cycle. Rainfall. Loss of water. Photo-interpretation in hydrology: availability of water in the river basin. Estimation of water consumption. Photo-interpretation in hydrology: sedimentation. Examining of the damage produced by flooding.

4. Geophysics

Geophysical method in hydrology. Electric survey. Seismic survey. Practical application of geophysics in hydrology.

5. Geology

General introduction. Petrology. Genesis and basic rock types. Basic stratigraphy. Basic tectonics. Principles of geomorphology. Rock alteration processes. Their effect on hydrology. Carbonated rocks. Hydrology and characteristics in connection with hydraulics works. Evaporitic rocks. Hydrological behaviour and in public works. Hydrology of metamorphic and plutonic rocks. Hydrology of volcanic rocks. Methods of geological prospecting in hydrology.

6. Fluvial hydraulics

Introduction to biphase flow. General statement. Properties of fluid. Properties of the sediment. Basic parameters. Fall velocity of particles. Revision of the concepts of fixed contour flow. Beginning of drag. Analysis of different criteria. Application of the project to stable river-beds. Solid transport. Carrying and suspension. Evaluation of solid discharge. Methodology. Comparative analysis. Fluvial morphology concepts. Longitudinal profile. Plant. Bottom (sill). Works in river-beds. Singularities. Defences. Channeling.

7. Agricultural hydrology

Soils. General characteristics. Plant-soil relationship. Physical and chemical properties of soils. Soil classification. U.S.D.A. classification 7th approximation. Soil evaluation. Storie index. Methodology of the studies of soil evaluation and classification. Water relationship. Parameter that makes its study necessary. Permeability. Infiltration. Humidity equivalent. Weathered state. Determination of permeability: basics. Determining of moisture content. Basics and use in irrigation. Natural and practical data in irrigation. Their meaning and application in irrigation. Mode of use. Surface of individual areas in irrigation. Times of year for irrigation. Methods of irrigation. Study of the calculation of individual areas in surface irrigation; its application. Irrigation systems; their use. Theory of Crevat in surface irrigation. Parameters of soil related to irrigation. Individual areas of irrigation. Area of irrigation. Infiltration. Speed of infiltration. Efficiency by spraying. Strip-irrigation. Irrigation by furrows.

8. Applied hydrology

Method of double-mass curves. Calculation of the curves of flood discharge depths. Outlines of isohyets. Hydrographs. Correlation and distribution laws. Methods of regulation. Hydrological balance. Methods of flood estimation. Use of photo-interpretation in hydrology. Relation between hydrological elements and physico-geological elements. Methodology in hydrographic studies. Physico-geographical characteristics. Hydrological statistics. Climatological and meteorological characteristics. Practical methodology for rainfall studies. Practical methodology for contributional studies. Practical methodology for the study of regulation and protection. Practical methodology for the study of maximum growth. Practical methodology for the study of infiltration areas. Practical methodology for the study of subterranean water. Practical methodology for the study of erosion, drag and sedimentation. Integral exploitation of the hydrographic basin. Studying and planning of hydraulic resources. Economic studies.

9. Forest hydrology

Ecology. Systems and structure. Indicators: concept and conditions. Indices and graphs of Gaussen. Indication of vegetable communities. Systems of classification. Forms of life and their meaning. Use of vegetation. Main kinds of vegetable formation. Hydrological characteristics. Phreatophytes. Limnology. Eutrophication. Causes and effects. Loads and critical levels. Direct and indirect fight against eutrophication. Concept of forest hydrology. Historic evolution. Definitions. The torrent phenomena. Mechanisms of hydraulic erosion. Mathematical models of soil erosion by water. Factors that govern hydraulic erosion in a basin: soil, relief, vegetation, rainfall. Transportation of materials. Granulometry. Study of bed load. Study of suspensions. The depositing of materials. Sedimentation in reservoirs. Evaluation of hydraulic erosion: in experimental areas and small basins. In large basins. Methods of predicting the deterioration of a river basin. The similary in torrential phenomena. Influence of vegetation. Interception of rainfall by vegetation. Evaporation and transpiration. Horizontal precipitation. Role of vegetation in the hydrological regime. Project for hydrological-forestal restoration in river basins. Specific legislation. Models.

10. Karst hydrology

Karst. Karstic forms and the karstification process. General ideas about the morphogenesis of karst. Hydraulic balance. Relationship between surface and the subterranean water in karst. Special methods of recognition and study in karstic areas.

11. Subterranean hydrology

Concept of hydrogeology. Advantages and disadvantages of the exploitation of subterranean water reserves. Classification of porous media according to storage capacity and/or water transmission capacity. Types of aquifers. Hydraulic parameters of the different types of aquifers. Surface-water-subterranean water relationship. Hydrogeological maps. Hydrogeological zonality. Basic concepts of subterranean hydrostatics and hydrodynamics; piezometric level. Hydraulic gradient. Intrinsic permeability. Darcy's Law. Validity of Darcy's Law. Equation of continuity in stationary and variable regimens. Co-efficient of storage. Solution of the continuity equation. Contour conditions. Methods of images. Solution of the equation of continuity by models. General concepts of hydraulics in the capturing of subterranean water. Basic formulas of hydraulics in the capturing of subterranean water in steady and variable regimes. Variations in level and piezometric surfaces. Pumping tests and practical methods. Hydrogeological characteristics in sedimentary rocks. Hydrogeological characteristics in volcanic rocks. Hydrogeological characteristics in plutonic and metamorphic rocks. Plan of a hydrogeological study; its phases. Principles of mechanical sounding. Construction of wells. Testing of soundings. Development of wells. Gauging of wells.

12. Surface hydrology

Introduction to hydrology. Water and the hydrological cycle, methods of measurement. Presentation of basic data in statistics. Equipment for flow measurements. Conventional gauging. Chemical gauging. Gauging by compared solutions. General outlines. Hydrological cycle. Rainfall. Evaporation. Indirect estimation of losses. Regulation of rivers. Study of rising of waters; usual methods. Estimation of maximum peaks. Hydrometeorological prediction.

13. Hydrochemistry

Potability of water; general characteristics. Legal provisions. Sample-taking. Ganoleptics. Physical determination. Chemical determination. Dry residue. C.O.D. Chlorides. Sulphates. Nitrates. Nitrites. Ammonia. Hardness. Calcium. Magnesium. Iron. Manganese. Sodium and Potassium. Oxygen (dissolved). B.O.D. Carbon dioxide. Strange constituents. Microbiology in water. Dissolving. Solubility of salts. Mineralization of water. Phenomena which modify water composition. Suspended matter. Physico-chemical characteristics and quality of subterranean water. Quality of water for irrigation. Chemistry of subterranean water. Cartographic hydrochemistry. Salinization of subterranean water. Sample-taking of water in a river. Measurement of water temperature. Determining of dissolved oxygen. Determination of C.O.D. Determining of "Coliform" group by membrane filters. Determining of ammonia, nitrites, nitrates. Determining of ph, turbidity, colour, chlorides and sulphates hardness, calcium, magnesium and iron. Determining of detergents. Determining of sodium and potassium by flame photometric method.

14. Instruments

Hydrometeorological variables. Instruments - general quality. Conditions of hydrometeorological instruments. Errors. Kind of precision. Inertia. Recording; general conditions. Correction of records. Rainfall. Basic parts of a pluviometer. Base of pluviometric measurement. Different pluviometric models. Totalizators. Comparison pluviometric measurements. Elimination of errors and conditions for installing of pluviometric instruments. The effects of wind on pluviometric measurements. Norms of the W.M.O. Dew; basic concepts. Measurement of dew. Evaporation; basic concepts. Evaporimeters. Types. Evaporation pans. Measurement with pans. Evaporigraphs. Norms of the W.M.O. Basics of temperature measurement and of wind and humidity measurements. Thermometry. Models of thermometers. Meteorological houses and shelters. Geothermometers.

15. Isotopes

Basic concepts of radioactivity. General considerations of tracers. Isotopes in surface hydrology. Geonuclear testing. Use of isotopes in sedimentology (river and sea). Atmospheric isotopes in subterranean hydrology. Artificial tracers in subterranean hydrology.

16. Meteorology

Introduction to meteorology. Atmosphere processes. Criteria for stability of dry and humid air. Clouds; classification and types. Rainfall; types of, and clouds associated with their distribution. Hail. Atmospheric pressure. Anticyclone and storm. General atmospheric movements. Air masses and cloud fronts. Gusts of wind at great height. Surface wind. Periodical winds. Geostrophic wind. Acceleration of Coriolis. Pressure. Temperature. Humidity. Variations in space and time. Weather and climate. Application to rain.

17. Models

Introduction, justification and types of mathematical models. Basic theory. Differences equation, limits and methods of resolving the equations system. Boundary conditions. Special cases. Semi-confined aquifers, induced infiltration and evapotranspiration. Phases in the construction and use of models. Dimensional analysis. Magnitudes of fluid mechanics. General equations of hydraulics. Basic numbers. Theory of similitary: geometric similitude. Mechanical similitude. Hydraulic similitude. Similitude of Froude, Reynolds, Weber and Cauchy. Criteria for the selection of types of similitude. The critical and practical criteria of the selection of scale in reduced-size models of free regime with fixed contours and reduced-size fluvial models. Distorted scale models. Testing of hydraulic machinery. Testing with cavitation. Recommendations for the taking of data in the prototype, with view to construction of and experimenting with a fluvial reduced model of non-stationary beds. Methods of visualisation of flow. Methods of measurement of hydraulic variables in models. Electronic instrumentation. Project, construction, testing and servicing of a scale model for future operation. Complementary experimenting and control over prototypes. Introduction to analogue models; definition; types. Mathematical planning of digital models. Practical application in the use of models. Analogue models.

18. Computers

Introduction to computers. Forerunners. Numerical representation. The abacus. The age of the machine. The Automatic Age. Peripherical units. (Imput. Output); reader, punching, printer, plotter. Supports of information (card, tape). Codes used. Storage units. Ways of storing. Data representation. Binary system. Codes. Processing unit. Stored programme. Instructions. Flow diagrams. System of programming. Fortran IV. Arithmetical systems. Control sentences. Imput/output sentences. Sentences of format. Types of specification. Other types of sentence. Practical application.

19. Pollution

Definitions, origins and indicators of pollution. Decontamination. Measurement of pollution. B.O.D., D.I.O. Transferring of O_2 to clean and polluted waters. Conditioning factors and essential factors. Self-purification capacity of rivers and lakes. Biology of water. Mechanism of aerobic and anaerobic decomposition. Fields of application. Treatment of household water. Processes and limiting factors. Treatment of industrial water. Special planning for main groups. Technical water-purifying processes: statics, septic tanks, lagoons. Efficiency and calculations. Dynamic technical processes: (a) Trickling filters-activated sludge; efficiency and calculation; (b) Prolonged oxidation; mixed processes. Sludge treatment: (a) Anaerobic digestion; aerobic digestion; mechanism and technology; (b) Thickening and dehydration of sludge; technical processes. Waste to the sea. Hydrodynamic phenomena of dilution, technical processes. Underwater emissions; control and efficiency. Constructive parameters and current technical processes. Built-in processes. Treatment of sludge and residues, urban solids. Practical results. Economic and energy factors. Solar energy and its possible applications in sludge-treatment. The decontamination of water and the ecological challenge. Present balance.

20. Dams

Dam-reservoir unit. Typology of dams. Spillways: typology and operation. Multiple uses of reservoirs. Economic optimization of reservoirs.

21. Practical work

a. Limnimeters: kinds. Float and counterweight stage-level recorders: one plume, two plumes. Manometric or pneumatic limnographs. Photochrones.
b. Gauging with current meter. Distribution of velocity in a vertical. Average velocity of a vertical; by points, by integration. Current meters. Kinds: miniature meters, ordinary meters, salmon type current meters. Gauging with power reels. Bank-operated reels. Cable and basket gauging with current meters: field data, calculation of stage. Observations for calculation (on banks, on heads).
c. Gauging with chemical tracers. Method of integration: equipment, field forms. Method of continuous injection: equipment, field forms. Gauging of rising levels. Stream flow curves. Statistical adjustments by 2nd grade parabolas. Adjustment by a potential: double logarithmic paper. Adjustment by Manning formula. Charting by means of electric reader.

d. Treatment of data with electronic reader and computer.

e. The river hydrographs. Determination of the hydrograph. (Flow curve). Parts of hydrograph. Pumping curve. Curve of chronological flows.

f. Kinds of gauging stations in the official network. Of natural beds: with limnograph on the bank. Gauging equipment.

g. Canalised stretches: step weirs, wall weirs, multiple weirs, sensible canals.

h. Calculation, by students, of a gauging with current meter and chemical tracers. Presentation of results.

i. Doing a complete hydrological study of surface and subterranean water consisting of:
   - (i) Contrasting, correcting and completing the various series of pluviometric data over a given period.
   - (ii) Drawing the isohyet average for the period and also of dry and wet years.
   - (iii) Determining the physical data in all the stations and reservoirs.
   - (iv) Contrasting and correcting of annual contribution and completion of the various series of monthly contributions.
   - (v) Calculation of the evapotranspiration of the zone by the Turc and the Coutagne methods and investigating the evaporation by empirical formulas.
   - (vi) Calculation of maximum peak flows by empirical, statistical and hydrological methods with calculation of the hydrograph for diverse instances of recurrence.
   - (vii) Obtaining of the laws of distribution of rainfall and flow.
   - (viii) Obtain the rating curves for constant and variable flow and for various guarantees.
   - (ix) Given a series of reservoirs with their respective capacities, calculate the total volume regulated by the system.
   - (x) Study the movement of water in a given reservoir with regard to specific consumption, taking into account evaporation.
   - (xi) Calculate and plot the hydrograph using the rating tables, establishing at the same time the separation of the surface and subterranean run-offs.
   - (xii) Calculation of hydric balance.
   - (xiii) Calculation of monthly and annual consumption using the Thornthewaite, Blaney-Criddle (and mixed) methods.
   - (xiv) Plot the average consumption, maximum consumption, and means of consumption curves.
   - (xv) Calculate the quantity of water on a monthly basis with diverse efficiencies and in a given time.
   - (xvi) Estimation of the erosion and sedimentation indexes.

G. INTERNATIONAL COURSE IN HYDROLOGY - INTERNATIONAL CENTRE OF HYDROLOGY "DINO TONINI", UNIVERSITY OF PADUA, PADUA

Duration of programme: 6 months. Language: English.

List of courses and their syllabi

1. Hydrometeorology

a. Properties and structure of water.
b. Analytic and synoptic meteorology.
c. Water cycle in the atmosphere.
d. Climatology.
e. Rainfall.
f. Evapotranspiration.
g. Snowfall.
h. Elements of physical glaciology.

2. Hydrometry

a. Instruments and operational methods.
b. Open channels and river measurements.
c. Organization of Hydrographic Services.
d. Use of tracers and isotopes in investigation of surface and groundwater.
e. Data automatic processing.

3. Surface water hydrology

a. Hydrological cycle. Rainfall-run-off relationships.
b. Drainage basin morphometry.
c. Influence of forest on the run-off regimen.

d. Agricultural hydrology.
e. Continental erosion and erosion control.
f. Regimen of artificial and natural lakes.

4. Statistics and probability calculations

a. Application of statistics and probability calculations to the hydrological occurrences.
b. Parametric and stochastic processes in hydrology.
c. Extreme values theory and other theoretical frequency distributions.
d. Some particular problems related to hydrology (Monte Carlo method, Markov's chains, etc.).
e. Mathematical modelling in surface hydrology.
f. Unit hydrograph procedures.

5. Groundwater hydrology

a. Hydrogeology.
b. Groundwater flow.
c. Groundwater management and salt water intrusion.
d. Groundwater pollution: methodology and modelling.
e. Land drainage.

6. River and coastal hydraulics

a. Principles of river hydraulics.
b. Propagation of flood and tidal waves in channels.
c. Mechanics of sediment transportation.
d. Behaviour and morphology of river mouths.
e. Beaches, lagoons and estuaries.
f. Hydrological factors in coastal engineering problems.
g. Hydraulic models.

7. Water resources development

a. Evaluation of water resources in a region.
b. Hydrological maps.
c. Planning of water development projects.
d. Water resources systems analysis.
e. Economics in hydraulic structures.
f. Hydrological aspects in water resources development: irrigation, land reclamation, hydroelectric power plants, inland navigation, water supply.
g. Water pollution control.
h. Sea water and brackish water desalination.

8. General culture

a. Italian language.
b. Italian geopolitics.
c. Italian art.

H. INTERNATIONAL POST-GRADUATE COURSES IN HYDROLOGY - DEPARTMENT OF WATER RESOURCES, PRAGUE AGRICULTURAL UNIVERSITY, PRAGUE: HYDROLOGICAL DATA FOR WATER RESOURCES PLANNING

Duration of programme: 6 months. Language: English.

List of courses

1. Hydrometeorological and hydrological networks.
2. Processing of basic hydrological data.
3. Statistics.
4. Computer programming.
5. Principles of water resources planning.
6. Water quality and environment.
7. Hydrogeology.
8. Evaporation and evapotranspiration.

9. Deterministic models.
10. Stochastic processes.
11. Reservoir operation.
12. Hydrological forecasting.
13. Surface flow and design discharges.
14. Isotopes in hydrology.
15. Hydrological balance of selected geographical regions.
16. Engineering operations.
17. Experimental and representative basins.
18. Subsurface flow.
19. Water resources systems.
20. Hydrological maps.

Syllabi of courses

1. Hydrometeorological and hydrological networks

Precipitation. Precipitation networks. Evaporation. Indirect estimation of evaporation. Evaporation networks. Soil moisture and infiltration. Water stages and measuring equipment. Discharge measuring. Water gauging networks. Water temperature. Ice phenomena. Suspended sediments and bed-load sediments. Sediment networks. Groundwater and springs.
Extent: lectures 8 hours; exercises 6 hours.

2. Processing and basic hydrological data

Importance of basic hydrological information for hydrological service and national economy. Measurement accuracy and hydrological data evaluation. Water stages and discharges processing. Direct discharge measuring. Indirect measuring by means of current meter. Float and chemical measurements. Velocity formulae. Discharge rating curve. Discharge balance in month-cycle. Discharge processing in year cycle. Year books publishing. Measuring and evaluating levels, temperature and chemical properties of groundwater. Bed-load sediments evaluation. Water temperature and ice phenomena evaluation. Precipitation data processing. Computer data processing. Data bank of hydrological information.
Extent: 10/8.

3. Statistics

Basic statistical data processing. Some theoretical laws of frequency distribution used in hydrology. Theoretical distribution to adjust the line of empirical data frequency distribution. Statistical tests of significancy. Regression and correlation analyses. Statistical significancy of correlations.
Extent: 6/0.

4. Principles of computer programming

Task formulation. Mathematical model of the system. Selection of the computer type. Programming: analogue and digital.
Extent: 6/0.

5. Principles of water resources planning

Purpose of long-term studies and planning. Methods used in long-term studies and planning. Water resources efficiency evaluation and planning. Instructions and criteria to select the aims of long-term planning with respect to economical and social importance. Institutional and organisatory assumptions for water resources planning.
Extent: 8/2.

6. Water quality

Utilization of water for different purposes, data processing for water quality survey, field studies for surface water and groundwater. Water pollution control, waste water treatment, eutrophication. Water quality management, water quality models. Water quality for irrigation, salinity, water logging.
Extent: 10/0.

7. Hydrological data for water supply from groundwater

Relation of hydrogeology to other natural sciences. Tasks of hydrogeology in water economy. Relation rock-water-air. Hydrogeological characteristics of different rock kinds: eruptive, metamorphic, sediments. Hydrogeological structures. Types of springs. Physical properties of groundwater. Chemical composition of groundwater. Demands of drinking water. Mineral water. Position of groundwater in hydrological cycle. Hydrological balance; balance equation related to groundwater. Hydrological forecasts of groundwater. Hydrogeological research. Evaluating results of hydrogeological research. Hydrogeological problems and investigations of arid zones. Groundwater protection and hydrogeological tasks in human environment protection and investigation.
Extent: 10/6.

8. Hydrogeological data for agriculture

Definitions. Factors influencing water consumptive use of crops. Experimental methods for water consumptive use estimation. Meteorological factors and potential evapotranspiration. Water needs of crops investigation in Czechoslovakia. Biological curves application for the determination of irrigation requirements for project purposes. Biological curves used for operational purposes.
Extent: 10/8.

9. Deterministics models

Deterministics models. Stochastics models. Principles of system approach theory and system approach in hydrology. Lumped and distributed systems. Linear and non-linear systems. Input function to the system. System behaviour. Physical representation of the system structure.
Extent: 16/4.

10. Stochastic processes

Random events, terminology, stationary events, density of probability and the first distribution function, correlations, spectra. Markovian processes, definitions, matrix approach, Markovian chains. Stochastic models in hydrology, statistical prediction, filtering.
Extent: 16/2.

11. Reservoir operation

Purpose of reservoir operation. Reservoir types. Outflow from reservoir. Reservoir volumes and exploitation. Hydrological data. Basic methods of reservoir design to reach controlled increases of discharge. Direct solution based on observed time series. Special standpoints for solving controlled increase of discharge. Reservoirs with compensated operation. Flood control by reservoirs.
Extent: 16/8.

12. Hydrological forecasting

Basic conceptions. Information sources, collecting, processing and forecasts issuing. Errors and efficiency of hydrological forecasts. Short-term hydrometrical forecasts. Long-term hydrological predictions. Hydrosynoptical forecasts.
Extent: 14/4.

13. Surface water flow and design discharges

Data processing for design purposes, evaluation of design discharges-methods, open channel flow, flood routing.
Extent: 10/4.

14. Isotopes in hydrology

Extent: 8/0.

15. Hydrological balance of selected geographical regions

Methods for hydrological balance evaluation, hydrological balance of mountainous regions, marsh and swamp-lands, lakes, delta areas.
Extent: 16/0.

16. Engineering operations

Extent: 8/0.

17. Experimental and representative basins

Basin selection. Programme determination on the basis of investigation purposes. Observation programme for representative and experimental basins. Observed elements of main hydrological phenomena. Observation methods and instrumental equipment. Processing and publishing methods. Examples of experimental basins in Czechoslovakia and abroad.
Extent: 10/0.

18. Subsurface flow

Theory of unsaturated flow and groundwater flow, physical and mathematical models.
Extent: 6/0.

19. Water resources systems

Water resources requirements, hydrological data for water resources systems. Application of stochastic and deterministic models for a solution of water resources problems. Multi-reservoir operation. Design of hydro-power plants.

20. Hydrological maps

Extent: 8/0.

Optional courses in statistical mathematics, advanced hydraulics, and on models in hydrology are available according to the individual qualifications of applicants.

Practical training takes place in research insitutes of the Academy of Sciences, Water Research Institutes, Office for Water Resources Development and Planning, Hydrometeorological Institutes, Irrigation Research Institute - Laboratory of Evapotranspiration, and in other institutions.

I. INTERNATIONAL POST-GRADUATE COURSE IN HYDROLOGY - SCHOOL OF HYDROLOGY, UNIVERSITY OF ROORKEE, ROORKEE

Duration of programme: 2 semesters, about 12 months. Language: English.

The programme is composed of the following elements:

a.	Course work	8 units
b.	Seminar	½ unit
c.	Field work	½ unit
d.	Project	2 units
	Total:	11 units

List of courses for autumn semester		Units
1.	Hydrological elements and analysis	1
2.	Computer methods	½
3.	Hydrometeorology (1)	½
	or	
4.	Hydrogeology (2)	½
5.	Probability and statistics in hydrology	½
6.	Channel and fluvial hydraulics	½

(1) Subject for surface water and watershed management specialization.
(2) Subject for groundwater specialization.

		Units
7.	Mathematics	½
8.	Water resources planning and management	½
	Total for autumn semester:	4

List of courses for spring semester

a.	Compulsory	
9.	Land use and water quality	½
10.	Stochastic hydrology	½
11.	Basin investigation and instrumentation	½
b.	Options (one of the three options)	
i.	Surface water hydrology	
12.	Geohydrology	1
13.	Systems analysis and surface water planning	1
14.	Parametric hydrology	½
ii.	Groundwater hydrology	
15.	Groundwater hydrology	1
16.	Systems analysis and groundwater system	1
17.	Geophysical investigation	½
iii.	Watershed management	
18.	Planning and management of watershed	1
19.	Watershed behaviour and conservation practices	1
20.	System ecology and environmental planning	½
	Total for spring semester:	4

List of topics for guest lectures (some are given each year)

1. Management of hydrological cycle.
2. Design of hydrological network.
3. Water law and policy.
4. Use of satellite and remote sensing technology in hydrology.
5. Analogue models.
6. Modern methods in discharge measurements.
7. Long-term plans of international co-operation in hydrology.
8. Bench-mark basins, representative and experimental basin programmes.
9. Interbasin water transfers.
10. Management of flood plains.
11. Operational hydrology.
12. Nuclear hydrology.
13. Snow and glacial hydrology.
14. Geomorphology.
15. Photohydrology.
16. Use of computers in hydrology and water resources planning.

Syllabi of courses

1. Hydrological elements and analysis

Hydrological cycle, water balance. Hydrological elements; precipitation, evapotranspiration, infiltration and run-off. Organization of hydrological services and planning of network. Instruments and methods of hydrological observations. Hydrometry; tracer technique in hydrometry. Discharge measurement. Run-off cycle. Rainfall-run-off relationships for estimation of yield. Unit hydrograph methods. Mathematical modelling and IUH. Flood routing.

2. Computer methods

Machine description and organization. Fortran language, statements, subroutines and functions errors. Numerical solution of linear, non-linear and partial differential equations. Matrix operation. Application to hydrological problems.

3. Hydrometeorology

Atmospheric circulation, meteorology in hydrology. Precipitation processes, and artificial precipitation. Climates classification and water budgeting. Weather charts preparation and analysis. Monsoons and tropical cyclones. Hydrometeorological instruments, networks and observations; storm analysis, probable maximum precipitation. Hydrometeorological forecasts. Use of radar and satellite pictures in hydrology.

4. Hydrogeology

Rock cycle and hydrological cycle. Occurrence and origin of groundwater. Geological factors in water regime studies. Land forms, geological and hydrological mapping, water table fluctuations. Groundwater occurrence in different rock types. Thermal and non-thermal springs. Groundwater in arid and semi-arid regions. Groundwater provinces of India.

5. Probability and statistics in hydrology

Statistical parameters. Curve fitting, regression and correlation analysis. Theory of probability. Probability distribution. Plotting of data and limit curves. Sampling. Statistical tests. Analysis of variance.

6. Channel and fluvial hydraulics

Energy and momentum equations. Specific energy, uniform and critical flow. Gradually varied flow, profiles and computations. Overland flow. Hydraulic jump as energy dissipator. Sediment characteristics and initiation of movement. Transport of bed and suspended load. Collection and analysis of field data. Hydraulics of alluvial rivers. Channel routing, flow over weirs and flumes.

7. Mathematics

Solution of ordinary differential equations in series. Fourier series and its application to wave equation and diffusion equation. Bessel function and Legendre function. Gauss elimination technique. Crout algorithm. Cramer's rule. Cholsky algorithm, iterative techniques. Gauss-Seidal technique. Numerical solutions of partial differential equations. Finite difference techniques.

8. Water resources planning and management

Main elements and objectives. Integrated basin developments, principles. Estimates of water demand and other projections. Reservoir planning, planning for multi-purpose development. Economic analysis and cost allocation. Watershed management effect on regime of rivers. Water law and policy. Problems of interstate and international rivers.

9. Land use and water quality

Composition and properties of water. Water quality and standards. Physical, chemical and micro-biological analysis of water. Effect of geological formations on water quality. Hydrobiology of lakes. Water quality control. Effects of forests, fisheries, agricultural nutrients, pesticides, etc. on water quality. Water quality modelling.

10. Stochastic hydrology

Importance of stochastic modelling. Extreme value analysis. Fitting distributions to hydrological data. Estimation of minimum flows in droughts. Stochastic processes. Correlation and spectrum analysis. Generation of random numbers. Extending hydrological data and data generation. Range analysis. Storage analysis.

11. Basin investigations and instrumentation

Basic principles - preparation of hydrological, geomorphological and land inventory and hydrogeological maps. Representative and experimental basins. Observation network. Subsurface investigations, soil sampling, logging, strata charts. Data storage and processing. Basic electrical circuits, inductance and capacitance gauge, measuring bridge circuits. Electric and thermo-electric sensors. Cathode ray oscilloscope, oscillograph and bridge amplifiers. Instruments of different orders and their response, transducers.

12. Geohydrology

Groundwater in hydrological cycle. Geological factors in water regime studies. Occurrence of groundwater in different formations and different rock types. Well hydraulics, steady and unsteady flows to galleries and wells, well systems, battery of wells. Well losses, partial penetration and partial perforation. Well design. Methods of well construction, well casing and screens. Development and disinfection of wells. Test pumping analysis.

13. System analysis and surface water planning

Basic system concepts; system components and constraints, objective function. System optimization; Simplex method, other algebraic techniques, dynamic programming, sequential decision processing. Introduction to stochastic processes. Development, design and operational problems in water resources engineering. Reservoir planning and operational models. Optimum output from two and multi-reservoir system. Conjunctive management of surface and groundwater. Simulation methods for design of water resources systems.

14. Parametric hydrology

Systems approach in hydrology. Catchment action attenuation and translation effects. Conceptual identities - linear and non-linear reservoirs, linear channels. Deterministic systems, lumped and distributed, linear and non-linear. Instantaneous unit hydrograph theory and its applications. Lumped hydrological models. Linear distributed parameter hydrological model.

15. Groundwater hydrology

Properties of water bearing formations. Occurrence of groundwater. Measurement of permeability. Steady and unsteady flows towards drains, galleries and wells, seepage from canals. Groundwater hydraulics, effect of partial penetration and interference, test pumping analysis. Groundwater inventory, replenishment, artificial and induced recharge. Groundwater investigation. Groundwater development, design, construction and completion of wells, safe yield and overdraft. Radial collector wells and infiltration galleries. Seawater intrusion in coastal areas.

16. System analysis and groundwater systems

System concept, components, constraints, objective function, system optimization, linear programming, Newton's method, dynamic programming, decision processing. Introduction to stochastic processes. Implicit, explicit methods; finite difference forms, discrete Kernel approach, stream-well-aquifer relations. Finite element methods and their applications to groundwater models. Simulation technique in groundwater, groundwater models, accuracy and cost. Groundwater management. Conjunctive management of surface and groundwater.

17. Geophysical investigations

Basic principles of geophysical practices. Methods and instruments used. Interpretation and data anomalies. Radio-active prospecting. Seismic methods. Well logging for groundwater surveys. Case histories.

18. Planning and management of watersheds

19. Watershed behaviour and conservation practices

20. System ecology and environmental planning

Annex IIIB

Examples of post-graduate programmes leading to a Master's degree in hydrology

INTRODUCTION

The number of universities offering a complete programme of post-graduate studies leading to a Master degree in hydrology is still relatively very small. More usually, the Master degree offered is in water resources, in hydraulic engineering, or some related field. The programme can, however, be chosen in such a way that hydrological topics form the major part of the programme. The programmes are in most cases intended for one year of full-time studies. They are usually composed of two parts: study of a specified number of courses and a research or special study for a thesis on a selected topic. The relative weight of the two parts varies greatly between universities. Some may require the study of some five to eight courses and the preparation of an extensive thesis. Others may put the emphasis on the formal studies and require some 12 to 15 courses with a limited special study, equivalent to one or two courses, or without any requirement for a thesis.

There is also variability between universities in the method of selection of the programme of studies. Some universities may have a completely prescribed programme. Others may have a programme composed of some prescribed or compulsory courses and some courses to be elected from a given list of courses. The third possibility of giving the student the complete choice of courses from a prescribed list is also available in some universities. Examples of the three methods of course selection are given in the first section of this annex. The examples are taken from the first edition of this publication. The second section of this annex contains some examples of programmes received from national committees for the IHP in response to a request from the Division of Water Sciences of Unesco.

FIRST SECTION: EXAMPLES OF METHODS OF COURSE SELECTION IN STUDY PROGRAMMES LEADING TO A MASTER DEGREE

Example (a): Programme containing only compulsory courses

1. General hydrology
2. Meteorology
3. Statistical hydrology
4. Stochastic hydrology
5. Hydrological models
6. Groundwater hydrology
7. Open channel flow
8. Water quality

Example (b): Programme composed of compulsory and elective courses

Compulsory courses

1. Preparation of geological report
2. Meteorological instrumentation
3. Hydrological systems
4. Dynamics of the flow systems of the earth
5. Continental hydrology
6. Thesis

Elective courses

7. Geology
8. Meteorology
9. Mathematics/Statistics
10. Ecology
11. Chemistry
12. Resources economics

Example (c): Programme composed of elective courses only

Eight of the following subjects have to be chosen.

1. Hydrodynamics
2. Advanced hydraulic engineering
3. Flow through porous media
4. Advanced groundwater hydrology
5. Advanced surface-water hydrology
6. Geohydrology
7. Water resources engineering
8. Analytical methods in water resources engineering
9. Mathematics
10. Statistics
11. Engineering economy
12. Computer applications

SECOND SECTION: EXAMPLES OF PROGRAMMES OF STUDY AND OTHER REQUIREMENTS FOR A MASTER DEGREE IN HYDROLOGY OR IN A RELATED FIELD OF STUDY

A. UNIVERSITY RAFAEL LANDIVAR, GUATEMALA

1. Basic concepts and definitions: concepts of hydrology; the water cycle; aquifers.

2. Primary components of the hydrological cycle: applied climatology, elaboration of climatic data, water in the soil, evaporation and evapotranspiration, infiltration.

3. Surface-water hydrology: water courses, data treatment, analysis of hydrogrammes; regulations.

4. Groundwater hydrology: elemental theory of the flow in porous media, hydraulics of groundwater flow, relationship fresh water/saline water in coastal regions; projects for well constructions; artificial recharge.

5. Relationship groundwater/surface water: springs, influence of sub-surface storage on groundwater; man's influence on the relationship groundwater/surface water.

6. Other water resources: desalinization, re-utilization of water, artificial rain.

7. Application of groundwater hydrology to geotechnics: drainage, hydrogeological problems in relation to the surface layers.

B. FACULTY OF ENGINEERING - UNIVERSITY OF SAN CARLOS - SAN CARLOS, GUATEMALA

Post-graduate programme leading to a Master degree in Water Resources Engineering (hydrology). The programme is organized as part of the Regional School of Sanitary Engineering of the University of San Carlos. The duration of the programme is one year. The list of courses included is as follows:

First semester

1. Statistics
2. Economics
3. Water quality control
4. Fluid mechanics
5. Advanced hydrology
6. Flow in porous media
7. Special study

Second semester

8. Seminar
9. Computer programming and systems
10. Water resources systems
11. Groundwater
12. Potamology
13. Stochastic hydrology
14. Special study

C. MONASH UNIVERSITY, MELBOURNE, AUSTRALIA - DEPARTMENT OF CIVIL ENGINEERING - MASTER OF ENGINEERING SCIENCE IN WATER RESOURCES ENGINEERING

The Master of Engineering Science by Coursework programme in Water Resources Engineering is designed to meet the rapidly growing need for engineers with formal training in water resources engineering aspects. The programme has been developed with an emphasis on the application of the most recent developments and draws on the resources of several departments of the University.

The major section of the course covers the area of water resources planning, hydrology, hydraulics, public health engineering, coastal engineering, and water law. Related units such as regional planning, transport engineering, air pollution modelling, acoustics, and solar energy can also be taken. In addition a minor thesis in the candidate's special field of interest is required.

This course should be of particular interest to persons who are working in water resources, and who wish to further their skills and knowledge by formal study. Consultants in water engineering, engineers working for water authorities or local government, and others with an interest in the water-related aspects of environmental engineering will find the course to be of benefit.

Principal requirements for the degree

In order to qualify for the degree a candidate shall accrue a total of 48 credit points of which 42 are normally to be obtained by an approved programme of coursework units, and six by completing a minor thesis. A credit is defined as ten hours of formal contact time (such as lectures, tutorials or their equivalent).

Candidates for the degree can specialize in the water resources option of civil engineering. To this end a minimum of 27 credit points of coursework units must normally be selected from the specialization area. Within these guidelines candidates are free to select their course of study from units offered by the Department of Civil Engineering, other engineering departments and where appropriate, other faculties within the University.

Duration

The M. Eng. Sc. degree by coursework and minor thesis is primarily intended for part-time study though full-time enrolment is possible. Candidates will normally attend for six hours per week over a period of thirty weeks between March and November. Most part-time candidates will take between two and three years to complete the requirements for the degree, while full-time candidates will require about one and a half years.

Thesis

In addition to the formal coursework units, candidates are required to complete a minor thesis with a total value of six credits.

The thesis is an individual project, normally involving a critical survey or investigation of a water resources engineering related topic.

List of courses and their syllabi

The units available in Water Resources/Environmental Engineering are as follows:

Catchment planning and management (3 credits): B/C analysis; multiple objective planning; environmental assessment; flood plain mapping; planning and zoning; mitigation, forecasting; law and administration.

Coastal engineering (3 credits): waves; suspended and bedload sediment; design for beach protection, for harbour inlets and backwater.

Estuarine dynamics (3 credits): hydrodynamics of estuaries, including equations of motion, density currents; modelling, physical and mathematical.

Flood estimation 1 (3 credits): rational method; unitgraphs; rainfall and flood frequency; probable maximum precipitation.

Flood estimation 2 (3 credits): temporal and areal variability of rainfall; loss models; run-off routing.

Groundwater hydrology (3 credits): sources; hydraulics; pump tests; logging; image well theory; leaky aquifers; geohydrology.

Hydrological statistics (1½ credits): parameters; distributions; confidence limits; time series; regression analysis; joint probability.

Process modelling (1½ credits): processes; model synthesis, optimization, testing.

River hydraulics (3 credits): steady flow theory and practice; standard step method, bridge backwater; flood routing; long reaches; St. Venant; numeric routing.

Urban hydrology (3 credits): rational approach; run-off routing; process model; retarding basins; water quality modelling.

Water and waste water treatment (3 credits): physical, chemical, biological treatment processes; characteristics of waste.

Water law (3 credits): Relating to water, groundwater, drainage, EPA and town planning acts.

Yield hydrology (3 credits): duration and frequency curves; data generation; storage-yield analysis.

Water supply and sewerage (3 credits): overview of current state-of-art of water supply investigation and design; pipe distribution network analysis; multi-pump selection and operation; water conservation, strategies for reduction of overall consumption, household re-use; overview of state-of-art of sewerage investigation and design, lagoon and tertiary treatment design; design of ocean outfalls; irrigation and aquifer and recharge with effluent.

Advanced hydraulics (3 credits): hydraulic transport of solids in pipes, sediment transport in open channels; unsteady pipe flow (water hammer and surge tank analysis and design); physical hydraulic models (fixed bed and mobile bed); hydraulics of bridge waterways; new developments in open channel flow measurement; transition design in subcritical and supercritical flow; high speed open channel flow.

Related units

Atmospheric pollution (3 credits): meteorology; chemistry of pollutants; thermal plumes and diffusion; large scale modelling.

Environmental acoustics (1½ credits): properties of sound; measurement; environmental noises; effects; legislation; lab. measurements.

Ocean engineering structures (3 credits): waves; generation, velocity distributions; pressure distribution and forces on ocean structures, effect of structures on flow field. Design considerations and fabrication methods.

Solar energy (3 credits): energy resources; insolation/geometric factors, collectors; use of and conversions of solar energy; social political factors.

Traffic systems (3 credits): human factors in traffic system design, traffic safety, traffic management and control, fleet scheduling.

Transport and regional structure (3 credits): the development process, with special reference to the role of transport in influencing growth; social and physical impact, development models.

Soilwater (3 credits): permeability; seepage flow; flow nets; soil physics; moisture and soil properties.

Water Resources II (undergraduate)

Scope and importance of hydrology: importance, history and applications; nature and availability of data; the hydrological cycle; conservation of mass and energy.

Climatology: solar radiation; circulation of the atmosphere, and Australia's position; water resources of Australia.

Atmospheric moisture: elements of meteorology; movement of air and atmospheric moisture; condensation.

Precipitation: types of precipitation; graphical representation of data; areal averaging of storm rainfall by arithmetic mean, Thiessen and isohyetal methods; intensity frequency duration analysis; correction of precipitation records.

Run-off cycle: description; discussion of component phenomena including infiltration, soil moisture and evapotranspiration; variation of components with time.

Stream gauging: discharge measurements by velocity area methods; current meter measurements; float gaugings; other miscellaneous methods; stage discharge relations; the control; stage measurement and recording.

Hydrograph analysis: the hydrograph; component flows; separation of components; factors affecting hydrograph shape.

Storm run-off and loss rates: relation of storm rainfall and run-off; run-off coefficients; infiltration indices and loss rates, applications, derivation and design values; graphical correlation methods.

Synthesis of design storms: the problem; design point rainfall from 'Australian Rainfall and Run-off' Design frequency; critical storm duration; reduction of point intensity for area, temporal pattern.

Water Resources III (undergraduate)

The subject is in four strands, all taken by all students.

Strand (i) Water resources systems.
(ii) Surface water hydrology.
(iii) Groundwater hydrology.
(iv) Hydraulics.

Week		Topic
1.	(i)	Systems analysis relating to water resources systems, reservoir system simulation.
2.	(ii)	Data availability for solving hydrological problems.
	(iii)	Australian groundwater systems, classification of aquifers.
3.	(ii)	Description of hydrological problems.
	(iii)	Derivation of confined aquifer equation, storage coefficient, transmissivity.
4.	(ii)	Unit hydrographs - review of theory.
	(iii)	Superposition solution, straight time solutions.
5.	(ii)	Unit hydrographs - elementary tutorial practice.
	(iii)	Hydrogeologic boundaries, image theory.
6.	(ii)	Unit hydrographs - non-uniform storms.
	(iii)	Two dimensional finite difference aquifer model.
7.	(ii)	Synthetic unit hydrographs.
	(iii)	Application of 2D model to regional groundwater system.
8.	(i)	Reservoir system simulation. System optimization - response surface sampling.
	(ii)	Design storms and hydrometeorology.
9.	(i)	System optimization - linear programming.
	(ii)	Flood routing.
10.	(i)	System optimization - dynamic programming.
	(iv)	Discharge coefficients of spillway profiles.
11.	(i)	Benefit/cost analysis - benefit estimation.
	(iv)	Energy dissipators.
12.	(i)	The demand for water-irrigation, urban, etc.
	(iv)	Tail-water effects.
13.	(i)	Multiple purpose systems.
	(iv)	Pipeline design.
14.	(i)	Multiple objective design and conflict in water.
	(ii)	Review and assessment.

D. UNIVERSITY OF NEWCASTLE UPON TYNE, DEPARTMENT OF CIVIL ENGINEERING, NEWCASTLE UPON TYNE, ENGLAND

For the MSc course in Engineering Hydrology the students have to study three majors and two minors during the first two academic terms (6 months) and then submit an individual dissertation by the end of the academic year. The three majors and two minors can be selected from the following:

Majors

1. Introductory and fluvial hydraulics
2. Advanced and fluvial hydraulics
3. Physical hydrology
4. Hydrological theory and design
5. Hydraulic structures

Minors

1. Water resources management
2. Hydraulic structures
3. Probability and statistics
4. Three units of mathematics

E. UNIVERSITY OF ROORKEE, ROORKEE, INDIA - DETAILS OF PROGRAMME AND SYLLABI FOR MASTER OF HYDROLOGY

Programme of study

1. Physical hydrology and analogs

Pressure, density, surface tension, capillarity and their impact on hydrological process. Phase changes and dissolution characteristics. Thermodynamic characteristics and processes of heating and cooling. Mass transport characteristics and processes. Vapour transport and nucleation process. Snow and glacier melt. Impact of properties and processes on overland flow, infiltration and unsaturated flow. Multiphase flow.

Dimensional analysis and similitude. Geometric, kinematic and dynamic similarities. Models for open channels and river systems. Other analogues. Analogue computers, their types. Components of analogue computers; use of analogue computers; solution of differential equation. Hydrological problems; unscaled and scaled solutions.

2. Photohydrology

a. Basic principles
Basic definitions and principles of photogrammetry. Types of photographs used and their scales. Principles of stereoscopy. Fundamentals of photo-interpretations. Elements of remote sensing. Fields of application of point interpretation and remote sensing.

b. Application
Land form and geomorphological studies. Terrain and drainage pattern analysis. Analysis of land use patterns, vegetal cover and soil conditions. Groundwater studies. Water pollution studies. Determination of various hydrological parameters and surface run-offs.

3. Nuclear methods in hydrology

a. Elements of nuclear techniques
Radio active isotopes and radiations. Alpha, beta, gamma rays and neutrons. Principles of detection and counting equipment. Natural and artificial radio isotopes.

b. Applications to hydrology
Measurement of surface flow. Estimation of sedimentation in and leakage from lakes. Snow pack and glacier studies. Subsurface flow studies. Study of inter-relation of hydrological elements.

4. Stochastic processes

Classification of hydrological processes. Range analysis of hydrological series. Analysis of hydrological series by runs. Markov Chains - transition probability matrix. Queuing processes - general queuing models. Theory of storage, storage analysis. Stochastic routing of floods.

5. Mathematics (integral transforms)

Complex variable. Integration of functions of a complex variable. Fourier transforms and their operational properties. Convergence of complex series. Laplace transforms and their operational properties. Application of transforms.

6. Water resources economics

Introductory concepts. Production function and costs. Demands for water resources system outputs. Optimal allocation of economic resources. Benefit-cost analysis, its development and meaning. Rules for and applications of benefit cost accounting. Multiple objective benefit cost analysis. System techniques in water resources economics.

7. Water use and management

Problems of irrigation, agriculture. Water distribution systems and management on farms. Irrigation intensities and cropping pattern. Institutional infrastructure requirements. Complementary inputs. Integrations with other management practices. Drainage criteria; reclamation of water-logged and saline lands. Optimal timing of irrigation.

8. Forest and agricultural hydrology

Influence of forests on hydrological processes. Land use and land capability classification. Causes of deterioration of watersheds. Watershed management techniques. Photostudies and experimental basins to study forest influences. Soil classification and hydrological soil groups. Estimation of run-off from precipitation and snowmelt. Problems of farm ponds design, irrigation and drainage systems.

9. Urban hydrology

Elements governing urban run-off. Computation of storm water run-off. Hydrograph analysis method, Los Angeles hydrograph, Chicago hydrograph method. Road Research Laboratory methods. Floods and urban water pollution problems. Urban road drainage. Airport drainage.

10. Flood forecasting

Forms of hydrological forecast. Data requirements; transmission and processing codes. Forecasting services, organization and operation. Forecast procedure, hydrometeorological and hydrological forecasts. Forecasts of groundwater levels. Accuracy and checking of forecasts.

11. Legal and environmental hydrology

Legislation and administration of water resources. Water rights, allocation of water, legal system concerning water rights. Government administration, public institutions and water tribunals. Principles of metering law. Water laws and its relation to man's influence on hydrological phenomena. Prevention of pollution and ecological relation of water in biosphere. Conservation policies.

12. Groundwater flow

Statistical hydrodynamics. Soil moisture theory. Flow in the zone of aeration. Too liquid flow in porous media. Dispersion and diffusion in porous media. Fluid transport equations. Linearization techniques and solution methods.

13. Drainage engineering

Basic soil characteristics. Vegetation growth and its effects on drainage. Subsurface flow to drains, excess irrigation. Formulation of drainage criteria. Drainage by artificial means. Sub-surface field drainage systems. Surface field drainages. Drainage of reclaimed lands. Maintenance of drainage works.

14. Hydrogeology of hard rocks

Rock cycle. Geological and hydrological classification of rocks: (I) Igneous and metamorphic rocks: (a) major rock types, texture and structure; (b) methods of well drilling, design and construction. (II) Soluble rocks, limestone and dolomites: (a) major rock types, textures and structures; (b) design and construction of wells. Development and conservation of groundwater. Case histories.

15. <u>Sub-surface investigations</u>

Classification of surface investigation methods for groundwater prospecting. Different types of drilling fluids; formation resistivity factor. Electrical logging. Radiation logging; y-ray logs, yy-ray logging. Nuclear magnetic logs. S.P. logs. Data analysis and interpretation.

16. <u>Hydrogeochemistry</u>

Chemical properties of water. Water as a solvent. Impurities and isotopic variation in water. Ion exchange phenomenon. Chemical mass balance of river and oceans. Chemical analysis of water and presentation of data. Chemical quality of water. Application of hydrogeochemical surveys.

17. <u>Conjunctive water resources planning</u>

System configuration. Interaction of surface and groundwater. Components of this system and economic, legal, hydrological and management constraints. Formulation of mathematical system. Optimal parameter identification and model decomposition. Optimization with deterministic and stochastic component. Effect on quality.

18. <u>Geomorphology</u>

Physical and chemical weathering, soil erosion and control. Estimation of sediment load in rivers. Study of hill slopes. Deserts; erosion, transportation and deposition. Oceans; waves, tides, currents, coastal erosion and submergence, coast protection. Glaciers; types and movements, deposits. Karst topography. Geomorphic sub-divisions of Indian subcontinent.

F. UNIVERSITY OF SAN JUAN, ARGENTINA

1. <u>The atmosphere</u>

Definition of hydrology, historical development, the hydrological cycle, classification of waters, importance of hydrology in hydraulic planning, connection between hydrology and fluvial hydraulics; the atmosphere, precision of data - variations and reasons for differences; barometry, dynamic reduction and correction; reasons for atmospheric mass circulation; wind zones.

2. <u>Precipitation</u>

General properties; vapour; characteristics of humid air; atmospheric humidity, variations and distribution; hygrometry; condensation; adiabatic cooling; cyclones and anticyclones; clouds; rainfall and discharge; snow, physical properties, geographical distribution; rainfall, mapping, typical evolutions.

3. <u>Pluviometry</u>

Instrumentation and systematics, installation of instruments; snow investigation; calculation of precipitation, corrections; recording, diagrams (chronological, cumulative), analysis of data, harmonic analysis, application of statistical methods.

4. <u>Precipitation</u>

Quantitative characteristics (duration, intensity, frequency; global and its variations; isolated), formula; evaporation, physical characteristics, coefficients for correction; terrestrial evaporation; global evaporation; evapotranspiration and its influencing factors.

5. <u>Sub-surface discharge</u>

Infiltration, methods of calculation, volume of infiltrating water, water in the soil, soil moisture, vertical distribution of water in the soil; groundwater, hydrogeological concept, concept of sub-surface basin, aquifers, aquicludes, aquitardes, aquifuges; geological formation as aquifers. Hydrological parameters: porosity, permeability, transmissivity; types of aquifer; basic concepts of the hydraulics of wells; pumping tests, interpretation of results; hydrological and geological studies of aquifers; artificial recharge; simulation models and prediction.

6. Surface discharge

Characteristics and influencing factors, coefficients; global discharge, formula and methods of estimation; snow melt; regimen of typical watersheds; discharge originating from isolated precipitation; hydrograms.

7. River floods

Reasons, formula, methods of estimation, retention, isohyets of storms, probabilities, graphical methods, probability paper; unit hydrograph, synthetic hydrographs; hydraulics of floods, equations, deducted relations, forecasting.

8. Hydrometry

Installation of hydrometric stations, location, equipment, instruments, methodology; elaboration of data (records and graphs), extrapolation of data, analysis of records, chronological and accumulating diagrams; physics and hydraulics of rivers, movement of water in the river bed; generation of the transversal profile; meanders; relation between water level and discharge; bed mobility; formula.

9. Sediment transport

Origin of material, forms of transport, transport velocity, concentration and distribution over cross section, turbidity, calculation of data; physical characteristics of sediments. Bed load, different methods and formula, equipment, nature of material.

10. Flood protection

Method applied, systematics of origin of floods (limits of application), construction works, protection of foreland, dykes, calculations, construction principles. Retention groynes, deviation of floods, combined systems.

G. CURRICULUM OF MASTER OF ENGINEERING SCIENCE (WATER ENGINEERING) COURSE, SCHOOL OF CIVIL ENGINEERING OF THE UNIVERSITY OF NEW SOUTH WALES, SYDNEY, AUSTRALIA

Entry requirements

For the Master of Engineering Science, an honours or good pass degree in an approved four-year undergraduate course.

Minimum duration of courses

1 year (full time)
2 years (part time)

Curriculum

Students may select an approved programme from a wide range of courses, each of 42 hours duration (28 hours lectures, 14 hours tutorials). Master of Engineering Science students normally take nine subjects plus a project equivalent to a further three subjects. Alternatively, they may take six subjects plus a research project equivalent to a further six subjects.

List of courses

Hydrological processes
Flood design
Advanced flood estimation
Reservoir design and yield determination
Groundwater hydrology
Groundwater hydraulics
Soil-water hydrology
Urban drainage design
Economic decision making in civil engineering
Water resources policy
Optimization techniques in civil engineering
Water resources system design
Irrigation
Drainage of agricultural land

Investigation of groundwater resources 1
Investigation of groundwater resources 2
Geomorphology for hydrologists

Hydromechanics
Closed conduit flow
Pipe network and transients
Free surface flow
Fluvial hydraulics
Estuarine hydraulics
Coastal engineering 1
Coastal engineering 2

Unit operations in public health engineering
Water distribution and sewage collection
Solid and liquid waste management
Water and waste water analysis and quality requirements
Water treatment
Sewage treatment and disposal
Water quality management

Some courses of major importance are described below in more detail.

1. Hydrological processes

Hydrological cycle, atmospheric circulation (6 hours): the hydrological cycle and water balance. Heat balance of the atmosphere. Circulation of the atmosphere and its effects on climate. Effects of circulation pattern on water resources.

Meteorological elements - temperature, humidity (3 hours): measurements and variations of temperature and humidity, lapse rates, absolute and relative humidity, dew point and precipitable water.

The precipitation process (3 hours): conditions for precipitation. Definition, forms, classification and measurement of precipitation.

Evaporation and transpiration (9 hours): the evaporation process. Estimation of evaporation. The transpiration process. Control of evapotranspiration.

Advanced stream gauging (6 hours): objectives of stream gauging, the control, current meter gauging, chemical gauging, miscellaneous modern developments in gauging, general gauging practice, data processing, gauging network design.

Storm run-off process (6 hours): General description. Horton theory, variation of components with time. Saturated surface flow, throughflow, partial area run-off, occurrence of different processes. Catchment storage, channel transmission losses.

Hydrology and land use (6 hours): effects of land use on precipitation, interception, infiltration, evapotranspiration. Resulting effects on yield, flood run-off, water quality, surface salting and sediment production.

Instrumentation and developments in data acquisition (3 hours): fundamentals, network design, measurement chain, data analysis. Remote sensing.

2. Flood design

Introduction of flood estimation and design (3 hours): outline, philosophy, meaning of frequency, design on frequency basis, flood estimation from rainfall data.

Rainfall data (6 hours): measurement, methods of display, estimation of areal average, interpretation and correction of records, intensity-frequency-duration analysis, storm patterns, design storms.

Hydrograph analysis (3 hours): description, factors affecting hydrograph shape, storage effects, lag, component flows, hydrograph separation.

Storm rainfall-run-off relationships (3 hours): variation of components of run-off cycle during storm, initial loss, storm rainfall-run-off relationships and models, design case.

Loss rates (3 hours): definitions, applications in engineering practice, derivation of loss rates, variation of loss rates, availability of data.

Rational method of flood estimation (6 hours): basis, run-off coefficient, time of concentration, deterministic and statistical interpretations, application.

Unit hydrographs (9 hours): definitions, theory, single period unit hydrographs, estimation of flood hydrograph, changing specified time period, distribution graphs, introduction to derivation of unit hydrographs from complex storms, design unit hydrograph.

Introduction to urban drainage (3 hours): differences from rural, layout of drainage system, application of rational method.

Flood frequency studies (6 hours): method, data required, extension of data, types of distributions, estimation of population from sample, applications.

3. Advanced flood estimation

Flood routing (9 hours): principles, effects of storage, reservoir and distributed storage, routing procedures, graphical and numerical methods, solution of the equations of unsteady flow.

Catchment characteristics (6 hours): numerical and graphical measures of physical characteristics of catchment areas and stream systems, bankfull frequency, variation of flood velocity over a catchment.

Hydrograph synthesis by run-off routing (6 hours): principles, computational models of rainfall excess input and of catchment storage, evaluation of model parameters for practical application of models, application to computation of hydrographs for selected models.

Synthetic unit hydrographs (6 hours): methods evaluating salient points on the unit hydrograph (such as Snyder and Taylor and Schwarz), run-off routing methods, and procedures utilizing equations of hydrograph shape.

Urban drainage design (6 hours): principles, review of the rational method and evaluation of design data. Hydrological models for discrete storms and continuous simulation of hydrographs. Hydraulic design.

Regional empirical flood estimation methods (6 hours): review of regional flood frequency methods and design hydrograph procedures based on rainfall and flood data, including the U.S. Soil Conservation Service method, critical evaluation of best modern procedures and application to Australian conditions.

Advanced unit hydrograph theory (3 hours): model formations of unit hydrograph theory, derivation of unit hydrographs by optimum fitting methods, programming techniques, use of orthogonal functions and other systems techniques.

4. Reservoir design and yield determination

Introduction, storage yield analysis (7½ hours): regulation for water supply, storage analysis using simulation studies of historical or synthetic records, graphical and numerical techniques, concept of probability of failure.

Extension of streamflow records (4½ hours): the need, streamflow correlations, rainfall-run-off relations, rainfall-run-off (deterministic) models, statistical methods, consistency of data.

Introduction to hydrological systems (1½ hours): hydrological systems, models and data synthesis.

Deterministic catchment models (7½ hours): description of some typical models, evaluation of model parameters, application in synthesising run-off records.

Stochastic models (9 hours): statistical parameters and analysis of streamflow records, time series analysis, serial correlation, Markov and other models, elements of correlograms and variance spectrum analysis, analysis of range, generating models and generation of synthetic sequences.

Storage-yield-probability of failure (6 hours): interrelationship of input, output and storage state, probability analysis of storage states, Morans theory of storage.

Spillway capacity (6 hours): extreme precipitation, available moisture, transposition of observed storms, storm models, empirical and statistical methods. Flood routing through reservoirs, optimum spillway configuration.

5. Urban drainage design

Introduction of flood estimation and design (3 hours): outline, philosophy, meaning of frequency, design on frequency basis, flood estimation from rainfall data.

Rainfall data (6 hours): measurement, methods of display, estimation of areal average, interpretation and correction of records, intensity-frequency-duration analysis, storm patterns, design storms.

Hydrograph analysis (3 hours): description, factors affecting hydrograph shape, storage effects, lag, component flows, hydrograph separation.

Storm rainfall-run-off relationships (3 hours): variation of components of run-off cycle during storm, initial loss, storm rainfall-run-off relationships and models, design case.

Loss rates (3 hours): definitions, applications in engineering practice, derivation of loss rates, variation of loss rates, availability of data.

Rational method of flood estimation (6 hours): basis, run-off coefficient, time of concentration, deterministic and statistical interpretations, application.

Urban drainage design (18 hours): hydraulic design, urban catchment characteristics, design models, design procedures.

Annex IIIC

Examples of short duration specialized programmes

INTRODUCTION

The short duration specialized programmes are usually continued education programmes intended for practising hydrologists. They are organized according to one of the following three methods. One is a collection of post-graduate programmes offered regularly by a university department. The courses are taken by interested professionals without completing the requirements for a degree. The selection of courses is done by the participants according to their needs. Another method, more common, is for these short duration specialized courses to be organized specifically for a group of participants according to their needs for upgrading their knowledge on special topics. The third possibility is for the courses to be organized according to the special knowledge or experience of the teaching staff in the university department or research institute offering the programme. Students for such courses come on the basis of their interest in the programme which is advertized either on a regional or an international basis. The examples included in this annex include these three types of short duration specialized courses.

A. DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF BIRMINGHAM, BIRMINGHAM, ENGLAND - WATER RESOURCES TECHNOLOGY IN DEVELOPING COUNTRIES

Duration of programme: 20 weeks of lectures, 1 week of study tour and 3 weeks of preparation of short dissertation.

Outline of subjects covered

The main areas covered are surface and groundwater hydrology, reservoir design and management, irrigation, water quality and health, water collection treatment and distribution, sanitation, basic hydraulics, flood alleviation, urban drainage and engineering economics. Mathematical techniques including computing and statistics are also part of the syllabus.

List of courses

Statistics
Computer programming
Revision mathematics
Rainfall-run-off and climatic variables
Descriptive groundwater
Water quality and health
Hydraulics of pipe flow networks and streamflow gauging
Reservoir design
Steady state groundwater flow
Water collection, treatment and distribution
Flood estimation
Collection, treatment and disposal of waste water
The top 2m of soil profile
Irrigation engineering
Open channel hydraulics including river training
Flood alleviation and urban storm drainage
Time-variant groundwater flow
Reservoir management
Economics of water resources planning

B. POST-GRADUATE TRAINING COURSE ON GROUNDWATER TRACING TECHNIQUES - DEPARTMENT OF HYDROGEOLOGY, UNIVERSITY OF TECHNOLOGY, GRAZ, AUSTRIA

Duration of programme: 5 weeks. Language: English.

Programme of course:

1. Lectures on: collection of field data and water tracing by sodium chloride, potassium chloride, dyed lycopodium spores, and fluorescein dyes.
2. Exercises in mapping, water analyses, selection of data, spore dyeing techniques, production of charcoal samples.

3. Lectures on: the use of radio-isotopes in water tracing, and water tracing by activation analysis methods.
4. Exercises in microscopic techniques. Excursions in the field and preparation of field experiments in the groundwater field of the Graz basin (Grazer Feld) and the karst areas west and north of Graz.
5. Field experiment in groundwater tracing in gravel and sand (Grazer Feld).
6. Report on the experiment.
7. Six-days day-and-night experiment in the region of the Central Styrian Karst. Injection of various tracers, collection and investigation of samples by working groups.
8. Final report.

C. MODEL TRAINING COURSE, HANNOVER, FEDERAL REPUBLIC OF GERMANY

This course consists partially of correspondence courses and partially of up-grading courses at the Technical University of Hannover.

1. General: mathematics, statistics, probability, time frequency analysis, correlation and regression.
2. Principles of water resources: water balance.
3. Principles of geosciences: geology, hydrogeology, soil science, morphology.
4. Principles of biology and chemistry for hydrology: saprobic system, self-purification, biological and chemical parameters.
5. Principles of meteorology: precipitation, evaporation, radiation, heat balance of water bodies.
6. Principles of limnology: physical, chemical, biological, eutrophication.
7. Selected fields of hydraulics: unsteady flow, groundwater flow.
8. River morphology: sediment transport, governing laws of the formation of the river shape.
9. Measurement, precipitation, and other meteorological parameters, flow velocity, discharge, water level, water quality, tracers.
10. Evaluation, precipitation, discharge, statistics of extreme values, sediment and water quantity transport, hydrological parameters.
11. Selected fields of data processing, programming, data bank techniques, data transmission, electronics, devices.
12. Selected fields of modelling: precipitation-run-off models, flood routing models, water quality models, heat balances, stochastic procedures, forecasting, groundwater models.

D. INTERNATIONAL HIGHER HYDROLOGICAL COURSES, MOSCOW STATE LOMONOSOV UNIVERSITY, MOSCOW, U.S.S.R.

The course treats subject areas which differ from one year to another completely. The duration of each course was two months including a period of two weeks for visits to institutes of higher education and research institutes. Each course comprised about 150 hours of lectures.

List of topics of courses and their programmes

1. 1969 - River run-off phenomena and hydrological calculation

Cyclic variation of streamflow. Analysis of physical and geographical factors effect on streamflow regime and formation. Run-off continental and global processes. Estimation of the average perennial world runoff. Modern considerations of the run-off as a probabilistic process. Mathematical modelling of run-off processes. Annual run-off distribution.

2. 1970 - Problem of hydrological forecasting

Analysis of present-day and future state of world water resources. Methodical basis of hydrological forecasting and problems connected with the application of methods of mathematical statistics. Short-term and long-term run-off forecasts; particularly, run-off forecasts for mountain rivers. Interaction of surface and groundwaters. Forecasting the groundwater regime. Estimation and forecasting of water quality in solving water management problems.

3. 1971 - Underground water hydrology

Interrelation between surface and groundwater run-off. Groundwater run-off and its role in river recharge and in water balance of territories and catchments. Groundwater dynamics. Modelling of groundwater dynamic processes. Geochemistry of groundwaters. Meliorative hydrogeology. Groundwaters of arid areas. Main tasks and future activities concerning investigations in groundwater hydrology.

4. 1972 - Man's activity impact on hydrological processes and phenomena

Main problems of inland waters regime reform. World water resources and their future. Hydrological forecasting and its relationship with planning of water resources utilization, with implementation of large-scale water-management projects and with river systems reform. Probabilistic characteristics of river run-off; theory of its regulation. Urbanization impact on river regimes and water quality. Irrigation, agricultural and melioration effects on run-off. Forms and methods of toxic waste waters storage in deep earth crust aquifers. Laws for utilization and protection of water resources, water legislation in the U.S.S.R.

5. 1973 - Hydrology of lakes and reservoirs

Lakes and man-made reservoirs of the globe, their contribution to the water cycle. Natural and man-made reservoirs as components of hydrological system. Perennial fluctuations of levels of lakes. Water budget of lakes and reservoirs. Methods for determining components of water budget. Thermal regime of reservoirs; heat budget, thermophysical calculations, ice-cover regime. Dynamic phenomena in lakes and reservoirs. Modification of banks and beds of reservoirs, sediment budget, siltation processes. Hydrochemical regime, classification of lakes and reservoirs by salt composition. Lymnological cycles, biomass production processes, biology of heated waters. Modern methods for lymnological observations and studies. Complex approach to study of lakes and reservoirs.

6. 1974 - River hydraulics and channel processes

Modern problems of river hydraulics, one-dimensional, plan and space problems. Structure of turbulent streamflow, processes of diffusion and suspended particles transport. Channel deformations, theory of channel processes. Dynamics of hydrographic network, channel processes in deltas. Modelling of river streamflow in erodable and non-erodable beds and present-day technique of laboratory and in situ measurements of turbulent streamflow parameters. Theory of stratificated currents, bottom and mud flows motion.

7. 1975 - Water resources and the environment

Global water resources, their present-day and future state. Regional and global water balances. Man's activity impact on water balance elements. Interchange of matter and energy in geosphere. Multipurpose hydraulic projects and water utilization impact on surface and groundwater regimes. Groundwater resources. Closed technological cycle of water consumption. Water component in long-term geographical forecasting. Basic principles of regional geographical forecasting. Ecological effects of waste heat disposal. Time-space characteristics of man's activities effect on hydrological cycle. Theory and practice of hydrological modelling. System approach in hydrological problems.

8. 1976 - Hydrological forecasting in water management

Forecasting of river discharges and water levels on the basis of river flow motion regularities. Run-off forecasting and water storage in river systems. Forecasting of rain floods. Long-term forecasts of summer flood of mountain rivers and spring flood of lowland rivers. Forecasting of summer, autumn and winter run-off. Calculation of river hydrograph for the period of snow floods. Short-term forecast of river, lake and reservoir freezing and ice breaking up. Automatic processing of urgent hydrological information. Hydrological forecasting service organized in the U.S.S.R. Mathematical methods in the problem of forecasting. Representative and experimental basins and their contribution to forecasting.

9. 1977 - Experimental investigations of hydrological processes and phenomena

Investigations on the experimental and representative basins. Large- and medium-scale classification. Main results for IHD period. Water budget research. Surface and subsurface waters interaction. Investigations of reservoirs and lakes. Large-scale measuring of diffusion in lakes. Pollution and purification control. Budget methods of control. Aerospace and remote sensing methods of investigations. Aeroplane and satellite surveys. Aerospace information utilization in hydrological processes investigations. Stereophotogrammetric surveys. Stable and radioactive isotopes and nuclear radiation application in hydrological research work. Luminiscent substances methods of studies. Physical, mathematical and stochastic simulation of hydrological processes.

10. 1978 - Scientific basis of groundwater research and protection

General regularities of groundwater formation. Varieties of groundwater resources and their vertical stratification. Artesian basins, river valleys, fissured and karst-fissured strata as the basic structures for groundwater accumulation. General regularities of the surface and subsurface waters interrelation. Groundwater resources and regularities of its formation. Regional maps of prognosticated groundwater resources. Methods of operational reserves evaluation. Regional regime and forecast of groundwater operational conditions as a scientific basis of groundwater protection from pollution and depletion. Intensive withdrawal of water from deep layers; technogeneous processes impact.

11. 1979 - Calculation methods for run-off

Characteristics of run-off and methods for their calculation. Long-term run-off variation. Stochastic models of run-off variation. Methods of correlational and spectrum analysis of long-range flow observations. Annual run-off. Annual distribution. Maximum and minimum water discharges. Calculation of snow and rain floods. Calculation of main run-off characteristics in case of insufficient or no hydrometric observations. Calculation of run-off for water system management and projects. Hydrological modelling in water management projects, in planning water resources utilization and water system management. Methods for estimation of initial hydrological information. Premises for standardizing calculational run-off characteristics.

12. 1981 (there was no course in 1980) - Modern problems of irrigated lands hydrology

Water resources of arid and semi-arid regions and territories with insufficient humidity. Specific features of the arid regions' river regime and the interannual run-off distribution. Moisture transfer over arid lands and irrigated areas, interrelation of atmosphere and underlying surface; relief and soil cover influence. Water and heat balance of irrigated and non-irrigated lands. Moisture, heat and salt exchange in the near earth air layer and the aeration zone. Regime of evaporation, transpiration and infiltration as a function of the irrigation intensity and physical properties of soils. Runoff regulation in catchments and its interrelation with irrigation regime. Influence of irrigation on the surface and underground run-off, consideration of different irrigation techniques. Effectiveness and intensity of drainage systems. Balance of underground waters on irrigated areas. Salination of soils and groundwater mineralization. Salt regime and balance and the hydrochemical regime of groundwater. Forecasting of groundwater level. Mathematical models of surface and sub-surface run-off formation on irrigated land.

E. NATIONAL COMMITTEE FOR THE INTERNATIONAL HYDROLOGICAL PROGRAMME IN CHINA, NANJING, CHINA

Topics of short-term training programmes in China

1. Application of new techniques and equipment in hydrometry.
2. Short-term hydrological forecasting.
3. Medium- and long-term hydrological forecasting.
4. Data processing.
5. Maximum probable precipitation.
6. Water quality analysis and monitoring.
7. Watershed hydrological experimentation.
8. Algorithmic language and programming.
9. Network design.
10. Hydrological computation and design.
11. Reservoir operation with hydrological forecasting.
12. Groundwater forecasting and development.
13. Remote sensing techniques in hydrology.

The durations of these programmes are given as several weeks, probably three to seven weeks, for each programme. The programmes are organized by institutions of higher education. The participants are practising hydrologists, engineers and technicians.

F. REGIONAL TRAINING COURSE ON THE HYDROLOGY OF SNOW AND ICE, SANTIAGO, CHILE - ORGANIZED BY UNESCO WITH THE AID OF UNDP

Duration of course: 1 month.

1. Introduction

Role of snow and ice in hydrology. Glacier types; glacier variations related to water resources. Physical properties of snow and ice, a review.

2. Physical properties of snow and ice in relation to practical application

Classification of snow. Thermal properties: metamorphism of snow, sublimation, superimposed ice. Mechanical properties: snow densification, rammsonde measurements, avalanches, seismic waves. Electrical properties: Albedo, artificial increase of albedo to promote snow melt, satellite measurements. Isotope composition: environmental isotopes and water resources.

3. Glacier mass balance

Various methods of study and their application. Field techniques. Methods of calculation, including use of computers.

4. Glacier hydrology

Hydrology of streams from glacierised and glacier-free basins. Water power production in glacierised areas. High-mountain hydrology, including special gauging methods. Run-off prediction for glacier streams. Water balance of a glacierised or snow-covered basin. Sediment transport in glacier streams. Silting of reservoirs and lakes.

5. Heat balance

Radiation measurements: instrumentation and calibration. Turbulent heat transport, evaporation, condensation, sublimation, sensible heat. Use of appropriate meteorological instruments. Complete heat balance determinations. A programme of combined mass and heat balance studies.

6. Glacier dynamics

Ice movement and deformation, dangerous crevasses. Glacier slip on the bed-rock for temperate glacier. Glacier response on climatic changes. Catastrophic advances (surges).

7. Morphological effects of glaciers

Terminal moraines and their formation, moraine dammed lakes. Ablation moraines, rock glaciers. Glacier erosion, moraines and typical land forms. Earthquake effects. Glacier dammed lakes, water pockets within glaciers.

G. GRADUATE COURSE IN HYDROLOGY, THE SCHOOL OF CIVIL ENGINEERING OF THE UNIVERSITY OF NEW SOUTH WALES, SYDNEY, AUSTRALIA

Entry requirements: Degree in engineering or science, but a lesser qualification from persons with experience will be considered.
Duration of course: 14 weeks (full time); March to June each year.

Brochure: A brochure for each year's course can be obtained from the Head, School of Civil Engineering, the University of New South Wales, P,O. Box 1, Kensington, NSW 2033, Australia.

Admission procedure: Applications should be sent to the above address before 31 December of each year. Persons wishing to obtain an Australian Government award should apply through their local Australian diplomatic post, preferably by 30 September of each year.

Students may specialize in either surface water hydrology or groundwater hydrology. All students take a common core of subjects, plus two elective subjects. The common core, electives and syllabi of all subjects are listed below.

Common core

1. Special course work (40-40) (1)
2. Hydrological processes (28-14)
3. Flood design (28-14)
4. Groundwater hydrology (28-14)
5. Investigation of groundwater resources 1 (28-14)

Electives

Surface water option

6. Advanced flood estimation (28-14)
7. Reservoir design and yield determination (28-14)

Groundwater option

8. Groundwater hydraulics
9. Investigation of groundwater resources 2 (28-14)

Syllabi

1. Special course work

Statistics and computing for hydrologists. Basic hydraulics. Special lectures, excursions and demonstrations arranged to suit the needs of the class.

2. Hydrological processes

Hydrological cycle, water and energy balances, atmospheric moisture, precipitation process, evaporation and transpiration, storm run-off process, land use and management, stream gauging, instruments.

3. Flood design

Introduction to flood estimation, design rainfall data, hydrograph analysis, storm run-off, loss rates, rational method, unit hydrographs, introduction to urban drainage design, flood frequency.

4. Groundwater hydrology

Occurrence and distribution of groundwater, confined and unconfined aquifers, aquifer characteristics. Analogue models, Hele-Shaw analogue, resistance-capacitance network. Digital models of aquifer systems, solution using high-speed computers. Water movement in the unsaturated zone, instrumentation, hydrological characteristics of unsaturated soil, steady state systems, infiltration, drainage, computer solutions. Groundwater recharge. Groundwater quality, salinity. Sea water intrusion.

5. Investigation of groundwater resources 1

Occurrence and extraction of groundwater, investigation and drilling methods, systems approach, optimization techniques, conjunctive use studies, quality of groundwater.

6. Advanced flood estimation

Flood routing, catchment characteristics, run-off routing, synthetic unit hydrographs, urban run-off, regional empirical flood estimation methods, advanced unit hydrograph theory.

7. Reservoir design and yield determination

Storage-yield analysis, extension of run-off records, deterministic catchment models, stochastic hydrology, storage probability studies, spillway capacity and reservoir flood routing.

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(1) The two figures in brackets after each subject name show the total hours of lecture and tutorial time respectively.

8. Groundwater hydraulics

Mechanics of flow in saturated porous materials. Steady and unsteady flow to wells, constant discharge and constant drawdown conditions. Leaky aquifers, partial penetration, multiple aquifer boundaries, delayed yield from storage. Step drawdown analysis. Regional studies. Introduction to conformal transformation solutions.

9. Investigation of groundwater resources 2

Geophysical methods, remote sensing, photo-interpretation, arid environment studies, analogue models, case studies.

H. REGIONAL TRAINING COURSE ON THE USE OF COMPUTERS IN HYDROLOGY, TOKYO, JAPAN - ORGANIZED BY UNESCO WITH THE COLLABORATION OF ESCAP AND THE NATIONAL COMMISSION FOR UNESCO IN JAPAN

Duration of course: 1 month (85 hours of lectures).

1. Introduction

Hydrological data, origin of data. Analysis of series from the hydrological viewpoint. Reliability, homogeneity, significance of data.

2. Treatment of data

Numerical and statistical techniques. Statistics, regression and correlation. Processing and retrieval of data. Role of computers in hydrological information systems and for evaluation of data.

3. Introduction to the use of computers

Programming languages. Simulation techniques. Analogue and/or digital computers. Analogue computers. Digital computers. Hybrid computing techniques.

4. Application to hydrological problems

Groundwater flow. Flood routing, riverflow. Watershed models, run-off hydrology. Forecasting. Water quality.

In addition to lectures, the course includes 40 hours for exercises, workshops and discussions.

I. A SHORT COURSE ON PRACTICAL TECHNIQUES FOR REGIONALISING AND TRANSFERRING HYDROLOGICAL VARIABLES, INSTITUTE OF HYDROLOGY, WALLINGFORD, UNITED KINGDOM

Duration of programme: 4 weeks.

The four main topics in the syllabus are (i) description and indexing of catchment, climate and flow characteristics; (ii) correlation and regression analysis and the fitting and use of probability distributions; (iii) flood and flow modelling; (iv) low flow analysis. Additional lectures are included on related topics.

List of topics

Flow routing
Soil moisture accounting
Statistical applications
Microprocessors and instrumentation
Overseas flood estimation
Crop water use
Interpretation and mapping
Low flow hydrology
Frequency analysis
Case studies
Rainfall run-off modelling
Overseas applications
Geomorphological characteristics
Data archiving
Groundwater modelling
Evapotranspiration
Flood estimation

Programme of course (by weeks)

1. Introduction, regression studies, catchment and climate characteristics and visits to a low lying area, the Hydraulics Research Station and the Institute of Hydrology.

2. Advanced regression topics, probability, risk and frequency analysis, visits to the Water Data Unit and the Institute of Hydrology.
3. Low flow studies, visits to research catchments, a Water Authority and the Institute of Hydrology.
4. Flood event models, hydraulic routing, reservoir routing. Case studies from overseas, visit to Institute of Hydrology and departure.

Annex IV

Curricula and syllabi for some undergraduate and graduate options in training for degrees in fields other than hydrology

INTRODUCTION

A good method of becoming a professional hydrologist, without following a complete undergraduate training programme in hydrology, is to adopt hydrology as an option of specialization in undergraduate or graduate studies towards other degrees. This should be followed by special courses of advanced study in specific topics for a complete hydrological education. However, in many cases, the hydrological option of programmes for other degrees can give an adequate basis for professional work in hydrology.

Following this option usually implies the study of a wider spectrum of courses related to hydraulics and water resources engineering rather than a programme devoted only to hydrological topics. It is beneficial in the sense that it gives the student some broader outlook about the use of the results of hydrological studies. The examples of hydrology option programmes in this annex were received from national committees for the IHP in response to a request from the Division of Water Sciences of Unesco.

A. FACULTY OF ENGINEERING, KASETSART UNIVERSITY, BANGKOK, THAILAND - BACHELOR OF ENGINEERING PROGRAMME IN WATER RESOURCES ENGINEERING

Total required credit not less than 150.

First year

First semester	Credits	Second semester	Credits
1. Engineering drawing	2(1-3)	1. Descriptive geometry	2(1-3)
2. Calculus for engineering 1	3(3-0)	2. Workshop practice	1(0-3)
3. Analytic geometry	2(2-0)	3. Calculus for engineering 2	3(3-0)
4. General chemistry 1	4(3-3)	4. Solid analytic geometry	2(2-0)
5. General physics 1	4(3-3)	5. General chemistry 2	4(3-3)
6. English	3(3-0)	6. General physics	4(3-3)
7. Introduction to political science	3(3-0)	7. English	3(3-0)
	21(18-9)		19(15-12)

Second year

First semester	Credits	Second semester	Credits
1. Engineering mechanics 1	3(3-0)	1. Fluid mechanics	3(3-0)
2. Electric circuits	3(3-0)	2. Fluid mechanics lab.	1(0-3)
3. Electrical lab. engineering	1(0-3)	3. Engineering mechanics 2	3(3-0)
4. Digital computer programming	1(1-0)	4. Mechanics of materials	3(3-0)
5. Survey 1	3(2-3)	5. Survey 2	3(2-3)
6. Calculus for engineering 3	3(3-0)	6. Materials testing lab.	1(0-3)
7. Differential equation for engineering	3(3-0)	7. Advanced mathematics for engineering	3(3-0)
8. Introduction to economics	3(3-0)	8. Humanities (electives)	3(3-0)
	20(18-6)		20(17-9)

Third year

First semester	Credits	Second semester	Credits
1. Flow in open channels	3(3-0)	1. Introduction to environmental engineering	3(3-0)
2. Principle of hydrology	3(3-0)	2. Introduction to coastal engineering	3(3-0)
3. Water resources engineering	3(3-0)	3. Applied hydrology	3(3-0)
4. Groundwater	3(3-0)	4. Soil mechanics	4(3-3)
5. River mechanics environment	3(3-0)	5. Structural analysis	3(3-0)
6. Hydrology lab.	1(0-3)	6. Reinforced concrete	3(3-0)
	16(15-3)		19(18-3)

Fourth year

First semester	Credits	Second semester	Credits
1. Hydrogeology	3(3-0)	1. Design of hydraulic structures	4(3-1)
2. Economics of water resources	3(3-0)	2. Water resources planning evaluation	3(3-0)
3. Erosion and sedimentation	3(3-0)	3. Engineering watershed management	3(3-0)
4. Technical electives (1)	3(- -)	4. Technical electives (1)	3(- -)
5. Minors (2)	3(- -)	5. Minors (2)	3(- -)
6. Humanities (electives)	3(3-0)	6. Seminar	1(- -)
	18(- -)		17(- -)

B. DEPARTMENT OF CIVIL ENGINEERING, HYDROSYSTEMS DIVISION, VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY, BLACKSBURG, VIRGINIA, U.S.A.

List of courses in hydrology, water resources and related subjects and syllabi for courses in hydrology and water resources. Most of the courses are for 3 hours of lectures and 3 hours of class exercise per week for one semester of about 10 weeks.

Undergraduate courses

1. Hydrosystems

Analysis of hydraulic components of engineering projects: flow in closed conduits and open channels, introduction to engineering hydrology, the hydrological cycle and development of hydrographs.

2. Open channel flow

Analysis of free-surface flow of liquids; calculation of flow profiles; channel transitions and controls; supercritical flow phenomena.

3. Hydrology

Analysis of hydrological data, concepts of frequency and probability applied to hydrological synthesis problems. Groundwater hydraulics, flow to wells. Flow routing and hydrological considerations in design of structures. Water law.

4. Hydraulic engineering

Application of the principles of fluid mechanics to hydraulic engineering; flow measurement; computer analysis of flow in pipes and pipe networks; hydraulic models; analysis, selection and testing of pumps.

5. Hydraulic structures

Hydraulic analysis and design of engineering structures for water control, including dams, spillways, stilling basins, drainage structures, hydraulic models.

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(1) Technical electives are the courses in the Department of Water Resources Engineering which are restricted electives and subjects in the graduate course.
(2) Minors are the courses in the Department of Civil Engineering and Irrigation Engineering.

6. Computer models in hydrology

Hydrological background of models like TR-20, HEC-1 and HEC-2. Explanation of input data requirements and interpretation of programme output. Application of programmes to solution of hydrological problems on actual watersheds.

7. Hydropower engineering

River operations studies for power, flood control and other uses; selection of pumps and turbines; cavitation and water hammer; design of penstocks, surge tanks and other plant components.

8. Environmental water management

Analysis of the laws and administrative structure that constitute the institutional framework for the environmental aspects of water resources management. Emphasis on water quality control and environmental constraints on water resources development projects.

Graduate courses

1. Hydraulic engineering design: hydromechanics

Application of the principles of fluid mechanics to the analysis and design problems in hydraulic engineering with major emphasis on potential flow, conformal mapping and free streamline solution.

2. Hydraulic engineering design: sediment transport

Properties of river sediment; turbulent flow in open channels; initiation of sediment motion; stable channel design; equations and theories for bed load transport and suspended sediment; forms of bed roughness; resistance to flow.

3. Hydraulic engineering design: coastal hydraulics

Tides, currents, wave theories, coastal structures and wave forces, inlets and estuaries, beach processes.

4. Experimental design in hydraulics

Laboratory methods for the experimental design of hydraulic engineering structures and projects; similitude and dimensional analysis; hydraulic models; laboratory instrumentation and equipment; planning of tests and analysis of data.

5. Water resources engineering: advanced hydrology

Formulation of the physical laws of hydrology and application to practical problems and statistical treatment of hydrological variables. Analysis of overland flow, flow in rivers, erosion, evaporation and morphology. Problems in extreme values of streamflow, persistence and variability.

6. Water resources engineering: water resources planning

Analysis of the water resources planning process and examination of public policy relative to water resources development. Includes consideration of criteria for determination of project feasibility, with emphasis on the theory and mechanics of economic evaluation.

7. Water resources engineering: analysis of water resources systems

Use of mathematical modelling techniques in the formulation of plans for the development, conservation and protection of water resources systems. Modelling techniques reviewed include optimization, simulation, and decision theory.

8. Groundwater and seepage

Derivation of basic groundwater flow equations. Dupuit theory of unconfined flow. Conformal mapping. Hodograph techniques. Closed form solutions of elementary groundwater flow problems.

9. Transient flow in hydraulic systems

Analysis of transient phenomena in open and closed conduits, using method of characteristics and impedance methods. Transients caused by turbopumps. Valve stroking.

10. Water law

Principles of law as applied to water rights and water allocations. Federal, state and local legislation and case law as related to water use and water resources development.

11. Dynamic meteorology

Fundamentals of dynamic meteorology; precipitation physics; applications of meteorological studies in hydrological engineering.

12. Special study: transport processes in waterways

Physical aspects of mixing, convection and diffusion processes in reservoirs, rivers, estuaries and coastal waters with emphasis on modelling techniques; hydraulic design aspects of waste disposals.

13. Special study: advanced analysis of water resources systems

Through the use of current literature and case studies, sophisticated and advanced systems being used to aid in the formulation of plans for water resources systems are analysed.

14. Advanced engineering hydraulics

Fluid turbulence, unsteady flow, hydraulic transients, flow in porous media, and other advanced topics in engineering hydraulics.

15. Advanced groundwater and seepage

Categories of seepage: steady, transient, confined and unconfined. Review of closed from and experimental procedures and limitations. Finite difference, finite element and characteristic methods for one-, two-, and three-dimensional flow. Darcy, non-Darcy and unsaturated flow. Applications: foundations, cofferdams, earth banks, tidal beaches, flow toward wells, dispersion, diffusion and salinity.

Selected supporting courses

1. Computational fluid dynamics
2. Dynamics of the ocean
3. Theory of stratified flows
4. Watershed engineering
5. Parametric watershed models
6. Applied finite element methods in civil engineering
7. Stream sanitation
8. Applied systems engineering
9. Numerical methods for partial differential equations
10. Theory of continuous media
11. Mathematical theory of incompressible fluids
12. Introductory viscous flows
13. Turbulence and turbulent flows
14. Perturbation methods
15. Applied optimization methods
16. Mathematical programming
17. Dynamic programming
18. Introduction to numerical analysis
19. Applied mathematics for engineers
20. Applied partial differential equations
21. Numerical analysis
22. Applied statistics
23. Probability and distribution theory
24. Stochastic processes

C. PROGRAMME OF STUDIES FOR A HYDRAULIC ENGINEERING AND HYDROLOGY OPTION IN CIVIL ENGINEERING AT TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY, FACULTY OF CIVIL ENGINEERING, HAIFA, ISRAEL

The total programme in civil engineering comprises 165 study units over a period of four years (eight semesters). Each study unit is equivalent approximately to 14 hours of lectures or about 28 hours of class exercise. The programme consists of some 125 units of required courses and 40 units of electives.

The courses in hydraulics, hydrology and related subjects in the list of required courses are:

1. Fluid mechanics - 3 units
2. Hydraulics and hydraulics laboratory - 3 units
3. Elements of engineering hydrology - 3 units
4. Environmental engineering - 4 units

The list of elective courses includes the following courses in hydrology, hydraulic engineering and related subjects:

1. Groundwater hydrology - 2 units
2. Advanced surface hydrology - 2 units
3. Flow in porous media - 2 units
4. Hydrodynamics - 2 units
5. Hydraulic engineering - 3 units
6. Drainage engineering - 3 units
7. Water resources engineering 1 - 3 units
8. Coastal engineering - 2 units

D. CURRICULA AND SYLLABI OF CIVIL ENGINEERING, KYOTO UNIVERSITY, JAPAN

For undergraduate students

1. Probability and statistics

Brief review of fundamental concepts of probability theory (probability distribution, Bayes theorem, joint distributions and related topics); exercises: their application to the phenomena and systems of interest in civil engineering.

2. River hydrology

Fundamental concepts and laws contained in the hydrological cycle run-off system models (deterministic and stochastic); exercises: to develop the students' own run-off system model by utilizing the given data of rainfall and run-off discharge.

3. Water resources engineering

Fundamental concepts on planning and management of water resources systems and their methodology (including economical feasibility).

For graduate students

1. Stochastic process

Brief review of fundamental concepts of stochastic process with special emphasis placed on analysis and synthesis of hydrological time series.

2. Groundwater hydrology

Basic subjects in order to analyse the role of groundwater in the hydrological systems. Lumped parameter models for simulation and prediction of groundwater yield.

3. Advanced course of hydrology

Integrated hydrological processes. Exercises: their exercise on the appropriate subjects, such as flood routing, river morphology, run-off system analysis, flood forecasting, statistics of hydrological events.

4. Water resources system analysis

Analysis of both deterministic and stochastic hydrological processes (including hydrological criteria, public investment theory, optimization methods, statistics, computer simulation, and public policy issues). Exercise: case study to provide the experience in water resources planning.

E. CURRICULA AND SYLLABI IN HYDROLOGY AT SEOUL NATIONAL UNIVERSITY, KOREA

Description of undergraduate courses:

1. Elementary fluid mechanics 1

Fundamentals, fluid statics, kinematics of fluid notion, flow of an incompressible ideal fluid, flow of a compressible ideal fluid, the impulse-momentum principle, flow of real fluid.

2. Elementary fluid mechanics 2

Similitude and dimensional analysis, fluid flow in pipes, liquid flow in open channel, fluid measurements, elementary hydrodynamics, fluid flow about immersed objects.

3. Hydraulics and lab. 1

Properties of water, hydrostatics, fundamentals of hydrodynamics, laminar and turbulent flow, steady flow in pipe, steady flow in open channel.

4. River engineering

Water resources and river engineering, hydrometeorology, hydrology, geomorphology, investigation for river planning, river planning, hydraulics for rivers, river engineering.

5. Water resources engineering

Probability concepts in water resources planning, engineering economics, irrigation and drainage, hydropower engineering, navigation, flood control, water resources planning.

6. Hydropower engineering

General introduction of hydropower engineering, planning of hydropower, general theory of dams, gravity dams, rockfill and earthfill dams, surge tank, turbine and powerhouse, spillway.

7. Hydraulics and lab. 2

Fluid resistance, fluid measurement, water wave, sediment transport, groundwater and seepage, dimensional analysis and hydraulic similarity.

8. Introduction to hydrology

Water and hydrology, precipitation, streamflow, evaporation and transpiration, surface hydrology, groundwater hydrology, streamflow hydrograph, relationship between precipitation and run-off, probability in hydrology, stochastic hydrology, sedimentation.

Description of graduate courses:

1. Open channel hydraulics and lab.

Basic principle, theory of uniform flow, conitinirity and momentum principle, theory of gradually and rapidly varied flow, spatially varied flow, unsteady flow.

2. Advanced hydrology

Precipitation mechanism, sampling method, distribution of precipitation in time and space, frequency analysis, statistical inference, correlation and regression, evapotranspiration, infiltration, hydrological simulation, flood estimation.

3. Theoretical hydrology

Transport process, energy balance of earth, mathematical models, deterministic process, stochastic process.

4. Groundwater hydrology

Basic principle, Darcy equation, continuity equation of steady flow, well hydraulics, unsteady flow, unsaturated flow theory, application.

5. Water resources system

Procedure for water resources system planning, guidelines for investigation, analysis and design of water resources system, application of linear and dynamic programming, case study.

6. Hydraulic and hydrological modelling theory

General theory of hydraulic and hydrological modelling, dimensional analysis and similitude, modelling of fluvial channel, theory of mathematical modelling, modelling of river basins.

Annex V

Examples of hydrology subjects included in programmes for other degrees

INTRODUCTION

Before the introduction of the International Hydrological Decade, hydrology was taught as an independent course of study only in a few universities. Some hydrological topics were covered usually within other courses such as hydraulics, water supply and sewerage, hydraulic engineering, etc. In some universities, hydrology did appear as a separate subject but, in many cases, it was one of the optional courses. The situation has completely changed in recent years. Most universities include now a course on hydrology in the civil engineering programmes and in other engineering programmes such as agricultural engineering, environmental engineering, transportation engineering, etc., as well as in some non-engineering programmes such as geography, geology, forestry, etc.

The basic course is taught under a variety of names such as:

Hydrology
Applied hydrology
Engineering hydrology
Elements of hydrology
Elements of engineering hydrology
Hydrology and meteorology
Hydrology and climatology
Hydrology and hydrometeorology
Hydrology and hydraulic engineering
Applied hydrogeomorphology.

In some institutions, the basic course is divided into two parts which usually go under the names of: Part 1 - Surface hydrology; Part 2 - Groundwater hydrology; or some similar names.

The syllabus for this basic course, or the combined syllabus for the two courses if the course is given in two parts, includes usually the range of topics listed in the first edition of this publication under the heading 'Hydrological topics which are indispensable for all hydrologists' (section 2.2). The list which is reproduced below as Section 1 of this annex represents topics now considered essential to all professionals taking a course in hydrology even though they are not classified as hydrologists.

Examples of syllabi for the above courses are given in Sections 2 and 3 of this annex. Section 2 lists some of the syllabi received from national committees for the IHP in response to a request from the Division of Water Sciences of Unesco. Section 3 reproduces some of the syllabi which appeared in the first edition of this publication under the course names given above.

SECTION 1 - HYDROLOGICAL TOPICS WHICH ARE ESSENTIAL FOR ALL STUDENTS OF HYDROLOGY

1. Introductory material

Definitions and relation of hydrology to other sciences. The hydrological cycle. Physical characteristics of the watershed. Importance of data. Variability and randomness of hydrological phenomena. International organizations and associations dealing with hydrology. The International Hydrological Programme.

2. Precipitation

Forms and mechanisms of precipitation. Determination of amounts, intensity and duration and spatial and temporal distribution of precipitation. Measurements of precipitation and their accuracy. Snow. Estimation of missing data.

3. Evaporation and evapotranspiration

Definitions. Determination by measurement and by computations. The energy and mass transfer approaches. Evaporation from water surfaces, soil, snow and ice. Transpiration. Total evaporation and total losses. Evaporation control.

4. Infiltration

Soil moisture. Laws governing infiltration. Measurement. Infiltrometers. Empirical formulae.

5. Groundwater

The origins and occurrence of groundwater. Types of aquifer. Hydrological properties of various pervious materials. Interrelation between groundwater and surface water. Depletion. Springs and wells. Water-table fluctuations. Movement of groundwater. Recharge of groundwater reservoir. Simulation by physical or electrical models. Quality of water.

6. Surface run-off

Elementary hydrograph, separation of depletion flow and surface flow. Minimum flow. Types of run-off. Depression storage, overland flow, surface detention. Unit hydrograph techniques. Properties of the drainage basin. Synthetic hydrograph. Flood and droughts. Use of the unit hydrograph. Measurements. Statistical and other methods. Quality of surface water.

7. Water balance

Calculation of yield. Short-term and long-term variations. Water balance of lakes, swamps, watersheds and regions. Experimental drainage basins and representative basins.

8. Hydrometry

Collecting hydrological data as a technical and an organizational problem. Decision on duration and frequency of observations and on their required accuracy. Various methods of measuring water-levels, velocities and solid and liquid discharges. Storage and processing of data. Cost of measurements.

9. Rivers and lakes

The natural river as a medium of transport of water and sediments. The river as changed by man's influence. Morphology of river-beds. Natural and artificial lakes.

SECTION 2 - SOME SYLLABI RECEIVED FROM IHP NATIONAL COMMITTEES

A. UNIVERSITY OF BUENOS AIRES, FACULTY OF EXACT AND NATURAL SCIENCES, BUENOS AIRES, ARGENTINA DEPARTMENT OF METEOROLOGY

Duration of course: one semester. Time allocation: 4 hours of lectures and 4 hours of exercises per week.

Hydrology

Definition of hydrology and its essential parts. The hydrological cycle. Precipitation regime, precipitation maps. Intense storms, intensity-duration-frequency relations, area effects. Interception. Evaporation from water surfaces and from the soil. Modern theories of evaporation from wet surfaces, empirical equations, evaporation from natural wet surfaces. Transpiration, the process and factors influencing it. Transpiration from vegetation. Evaporation reduction. Physical and functional properties of watersheds, topographic and geologic properties, vegetation cover, drainage density. Natural storage capacity of surface and groundwater reservoirs. Surface flow variability, the hydrograph of run-off. Springs and various types of streams, classification of streams. Analysis of hydrographs and its separation into components. Infiltration capacity and its variation, factors affecting infiltration, indices of infiltration curves. Infiltrometers, rainfall simulators. Hydrograph analysis. Groundwater, hydrogeology, aquifers. Influence of physical and climatic factors on run-off. Hydrological balance of watersheds. Estimation of various types of run-off. Handling of hydrological data. Estimation of extreme values.

B. AUSTRALIA

The University of New South Wales

1. Geomorphology for hydrologists

Introduction. Hillslope forms and processes. Geomorphic parameters in drainage basins. Channel networks. Forms of river channels in relation to sediment load. Fluvial depositional landforms. Run-off processes and channel initiation. Influence of geomorphic characteristics on hydrological response. Role of geomorphology in representative basin and water resources studies. Effect of long-term climatic fluctuations on channel forms and networks. Effects of short-term climatic fluctuations on channel forms and networks. Effects of human activities on channel forms and networks.

The University of Melbourne

2. Arid zone hydrology

Arid zone rainfall characteristics; data collection and instrumentation; run-off processes; infiltration, transmission loss; recharge processes; flood characteristics and design; water yield; storage of water; evaporation and evaporation suppression; sediment transport and measurements.

3. Arid zone water resources management

Water as a resource: demand for and supply of water; works and management to match demand with supply. Special features of the arid zone: climate; water uses, quantification of demand quantities and qualities, arid zone grazing system modelling; water supplies, quantities and qualities; measurement of flow rate, volume, quality. Engineering works: design, construction, operation and maintenance of works, including excavated tanks, dams, pipelines, pumps, windmills, engines and motors, troughs; costs; reliability; energy sources for pumping. Special practices: water spreading; irrigation including trickle irrigation; evaporation reduction; desalination.

4. Surface hydrology (18 lectures and 6 tutorials)

Precipitation: atmospheric circulation, hydrological cycle, rainfall processes, measurement and data, error analysis and regression, spatial and temporal patterns, rainfall frequency. Streamflow: gauging, hydrographs, rational method, unitgraph and run-off routing models, flood frequency, yield from small and large catchments, rainfall-run-off models.

5. Agricultural water management (18 lectures and 6 tutorials)

Surface energy balance: radiative exchanges, conduction, turbulent transfer, heat balance of plants and animals. Evaporation: principles of evaporation as an energy consuming and as a diffusive process; lake evaporation; crop evapotranspiration, including soil and plant factors, and crop water requirements. Irrigation: methods, efficiency, salinity control. Drainage: surface drains, flood mitigation. Erosion control: water and wind processes - land use and planning.

6. Groundwater hydrology (18 lectures and 6 tutorials)

Unsaturated flow: moisture and temperature gradients, infiltration, redistribution. Saturated flow: confined, unconfined and leaky aquifers, well hydraulics, recharge of aquifers, subsurface agricultural drainage, seepage through earth banks. Analogue solutions.

7. Hydrology (18 lectures and 8 tutorials)

Hydrostatics, basic concepts of fluid flow in both closed conduits and open channels. Meteorological data, drainage basins, rivers and streamflow, streamflow measurement, flood hydrographs, stream morphology and sediment transport. Urban hydrology and urban drainage systems. Water supply, water quality, sewerage, site works associated with pipelines.

8. Forest hydrology (24 lectures and 48 hours practical work)

a. Basic principles of hydrology (10 lectures):
Hydrology, the hydrological cycle.

Basic hydraulics. Water properties and flow.
Precipitation - meteorological data.
Hydrological and physical features of drainage basins.
Rivers and streamflow. Streamflow variability and measurement, stream morphology, flood hydrographs.

b. Forest and forestry influences on the hydrological cycle (14 lectures):
Movement of water through forests. Interception, evapotranspiration, subsurface water, streamflow.
Erosion and sedimentation in relation to forests. Mechanics of water erosion. Sediment yields. Effects of forest operations on soil erosion.
Forests and streamflow. Effects of forest operations on streamflow.
Forests and water quality. Measures of water quality. Natural water quality. Effects of forest operations on water quality. The nutrient cycle.

9. Post-graduate courses (as part of a Master of Engineering Science degree by major thesis or mainly through course work)

9a. Advanced surface hydrology

This course builds on the material presented before and will treat the following topics: Matrix solution of unitgraphs, instantaneous and synthetic UH, application of run-off routing, review of flood routing, rainfall-run-off process modelling including overland flow, low flow analyses, frequency analysis of flood and low flow events, stochastic data generation and storage yield analysis.

9b. Special studies in agricultural engineering

For graduate students desiring further study of special topics. These could be in hydrology.

C. CANADA - EXAMPLES OF CURRICULA AND SYLLABI FOR COURSES IN HYDROLOGY AND RELATED TOPICS IN UNDERGRADUATE AND POST-GRADUATE STUDIES AT CANADIAN UNIVERSITIES

1. Civil engineering, undergraduate

a. Atmosphere - hydrometeorology, evaporation and evapotranspiration, infiltration and groundwater, topographical characteristics of a watershed, discharge and floods, probability and stochastic methods in hydrology, applications.

2. Civil engineering, undergraduate

a. Hydrological cycle, evaporation and transpiration, snow and snowmelt, infiltration, subsurface water, unit hydrograph and S-curve analysis of flood waters, well hydraulics, stream flow river and reservoir routing techniques, statistics of extreme values.

b. Types and physical properties of aquifers, Darcy's Law, hydraulic conductivity of isotropic, anisotropic and multilayered soils, uniform flow, undirectional and radial flow, steady and unsteady flow nets, methods of images, partially penetrating wells, leaky aquifers, application of mapping techniques to seepage problems.

3. Civil engineering, undergraduate

a. Unsteady flow in closed conduits: Analysis of water hammer in penstocks and in pumps; discharge levies by graphical and characteristics methods; influence of friction; optimum gate closure.

b. Steady flow in open channels: Energy and momentum principles, uniform and gradually varied flow, backwater curves. Flow through transitions, bends and obstructions.

c. Unsteady flow in open channels: Surge waves in power canals, locks and navigation canals, flood routing.

d. Rivers and canals: Morphology of rivers. The consequences of disturbing river regimen by engineering works. River-bed scour around flow obstructions. River regulation and control for navigation. Fishways. Mobile boundary open channel flow. Sediment transport. Tidal discharge computations and convergence of estuaries. Dredging practices. Inland waterways. Hydraulic models.

e. Estuary hydraulics: Estuary dynamics and classification, the effect of engineering works on salinity intrusion, physics of estuary pollution, the use of computers and hydraulic models.

f. Hydrology: Advanced applications of statistical methods, hydrograph analysis and routing techniques, flow forecasting procedures.

g. Water resources development: Availability of water, quantitative and qualitative requirements for water - municipal, agricultural, industrial, etc., drainage and flood control, water resources management.

h. Water resources systems: Application of systems engineering concepts to the planning, design and operation of water systems.

i. Forest watershed management: A quantitative analysis of forest industry influences on hydrological components of watersheds, fishery aspects of ecology of streams and lakes, evaluation and control of forest industrial water pollution, effects of land management on quality, quantity and timing of water flow, research in forest hydrology.

4. Geography, undergraduate

a. Introduction to hydrology: Principles of hydrology at site, watershed and larger regional scales. Introduction to techniques of measurement and analysis.

b. Atmosphere and environment: The relation of the principles of climatology/environmental interactions. Large and small-scale interaction between the atmosphere and the soil, vegetation, water, cities and man. Topics in applied climatology including air pollution, weather modifications, physiologic climatology.

c. Urban meteorology: The impact of urbanization upon atmospheric processes and climates. The energy and water balances of cities, models of the urban atmosphere.

d. Regional hydrology: Hydrological regionalization and the design of observation networks. Nature of hydrological parameters: illustration by studies of precipitation and surface water run-off. Regionalization of various geographical scales.

e. Fluvial geomorphology: Introduction to open channel flow and sediment transport. River morphology and channel types. Paleohydrology. The development of channel networks.

f. Permafrost and the arctic environment: An analysis of permafrost, periglacial forms, underground ice. Occurrence and characteristics of frozen ground. Theory of ground ice formation, classification of patterned ground.

g. Watershed geomorphology: The drainage basin as a fundamental unit of geomorphic enquiry. The role of experimental and representative basins. Sediment sinks and sources, mass fluxes of sediment and sediment routing models.

5. Geological engineering, undergraduate

a. Geomorphology: Geomorphological problems and concrete application. The periglacial environment, impact on the development, unstable equilibrium, instability of slopes, landslides. The pedological equilibrium as a reflex of climate and material. Historical concepts of geomorphology, evolution of ideas. Interpretation of topographical maps, identification of geomorphological forms.

b. Photo-interpretation: Teledetection, the electromagnetic spectrum, imageries, radar, infra-red, Landsat. Air photos, types of films and cameras. Geometry of the photos, instruments for detection. Photo-interpretation of bed rock and soils. Utilization of air photos for geological mapping and for practical application.

6. Geological sciences, undergraduate

a. Groundwater hydrology: Theory of groundwater flow, flow networks, regional groundwater resource evaluation, well hydraulics, role of groundwater in geological processes.

b. Groundwater contamination: Principles of groundwater chemistry, contamination in natural groundwater flow systems, sources of contamination, mass processes, hydrochemical behaviour of contaminants, nuclear waste disposal.

c. Advanced groundwater hydrology: Finite-difference models of steady-state and transient groundwater flow in the saturated and unsaturated zones, application to regional groundwater flow; groundwater recharge, subsurface contributions to streamflow, aquifer evaluation and groundwater contamination.

7. Soil science, undergraduate

a. Physical behaviour of soils: A study of the physical behaviour of soils as related to their use with emphasis on water movement and retention. Laboratory exercises in methods used to investigate physical properties and behaviour of soils.

b. Soil physics: Thermodynamics of soil water, soil hydrology with emphasis on the flow of water in layered soils.

8. Water resources engineering, undergraduate

a. Hydrology: Quantitative study of natural water circulation systems with emphasis on basic physical principles and interrelationships among major processes, characteristics of mass and energy; inputs to and outputs from watersheds; factors governing precipitation occurrence, evaporation rates, soil-water storage changes, groundwater recharge and discharge, run-off generation; methods of streamflow analysis; mathematical modelling.

9. Civil engineering, post-graduate studies

a. Hydraulics of open channels: Equations of open channel flow. Rapidly varied flow. Gradually varied flow in regular and natural channels. Unsteady flow. Application to flood waves and tides in natural channels. Sediment transport, bed and suspended load.

b. Hydraulics and porous media: Equations for saturated flow. Application to filtration and well problems. Flows with a free surface. Application to seepage, drainage and recharge problems. Partially saturated flow. Infiltration. Two-phase flow. Salt water intrusion.

c. Advanced fluid mechanics: Fundamental equations and relations of fluid mechanics; similarity and dimensional analysis; applications to the study of the hydraulic process of hydrology and water treatment.

d. Applied hydrodynamics: Two-dimensional irrotational flow, conformal mapping, channel flows, free streamline flows; irrotational flows with point vortices and vortex sheets. Axisymmetric irrotational flow, methods of solution. Effects of viscosity, boundary layers, free turbulent shear flows.

e. River engineering: Introduction to fluvial processes and flow regimes; modes of sediment transportation; suspended and bedload transport theories; sediment measuring techniques and their limitations; secondary circulation and the meander process; hydraulics of bridge waterways and pipeline crossings; local scour at bridge piers; erosion protection.

f. Waste disposal on land: Definition of the waste problem. Site selection criteria. Environmental impact assessment. Site design and operation.

g. Environmental assessment of civil engineering projects: Procedures and methods of systematic evaluation of the environmental impact of civil engineering projects including waste water disposal systems, solid waste disposal systems, and water resources development systems.

10. Water resources engineering, post-graduate studies

a. Water resources systems: Conservation of water resources. Multi-purpose project planning; study of domestic and foreign water development projects. Techniques for simulation, optimization, linear and dynamic programming.

b. Physical hydrology: Equations of overland and channel flow, computer and laboratory models of small basins. Flood waves in natural channels. Heat transfer to land, water and snow structures; evaporation, snow melt. Infiltration equations, methods of solution. Equation of groundwater flow, application to problems of recharge and depletion.

c. Groundwater and seepage: Types and physical properties of aquifers. Darcy's law; hydraulic conductivity of isotropic, anisotropic and multilayered soils; uniform flow; unidirectional and radial flow - steady and unsteady flow net; methods of images, partially penetrating wells; leaky aquifers; application of mapping techniques to seepage problems.

d. Dispersion processes in hydrological flows: Fundamental equations of diffusion and dispersion. One-dimensional dispersion equations. Applications to open-channel flows and groundwater flows. Field techniques. Transport of wastes in streams and estuaries, rates of waste removal and conversion. Mathematical and computer models of the differential equations governing the content of conservative and non-conservative substances.

e. Statistical methods in hydrology: Concepts of probability and random variable applied to hydrology. Statistical distributions, their approximation and analysis. Statistical inference, including tests of significance and estimation theory. Linear and multivariate correlation and regression techniques. Data generation and simulation techniques for design of water resources systems. Introduction to hydrological and meteorological time series.

f. Stochastic hydrology: Spectral analysis of hydrology time series. Stochastic operations and prediction theory of a stationary process. Univariate and multivariate spectral analysis. Estimation of frequency response functions; analysis and optimization of linear and non-linear systems for random processes.

g. Hydrological systems analysis: Concepts from modern systems analysis in hydrology. Linear, non-linear, discrete, deterministic and stochastic systems. Methods of analysis in the time and frequency domain.

h. Applied hydrology: Detailed discussion of the components of the hydrological cycle. Advanced techniques of analysis of hydrological data including synthesis and simulation.

D. CONGO, PEOPLE'S REPUBLIC OF; UNIVERSITY MARIEN NGOUABI, BRAZZAVILLE - DEPARTMENT OF GEOLOGY

Hydrological terms.
Water in the soil and hydrogeological parameters.
Aquifers and aquicludes.
The different types of aquifers in relation to the geological situation, permeability and hydrodynamics.
Springs.
Water movement in aquifers.

E. EXAMPLES OF CURRICULA AND SYLLABI FOR COURSES IN HYDROLOGY AND RELATED TOPICS IN UNDERGRADUATE PROGRAMMES OFFERED AT VARIOUS UNIVERSITIES IN THE FEDERAL REPUBLIC OF GERMANY AND IN WEST BERLIN

1. Berlin, West

a. Curriculum of hydrology

Undergraduate studies

i. First term
Introduction to problems of hydrology:
Hydrological cycle and balances.
Hydrology on the land (rivers and lakes).
Fundamental hydrographic quantities - sedimentation - run-off measurement and its evaluation.
Statistical forecast of flood waves.

ii. Second term
Introduction to hydrometeorology (heat balance, atmospheric layers, humidity, precipitation):
Evapotranspiration from lakes, soil, snow and ice.
Infiltration and groundwater flow - relations between precipitation and run-off - unit hydrograph.

Dimensioning of reservoirs - introduction to project planning.

Post-graduate studies

Instantaneous unit hydrograph:

Reservoir routing - channel routing - statistical and probability analysis of hydrological data - completion for forecast of floods and low water - stochastic dimensioning of reservoirs.

Practical exercises.

b. Hydrological and related courses

The university offers special courses for civil engineering students governing the following topics:

i. Computer programming and data processing including numerical methods and optimization.
ii. Fluid mechanics.
iii. Geophysics.
iv. Soil science.
v. Water quality.
vi. Urban hydrology.

The course of hydrology includes the following topics: hydrological cycle - channel and fluvial hydraulics, sedimentation - statistical forecast of floods - hydrometeorology - groundwater flow with computer models - parametric and stochastic hydrology - hydrological forecasting - project planning - precipitation and run-off.

2. Bochum

a. Courses in hydrology offered in the fifth, seventh and eighth semesters

i. Principles of hydrology (fifth semester): Hydrological cycle, precipitation, evaporation, run-off, groundwater, rainfall-run-off models (unit hydrograph), floods (flood routing), statistical analysis of hydrological time-series.
ii. Special topics in hydrology (seventh semester): Deterministic and stochastic methods, modern methods and their applications, on-line flood forecasting, man-made influences, synthetic generation of hydrological data.
iii. Remote sensing in hydrology (seventh semester): Practical applications of remote sensing and data collection and transfer, results of recent research developments on remote sensing.
iv. Hydrometric exercises (eighth semester): Measurements of flow velocities in a river, measurements of sediment deposits from a ship in a lake.

b. Courses in related topics

i. Principles of water resources systems analysis: Water resources systems, benefit-cost analysis, mathematical models for planning multipurpose water resources systems: simulation, linear and dynamic programming. Regional water resources planning.
ii. Analysis of water resources engineering projects: Presentation of foreign and national case studies including planning and operation of water resources systems.
iii. Applied hydraulics: Open channel flow, close conduit hydraulics, groundwater flow, multiphase flow.
iv. Introduction to constructive aspects of waterworks: River regulation measures, dam construction and design, alternative design possibilities.
v. Transportation and hydraulic constructions: Transportation, hydroelectric power plants, river regulation, canal construction, locks and harbours.
vi. Planning and operation of reservoirs: Mathematical models for design and operation of reservoirs with multiple purposes. Single and multi-reservoir systems. Conjunctive use of reservoirs and other facilities (groundwater, thermal power plants, etc.).
vii. Dam construction: Design and structural characteristics of different types of dams. Operation gates and spillways.

3. Göttingen (Institute of Soil Sciences and Forest Nutrition)

a. Undergraduate level

i. Soil water.

b. Graduate level

i. Soil physics.
ii. Principles of agrophysics.
iii. Advanced soil physics.
iv. Laboratory course in soil physics.

c. Graduate study leading towards advanced degrees (M.S., Ph.D.) in the following fields is possible:

i. Computer programming and data processing in hydrology.
ii. Numerical methods in subsurface hydrology.
iii. Water quality, geochemistry and quality modelling.
iv. Physical dynamical hydrology.
v. Models and analogues.
vi. Remote sensing and regional water budget studies.
vii. Agricultural hydrology.
viii. Forest hydrology.
ix. Soil science.
x. Ecology and environmentology.

4. München

Models and analogues: Development and application of simulation models, limits of mathematical modelling; rainfall analysis and design storms; run-off models for urban drainage systems; water quality modelling for rivers; network models in water supply; cost-benefit analysis and optimization models; optimization models for solid waste collection.

5. Stuttgart

a. Hydrology

References.

i. Hydrological cycle:
Rainfall (precipitation)
Evaporation -
  Interception
  Evaporation
  Transpiration
  Evapotranspiration
Infiltration

ii. Subsoil run-off:
Subterranean water
Groundwater

iii. Surface run-off:
Surface run-off from spring discharge
Surface run-off from groundwater discharge
Run-off from the surface
Relations between precipitation and surface run-off
Influence of form, kind and size of the drainage basin on the surface run-off

iv. Methods of flood prediction:
Water-(level)-gauge-related-curves of comparable water levels
Travel-time-curve
Δ Q-method

v. Synthesis of flood hydrographs:
Unit hydrograph method
Flood plan

vi. Variation of flood waves:
Hydraulic method
Hydrological methods -
  Muskingum method
  Kalinin-Miljakov method
Advantages and disadvantages of hydraulic and hydrological methods

b. Water resources management

i. Definition and aims

ii. Foundations:
    Run-off parameters

iii. Water resources effects of interventions to natural run-off regime:
    Change of rainfall, evaporation and infiltration
    Change of discharge by water ordering or water addition
    Change of water surface level by transforming the cross section
    Change of discharge by filling and emptying of storages -
        Graphical methods
        Numerical methods

iv. Dimensioning of storages; plans of water resources policy

v. Control of run-off:
    Regulation of water level and water volume -
        Head water control
        Tail water control
        Combined control
        Programme-controlled run-off regulation
    Advantages and disadvantages of head water and tail water control
    Control regulation

F. GHANA - UNIVERSITY OF SCIENCE AND TECHNOLOGY, DEPARTMENT OF CIVIL ENGINEERING, KUMASI, GHANA

1. Hydrology (compulsory to all undergraduate students)

Hydrological cycle. Precipitation and its measurement. Analysis of precipitation data. Evaporation and evapotranspiration. Infiltration and its measurement. Infiltration indices. Surface run-off - river gauging, flow rating curves. Rainfall-run-off correlation. Hydrograph analysis - unit hydrograph for various durations. Flood routing through reservoirs. Storage estimation. Statistical analysis of precipitation and streamflow data. Groundwater hydrology - Darcy's Law. Their non-equilibrium formulation; method of images, determination of aquifer constants from pumping tests.

2. Optional courses in water resources engineering

a. Hydropower: Storage and regulation of reservoirs. Types of dams. Forces on dams. Spillways. Types of hydropower schemes. Cost and value of hydropower. Turbine selection and operation. Surge tanks.

b. Sediment transport: Measurement and description of sediment characteristics. Types of sediment motion. Initiation of sediment motion. Design of stable alluvial channels. Local scour. Reservoir sedimentation.

c. Coastal hydraulics: Introduction to the hydrodynamics of deep and shallow water waves. Wave reflection, refraction and diffraction. Coastal erosion and littoral drift. Sea-walls, groynes, breakwaters, etc.

d. Irrigation and drainage engineering: Water requirements. Soil-water relationship. Methods of irrigation. Irrigation canals and structures. Drainage of irrigated lands. Storm drainage. Land and highway drainage.

G. ISRAEL - TECHNION - ISRAEL INSTITUTE OF TECHNOLOGY, FACULTY OF CIVIL ENGINEERING, HAIFA, ISRAEL

Syllabus for required course in 'Elements of engineering hydrology'

Time allocation: two hours of lectures and two hours of class exercise per week for one 14-week semester.

Components of the hydrological cycle and hydrological balance equations. Rainfall measurement and analysis of data. Intensity-duration-frequency diagrams. Design storm. Run-off measurements. Hydrograph analysis, unit hydrograph. Infiltration measurement and analysis. Evaporation and evapotranspiration. Rainfall run-off relationships on a yearly and seasonal basis. Antecedent moisture index. Relations for individual storms. Reservoir flood routing soil moisture. Hydraulic properties of the soil. Types of aquifers. Hydraulics of steady groundwater movement. Flow to wells in confined and phreatic aquifers. Draw-down near a single well and for a group of wells. Meteorological variables measurements and analysis. Definition of terms in meteorology. The standard atmosphere. Moisture and relative humidity. Adiabatic processes in the atmosphere. Cloud formation. Synoptic maps.

H. MALAYSIA

1. University of Technology, Faculty of Civil Engineering, Kuala Lumpur, Malaysia

Hydrology

a. Fundamental concepts of hydrology

Introduction to engineering hydrology, irrigation, flood control, hydro-electric power generation, water resources developments, etc.

The hydrological cycle and water balance equation. Chain of events describing precipitation, interception, percolation, surface run-off, evaporation, transpiration, and groundwater flow.

Meteo-hydrological data: climatic influences such as humidity, pressure, wind, temperature. Topographical influences such as lakes, marshland, stream flow. Geological influences such as the underlying rocks affecting groundwater flow and soil water.

b. Precipitation

Types and sources of precipitation: rain, snow, sleat, ice, dew, fog. Convective, orographic, cyclonic and frontal precipitation. Types of cooling: adiabatic, contact and rotational.

Recording precipitation (rainfall): description of the various types of recording and non-recording instruments. Siting of a raingauge. Errors in measurement of precipitation.

Computation of rainfall intensity: method of determining depth of precipitation over an area by arithmetic mean, isohyetal map and Thiessen polygon.

Analysis of precipitation data: representation of a precipitation intensity by hydrographs, mass curves and running or moving means plot. Analysis of dry and wet periods using residual mass diagram. Use of double mass curve for checking the accuracy of a particular rain gauge in a catchment.

c. Surface run-off

Streamflow measurements: velocity-area measurements of discharge, flow rating curves, streamflow hydrographs. Measurements of stage using gauges. Estimation of discharge using current meter. Other methods of flow measurement using weirs, floats and rods, salt dilution.

Estimation of run-off: presentation of mass curves for river flows, effects of rainfall intensity and duration over a catchment. Time of concentration and time of flow. Run-off from a moving storm. Time-area relationship. Maximum and minimum discharge from a catchment.

Effect of catchment characteristics on run-off: catchment area, slope, orientation of shapes, altitudes, stream patterns, soil types and vegetation, etc.

d. Intensity-duration-frequency relationship

Frequency of precipitation. Definition of frequency, water years, probable maximum precipitation and maximum probable flood. Calculation of the frequency of occurrences of an event using California, Hazen and Kimball methods.

Definition of recurrence interval. The discharge-return period, normal probability and Gumbel extreme value theory. Log-Pearson Type III distribution.

Intensity-duration-frequency relationship. Use of empirical formulae to express intensity-duration relationships.

e. Evaporation and transpiration

Factors affecting evaporation: solar radiation, wind, relative humidity and temperature. Transpiration process. Definition of evapotranspiration and potential evapotranspiration.

Quantitative determination of evapotranspiration rate. Water budget by storage equation approach. Empirical formulae by Penman, Thornthwaite and Papadakis. Evaporation pan.

2. University of Malaya, Kuala Lumpur, Malaysia - Civil Engineering Department

Hydrology

Engineering hydrology, general, hydrological cycle, physical aspects, rainfall, streamflow, evaporation and evapotranspiration, infiltration, hydrological data collection in Malaysia, quantitative hydrology, hydrograph analysis, routing, simulation models, floods, statistical analysis, regression, correlation, frequency analysis, depth area duration analysis, flow duration analysis, rainfall intensity duration, frequency analysis, data generation, probable maximum precipitation, application of Malaysian hydrological procedures, design rainstorm, flood estimation, hydrograph estimation, low flow estimation.

I. MOZAMBIQUE - UNIVERSITY EDUARDO MONDLANE, MAPUTO, MOZAMBIQUE

Course offered in the Faculty of Civil Engineering in the second semester of the third year.

1. Introduction

Scope of hydrology. The hydrological cycle. The atmosphere.

2. Hydrographical basins

Generalities. Basin shape and area. The soil. Altitude and slope. Drainage network.

3. Statistical and probability analysis of hydrological data

Frequency analysis. Regression and correlation analysis. Analysis of variance, covariance and time series. Sequential generation of hydrological information.

4. Rainfall

Introduction. Measurement methods. Average depth of rainfall over area. Frequency analysis. Extreme values frequency.

5. Evaporation and evapotranspiration

Introduction. Methods of estimation (water balance method, meteorological methods, Penman). Effective evapotranspiration and groundwater balance. Empirical formulae.

6. Soil water

Water retention potential of soils. Groundwater flow, Darcy's Law. Permeability. Continuity, Laplace equation. Dupuit-Forchheimer theory.

7. Streamflow

Discharge measurements. Discharge curves. Annual discharge. Minimum discharge.

8. Flood discharge

Determination of run-off from precipitation. Discharge-storage relationship. Flood routing. Unit hydrographs.

9. Practical applications

Spillway design. Flow under bridges. Urban hydrology.

J. NIGERIA - FACULTY OF ENGINEERING AND TECHNOLOGY, UNIVERSITY OF ILORIN, ILORIN, NIGERIA

Hydrology (for final year undergraduate students)

Elements of hydrology. Precipitation, infiltration, subsurface percolation, evapotranspiration, energy balance. Analysis of stream flow, peak and minimum flows, frequency analysis, mass diagrams. Groundwater, confined and unconfined aquifers. Hydrological data collection and analysis.

K. TUNISIA

1. Surface hydrology

Hydrological cycle. Precipitation. The hydrometeorology of a river basin. Hydrometry.

Data and their treatment. Discharge. Hydrological regimes. Sediment transport. Set-up of a hydrological service, installation of stations. Practical and analytical hydrology.

2. Geology

3. Hydrogeology

Properties of aquifers. Methods of water prospection and exploitation. Cartography. Techniques and economical aspects of water pumping. Test pumping. Hydrogeological water balance.

4. Drilling and water exploitation

5. Probability and statistics, applications in hydrology

Mathematical background.

6. Computers and their use

Hardware. Software.

7. Chemistry and bacteriology of water

8. Economy

9. Topography, geomorphology

10. Hydraulics

11. Conservation of water and soil

L. UNITED KINGDOM

1. Department of Environmental Sciences, University of Lancaster, Lancaster, England

Courses and syllabi in hydrology and related topics

a. Catchment hydrology

The principal catchment processes (precipitation, evaporation/transpiration, infiltration) are studied. The combined effect of these processes to produce both surface water run-off and groundwater flow are examined. Quantitative methods of analysis of the steady flow of water and the movement of flood waves are applied to natural rivers. Streamflow data requirements and methods of measurement are discussed.

b. Catchment geomorphic processes

The various processes controlling and modifying the morphology of a catchment are reviewed. A more detailed study follows, firstly of the influence of topography on sediment generation and movement, and secondly of the role of water in transporting and distributing sedimentary materials.

c. Principles of meteorology, climatology and upper atmospheric physics

This course is an introduction to the physical behaviour of the whole terrestrial atmosphere, in which the major atmospheric phenomena are related to underlying physical principles. Topics include the atmospheric boundary layer, cloud-forming processes, electrical phenomena in the atmosphere, large scale dynamics, climatic modelling, and the characteristic structures and processes of the ionosphere and magnetosphere.

d. Meteorology in the service of the community

A course designed to illustrate the contribution made by meteorological science to today's society. The lectures, by dealing with selected topics, attempt to show the diversity and significance of applications of meteorology. Wind effects on structures, storm surge forecasting and probable maximum precipitation are examples of the type of topic introduced in this course.

e. Groundwater resources and hydraulics

The course deals in greater detail with the processes of flow through the ground. Well construction, pumping tests, water chemistry, and unsaturated flow are covered and applied to practical problems of regional hydrogeology (abstraction, recharge, and saltwater occurrence).

f. Remote sensing

This course deals with techniques available for investigating the atmosphere and the interior and surface of the Earth and the planets by remote sensing.

2. Middlesex Polytechnic, The Burroughs, London, England

Option course - BSc. Geography/Environmental Science

Applied Hydrology - Syllabus outline

a. Introduction

The hydrological cycle and models of hydrological system; the river network and components of the working system.

b. Hydrometeorology

Hydrological controls and principles of interception, evaporation and infiltration. Soil moisture and sub-surface run-off. Groundwater movements and effects; pollution and waste disposal. Rainfall-run-off reactions; sources and volumes of surface run-off. Gauging methods. Problems of surface run-off; flooding, storage, detention and surface water pollution.

c. Channel hydraulics and morphology

Concepts, processes and forms of water and sediment in river channels. Concepts of river regime, dominant discharge and hydraulic geometry. Flow resistance, sediment bedload functions and sediment models. River pollution; processes, sources and modelling.

d. Class contacts

Four hours per week including three hours practical.

e. Practicals

Point/areal rainfall analysis. Intensity-frequency-duration analysis. Modelling groundwater movements. Soil moisture determinations. Soil water quality analysis. Hydrograph analysis. Gauging methods; direct, indirect, dilution, etc. Flow visualisation studies. Bedform and flow analysis in flume tanks. Nutrient budgets/analysis. Hydrocarbon analysis in river sediments (GC/HPLC). Water quality indices. Water quality analysis; nutrients, heavy metals, solids, chlorides, etc. Oxygen sag calculations. Hydraulic geometry. Evapotranspiration calculations.

3. National College of Agricultural Engineering, England

Compulsory for the second year of the BSc programme in Agricultural Engineering.

Hydrology and meteorology

Hydrometric instruments and networks: instrumentation, its use, operation, data recording for precipitation, run-off, temperature, pressure, humidity, radiation, wind, sediment and water chemistry. Station layout and network layout principles.

Storm analysis: precipitation data analysis, storm types and models, storm maximisation and transposition, probable maximum precipitation.

Land and subsurface processes: interception, infiltration, depression storage, overland flow, interflow, evaporation, groundwater storage and movement.

Catchment response: flow measurement, rating curves, hydrograph analysis, unit hydrograph, peak flow and yield in ungauged catchments.

Floods: frequency analysis of single stations, regional flood frequency, flood routing.

Stream flow regulation: calculation techniques to determine storage and yield for impounding reservoirs, reservoir routing, probability of failure of yield.

Agrometeorology: mapping and zoning of meteorologic variables, climate on the ground.

M. URUGUAY - UNIVERSITY OF THE REPUBLIC, FACULTY OF ENGINEERING AND AGRICULTURE

Courses in hydrology in hydraulic structures:

Definitions
Atmosphere
Precipitation
Climatology
Evapotranspiration
Hydrometry
Unit hydrograph
Floods

Courses in hydrology in agricultural engineering:

Distribution of water
General hydrology
Surface and sub-surface hydrology
The hydrological cycle (precipitation, hydrometry)
Agricultural hydrology
Irrigation and drainage, canals
Hydrometeorology

SECTION 3 - EXAMPLES OF SYLLABI PUBLISHED IN THE FIRST EDITION OF 'CURRICULA AND SYLLABI IN HYDROLOGY' FOR COURSES IN HYDROLOGY

1. Hydrology

a. Introduction. The hydrological cycle. Hydrographs. Economy and hydrology. International organizations. The International Hydrological Decade.
b. Precipitation. Measuring devices. Distribution and characteristics of rainfall. 'Horizontal' precipitation.
c. Evaporation. Evaporation from free water surfaces and evapotranspiration. Measuring devices. Lysimeters. Formulae and theories on evaporation. The energy approach. Use and application of methods and formulae.
d. Infiltration. The role of infiltration in the hydrological cycle. Infiltration as a factor in run-off and infiltration as recharge of groundwater. Comparison of methods.
e. Surface flow; yield. Characteristics of drainage basins. Minimum flow and depletion curves. Relation with geohydrology.
f. Surface flow; floods. Maximum floods and frequency of occurrence. Analysis of flood hydrographs. Method of the unit hydrograph and other methods for estimating surface run-off. Groundwater hydrographs. Synthetic hydrographs. Long-term and short-term forecasting of yield and floods. Flood routing.
g. Physical aspects of erosion. Wind erosion.

2. Hydrology

Introduction: hydrological cycle; precipitation; measurement of precipitation; processing precipitation data; mass curves and hyetograph; average depth of precipitation.

Water losses: elementary treatment of infiltration theory; evaporation; transpiration.

Run-off: factors affecting run-off; hydrographs; stage-discharge relationship; preparation of stage-discharge curves; unit hydrograph theory; derivation of unit hydrograph.

Peak flows: estimation of peak flows; use formulae; envelope curves; probability methods.

Groundwater: occurrence and distribution; aquifers; Darcy's Law; hydraulics of wells under steady flow conditions in confined and unconfined aquifers; effects of partial penetration of wells; characteristics of well losses.

3. Hydrology

Study of the problems of long-term basin yield and of short-term streamflow prediction from the viewpoint of the response of linear and non-linear physical systems to periodic, transient and random inputs. Presentation of physical hydrology in a manner suitable for problem formulation, with attention given to those statistical techniques needed in forecasting, fitting and evaluation.

4. Hydrological transport processes

The hydrological cycle and its interrelations with man; statistical analysis and simulation of hydrological data; floods; over-all mass balance; transport and dispersion of solutes, sediments and contaminants in rivers, lakes, estuaries; river morphology; physics of flow through porous media, including dispersion of solutes, flow toward wells, groundwater recharge, drainage, sea water intrusion in aquifers and estuaries; heat exchange and density stratification in natural waters; thermal pollution control.

5. Applied hydrology

Hydrological cycle, meteorology, streamflow, evapotranspiration, hydrographs, run-off relations, run-off hydrographs, groundwater, unit hydrographs, flood routing, frequency and duration studies, and application of hydrological techniques.

6. Applied hydrology

Mathematical statistics on hydrology. Practical procedures of treatment and processing of hydrological data. Statistical correlation of hydrological data. Estimation of basic records. Study of water management. Network planning and design. Systems of acquisition, transmission and processing of hydrological data.

7. Hydrology and climatology

Relationship between meteorology, surface hydrology and groundwater hydrology. The hydrological cycle. Hydrological water balance. Types of precipitation. Measurement of precipitation and other meteorological data. Statistical analysis of rainfall data. Evaporation, transpiration and their effect on the hydrological balance. Surface run-off and its measurement. Definition and properties of watersheds. Factors that affect the quantity and distribution of surface run-off. Rainfall-run-off relationships. Hydrographs and unit hydrographs. Flood flows. Statistical analysis of maximum flows. Aquifers and their properties. Groundwater flow and discharge of springs. Darcy's Law and applications. Phreatic and piezometric surfaces near wells. Pumping tests of wells.

8. Surface-water hydrology

Its quantitative interpretation in a balance equation. Catchment areas. Genetical interpretation based on the balance equation, instantaneous process of run-off on an elementary surface and in the catchment area. Hydrographs of precipitation, infiltration, subsurface and surface run-off.

Occurrence of surface run-off. Influencing factors: geographical and geometrical, geographical and physical. Regime of watercourses, their classification. The action of water on the development of river beds.

Daily means, monthly and yearly discharges. Long-term average yearly discharge. Determination based on analogy. Determination based on the balance equation, fluctuation of yearly discharges. Distribution of discharges during the year. Average monthly discharges. Duration curve of mean daily discharges. Extreme discharges. Design discharge. Hydrograph analysis of the flood wave. Drafting the statistical series of peak discharges and their processing. Method of unit hydrograph and its application for the computation of the flood wave.

Determination of peak discharges without direct observation, formulae. Minimum discharges. Definition. Computation when sufficient data based on direct observation are available. Formulae. Basic hydrological and hydrotechnical computations. Summary run-off curve, mathematical and graphical drafting. Transfer of floods through inundated areas and reservoirs, influence of ponds.

9. Surface-water hydrology

Introduction to hydrology. Hydrological cycle. Hydrological balance. Evaporation and transpiration. Basin topography. Basin geography and geology. Hydrographical net. Soil and infiltration. Run-over.

Use of the water. Study of flow rating. Indirect procedures to estimate flows.

Probabilistic distribution of flow ratings. Flow regulation. Methods of regulation. Flow forecasting. Reservoir exploitation. Flood hydrology. Methods to estimate maximum flows. Short-run forecast of the evolution of flood flows.

10. Surface hydrology

The hydrological cycle and its main components. Precipitation: measurement and interpretation of data. Run-off: components and measurement. Infiltration. Horton's and other formulae. Evaporation and evapotranspiration. Rainfall-run-off relationships. Graphical correlations. Soil moisture accounting methods. The hydrograph. Unit hydrograph. Peak discharges. The rational formula.

11. Hydrology of surface run-off

Scope and purpose of engineering hydrology. Hydrological cycle: consideration of the various sectors of the hydrological cycle, measurement and presentation of the various phenomena. Rainfall-intensity-duration relationships. Hydrographs and mass curves. Groundwater. Drainage basin inventories. Flow-gauging: controls and gauging sites. River phenomena and control: meandering, erosion, silting, flooding, transport of suspended matter and bed material and engineering control of these factors.

12. Groundwater hydrology

Definitions. Occurrence. Advantage as a water resource. Classification of aquifers. Groundwater movement. Darcy's Law. Anisotropy. Continuity equations. Boundary conditions. Mathematical statement of groundwater flow problems. Well drilling and completion. The Dupuit approximation. Hydraulics of wells in steady and unsteady flows, in confined and phreatic aquifers. Pumping tests. Regional groundwater balances. Artificial replenishment of aquifers. Surface and subsurface exploration methods. Sea water intrusion and hydrology of coastal aquifers.

13. Groundwater hydrology

Occurrence of groundwater. Porous media. Darcy's Law. Permeability, porosity, transmissivity; anisotropy, stratification. Potential flow, flow nets; boundary conditions. Incompressible flow analysis: exact, graphical and numerical, experimental. Effects of compressibility; storage coefficient. Pumping tests. Approximate techniques of analysis.

14. Geophysical aspects of groundwater hydrology

a. Introduction. Appraisal of groundwater resources.
b. Recapitulation of geology. Permeability of rocks. Structural geology.
c. Aquifers. Origin and occurrence of groundwater. Aquifers in geological structures. Hydrological properties of various pervious materials.
d. Prospecting methods. The use of various geophysical exploration methods in geohydrology. Geo-electrical prospecting; the resistivity method and its use and application in water supply geophysics. Location of groundwater reservoirs.
e. Seepage. Prediction of the amount of seepage. Practical consequences of seepage in reclamation works. Seepage of saline groundwater.
f. Conservation and use of groundwater. Groundwater mapping. Exploitation; safe yield. Purpose of artifical recharge.

15. Groundwater hydrology and hydraulics

Occurrence and movement of groundwater, determination of hydraulic characteristics of the groundwater reservoir with emphasis on non-equilibrium methods, interrelationship of surface-water bodies and the groundwater reservoir, and evaluation of groundwater problems, including salt water encroachment, depletion of groundwater reserve, temperature rise due to recirculation of spent cooling water, river infiltration, and industrial contamination.

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