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ABSTRACT

This collection of papers is intended to provide a means for the exchange of information on hydrological techniques and for the coordination of research and data collection. The objectives and trends in hydrological education are presented. The International Hydrological Decade (IHD) Working Group on Education recommends a series of topics that must be taught to ensure a minimum of theoretical knowledge and adequate practical training. Two examples of curricula and syllabi for complete undergraduate programs in hydrology are presented. One is from the U.S.S.R., the second from the United States. Post-graduate education in hydrology is discussed and three types of programs presented. Selected syllabi prepared by the IHD Working Group on Education, by the World Meteorological Organization (WMO) Working Group on Training in Hydrometeorology, by U.S.S.R. educators, by United States educators and by UNESCO are presented in the appendices. (EB)

ED 093600

Curricula and syllabi in hydrology

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A contribution to the International Hydrological Decade

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Unesco Paris 1972

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Preface

The International Hydrological Decade (IHD) 1965–74 was launched by the General Conference of Unesco at its thirteenth session to promote international co-operation in research and studies and the training of specialists and technicians in scientific hydrology. Its purpose is to enable all countries to make a fuller assessment of their water resources and a more rational use of them as man's demands for water constantly increase in face of developments in population, industry and agriculture. In 1971 National Committees for the Decade had been formed in 107 of Unesco's 127 Member States to carry out national activities and to contribute to regional and international activities within the programme of the Decade. The implementation of the programme is supervised by a Co-ordinating Council, composed of twenty-one Member States selected by the General Conference of Unesco, which studies proposals for developments of the programme, recommends projects of interest to all or a large number of countries, assists in the development of national and regional projects and co-ordinates international co-operation.

Promotion of collaboration in developing hydrological research techniques, diffusing hydrological data and planning hydrological installations is a major feature of the programme of the IHD which encompasses all aspects of hydrological studies and research. Hydrological investigations are encouraged at the national, regional and international level to strengthen and to improve the use of natural resources from a local and a global perspective. The programme provides a means for countries well advanced in hydrological research to exchange scientific views and for developing countries to benefit from this exchange of information in elaborating research projects and in implementing recent developments in the planning of hydrological installations.

As part of Unesco's contribution to the achievement of the objectives of the IHD the General Conference authorized the Director-General to collect, exchange and disseminate information concerning research on scientific hydrology and to facilitate contacts between research workers in this field. To this end Unesco has initiated two collections of publications: 'Studies and Reports in Hydrology' and 'Technical Papers in Hydrology'.

The collection 'Technical Papers in Hydrology' is intended to provide a means for the exchange of information on hydrological techniques and for the co-ordination of research and data collection.

The acquisition, transmission and processing of data in a manner permitting the intercomparison of results is a prerequisite to efforts to co-ordinate scientific projects within the framework of the IHD. The exchange of information on data collected throughout the world requires standard instruments, techniques, units of measure and terminology in order that data from all areas will be comparable. Much work has been done already towards international standardization, but much remains to be done even for simple measurements of basic factors such as precipitation, snow cover, soil moisture, streamflow, sediment transport and ground-water phenomena.

It is hoped that the guides on data collection and compilation in specific areas of hydrology to be published in this collection will provide means whereby hydrologists may standardize their records of observations and thus facilitate the study of hydrology on a world-wide basis.

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Foreword

The Working Group on Education and Training in Hydrology of the Co-ordinating Council of the International Hydrological Decade (IHD), among other tasks, has studied the existing systems of teaching hydrology. During discussions on this subject, it became obvious that among various countries there were great differences in approach, treatment, and even in definitions.

The Working Group met great difficulties when objectively comparing the teaching at various levels, and also noted the complexity in the relations between hydrology and allied subjects. Different possible approaches to teaching hydrology led to syllabi differing in extent and depth of coverage.

With a view to developing clear outlines of systems of hydrological teaching and in order to make an attempt to select the most suitable teaching methods, the Working Group studied curricula and syllabi collected by the IHD Secretariat and suggested that a casebook be prepared with the help of the panel of directors of Unesco-sponsored post-graduate courses in hydrology. This casebook would help all institutions concerned to select curricula and syllabi for adaptation to their conditions and standards.

The outline prepared by the panel was adopted by the Working Group at its third session in 1969 and served as a basis for Unesco consultant J. Dvořák, of Czechoslovakia, to prepare a first draft of the casebook.

The casebook contains a description of the objectives of hydrological teaching, bearing in mind the present trends and the possible future development of hydrological education.

In spite of the efforts of the drafting committees, the casebook probably has some shortcomings. No doubt this and the great upswing of hydrological education will call for the publication of an enlarged and revised analysis in the near future. Therefore the Working Group would appreciate receiving suggestions for the improvement of this publication.

A review of the manuscript was undertaken by an *ad hoc* panel which met in Paris in November 1970. This panel consisted of J. Bear (Israel), J. Dvořák (Czechoslovakia), W. H. Gilbrich (Unesco), L. J. Mostertman (Netherlands), J. Němec (WMO), R. M. Ragan (United States of America) and P. O. Wolf (United Kingdom).

The list of subjects from the report of the second session of the IHD Working Group on Education, from the report of the Working Group on Training in Hydrometeorology of the WMO Commission for Hydrometeorology and from the prospectuses of various educational institutes were not reviewed by the panel but adopted as previously published.

9/10

1 Objectives and trends in hydrological education

Among the various types of personnel needed for water resources development, the hydrologist takes an important position. He has to study and measure water as it occurs in nature. He analyses data to obtain an impression of the spatial and temporal distribution of water. In many organizations he also has to study and manage surface and underground reservoirs. The body of knowledge and abilities expected from a hydrologist is not constant—it varies between countries, organizations and the stage of development of water resources. An expert in an interdisciplinary field like hydrology should be able to work with members of other professions. On the other hand the professionals from neighbouring fields—civil and agricultural engineering, geology, geography, geophysics and environmental engineering—should have an understanding of hydrology. In fact, much hydrological work is undertaken by these professions. Therefore, they should have in their education at least a survey course in hydrology, and in many cases even a more extensive training. In many instances such courses, when part of undergraduate studies, will inspire students to go through a course of post-graduate education in order to become professional hydrologists.

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 resource, environmental and agricultural engineering, geology, geography and geophysics; hydrology as major option in undergraduate or post-graduate curricula; post-graduate education to train professional hydrologists.

Complete specialized undergraduate courses in hydrology exist in the Union of Soviet Socialist Republics and also in a few other countries in Eastern Europe. The graduates are primarily employed in the State Hydrometeorological Services (GUGMS in the U.S.S.R.) and other State Water Resources Services. These services influence to a certain extent the programme of this specialized education. In the United States of America and some other countries a few universities also offer training in professional hydrology at the undergraduate level.

At the present time, several universities in other parts of the world are considering introducing an undergraduate programme for training hydrologists.

General trends in university education throughout the world indicate that a high specialization in undergraduate study is not recommended unless special conditions for employment exist. This conclusion is valid for highly industrialized countries, but it is even more applicable to developing countries. It is not possible to give here a detailed classification of systems of university education. Two main types seem to emerge, however, out of many different patterns: the elective curricula type, in which the undergraduate, particularly in the last two years of study, has a choice among several elective subjects, and the compulsory curricula type, in which the student, after having made a choice of a study field, has to take all subjects which are prescribed.

There is no rigid geographical distribution of these types. For instance, in the United States some universities have the compulsory curricula system, although most have an elective system. In France the universities offer elective subjects

and the Grandes Écoles teach according to compulsory curricula systems. Consequently, the variety of fields in which a hydrology course is offered will be greater in the elective curriculum system. Major fields in which a general course of hydrology is offered are:

1. Agronomy and agricultural engineering.
2. Botany and plant physiology.
3. Chemical engineering.
4. Civil engineering.
5. Forestry.
6. Geography.
7. Geology.
8. Geophysics, including meteorology.
9. Sanitary or environmental engineering.

Under the continental type of university education (including the U.S.S.R.), courses in general hydrology are to a certain extent limited to the kind of schools mentioned under fields 1–7.

In both systems, as far as hydrology is concerned it is sometimes difficult to draw a sharp line between the undergraduate and lower post-graduate levels.

The situation in the developing countries of Africa, Asia and Latin America does not differ particularly from that described above. However, the number of universities which offer a course in hydrology is considerably smaller than in highly industrialized countries, mainly because of the lack of adequate faculties and also because of the relatively small number of students.

A professional hydrologist, particularly in a developing country, should have a wide range of knowledge. The natural and economic characteristics of countries often differ, however. Some may concentrate primarily on surface-water exploitation, others on ground water; some may have main problems in coastal hydrology. Many professional hydrologists, during part of their career, will be required to do other work, such as engineering design and supervision, topographical or geological survey, or even management of a service. Therefore, a hydrologist who has a basic undergraduate training in some other fields may have a big advantage.

On the other hand, the subjects which he studies in such an undergraduate education will form an excellent base for his post-graduate specialization in hydrology. The curriculum of such a post-graduate specialization can, therefore, be limited in its extent and duration.

Professional specialists, hydrologists and research hydrologists are at present being educated in the following ways: (a) post-graduate study (at the Master's or Doctor's degree level) as part of the university curriculum; (b) in special hydrology post-graduate training-courses (lasting from six months to a year), mainly international; (c) in a comprehensive study at the undergraduate as well as the post-graduate university level, specializing in hydrology (e.g. in the U.S.S.R.).

2 Topics in hydrological education

Because of differences in the educational systems and in the levels of education in the 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 geography or engineering. Still other institutions may wish to reserve hydrological education as a post-graduate programme. Thus, rather than a series of courses, the IHD Working Group on Education has recommended a series of topics that must be taught to ensure that the student receives the necessary minimum theoretical knowledge and adequate practical training. These topics can be distributed through a series of courses designed to reflect local conditions and the creative spirit of the instructors. It should be emphasized, however, that the topics should be taught in a manner that reflects a minimum level of proficiency in mathematics and science that the student must have achieved.

2.1 Topics from other disciplines that are basic requirements for the study of hydrology on the professional level

2.1.1 *Mathematics through analytical geometry and differential and integral calculus with simple differential equations.*
2.1.2 *Computer programming.*
2.1.3 *Probability and statistics with regression and correlation theory and theory of extreme values.*
2.1.4 *Engineering drawing and graphics.*
2.1.5 *Elementary physics.*
2.1.6 *Elementary chemistry.*
2.1.7 *Elementary geology and geomorphology.*
2.1.8 *Surveying cartography and the morphological interpretation of aerial photographs.*
2.1.9 *Fluid mechanics, including steady and unsteady open channel flow, theory of sediment transport, flow through porous media.*
2.1.10 *Soil science.*
2.1.11 *Plant physiology and ecology. Forest types and farm crops.*
2.1.12 *Elements of water resources engineering.*
2.1.13 *Elements of economics of water resources.*
2.1.14 *Water pollution.*
2.1.15 *Meteorology and climatology.*

2.2 Hydrological topics which are indispensable for all hydrologists

2.2.1 *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 Decade.

2.2.2 *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.

2.2.3 *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.

2.2.4 *Infiltration*
Soil moisture. Laws governing infiltration. Measurement. Infiltrometers. Empirical formulae.

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

2.2.6 *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. Floods and droughts. Use of the unit hydrograph. Measurements. Statistical and other methods. Quality of surface water.

2.2.7 *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.

2.2.8 *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.

2.2.9 *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.

2.3 Hydrological topics which are not necessary for all hydrologists but which can be added to a hydrology curriculum if circumstances require it and can be considered as electives

2.3.1 *Agrohydrology.*
2.3.2 *Urban hydrology.*
2.3.3 *Ground-water withdrawal techniques.*
2.3.4 *Hydrology of coastal and estuarine areas.*
2.3.5 *Geochemistry.*
2.3.6 *Limnology and hydrobiology.*
2.3.7 *Hydrology of ice, glaciers and permafrost.*
2.3.8 *Descriptive hydrology of a country or region.*

2.4 Options

As stated earlier in this chapter, there are a number of options available for the incorporation of these topics into a series of courses. To serve as a reference, examples of established curricula and selected syllabi are presented in Chapters 3, 4 and 5.

Appendix 1 contains selected syllabi, relating to determination of discharge data, hydrological forecasting, ground water and ground-water development, and hydrometry. The syllabi of Appendix 1 were developed by the IHD Working Group on Education. Appendix 2 contains curricula and detailed syllabi abstracted from a document prepared by the WMO Working Group on Training in Hydrometeorology.[1]

1. *Training of Hydrometeorological Personnel*, Geneva, WMO, 1967 (WMO No. 219, T.P. 116).

3 Examples of curricula and syllabi for complete undergraduate programmes in hydrology

The specialized undergraduate university education of hydrologists seems to be a privilege of large countries with adequate employment possibilities for the graduates of such specialized institutes.

The IHD Working Group on Education has stressed that the organization of complete undergraduate training in a small- or medium-sized country, or a country without an adequately developed economy, presented employment difficulties and was not recommended.

Two examples of such education are presented in this chapter. The first is from the U.S.S.R., the second from the United States.

3.1 Curricula and selected syllabi for complete undergraduate education in hydrology in the U.S.S.R.

For curricula, see Tables 3.1 and 3.2.
For syllabi, see Appendix 3(a).

3.2 Curricula and selected syllabi for complete undergraduate education in hydrology in the United States

For curricula, see Table 3.3.
For syllabi, see Appendix 3(b).

TABLE 3.1. Curriculum of the hydrological specialization of the hydrometeorological institutes of the hydrometeorological service of the U.S.S.R. (Leningrad and Odessa)

Recommended elective subjects

Photogrammetry, advanced hydrophysics, meteorological satellites, microclimatology, engines of cars and boats, river navigation

	Number of semesters	Duration (weeks)		Number of semesters	Duration (weeks)
Practical field-work			*Extramural on-the-job training*		
Geodetic survey	2	5	Water balance computations	6	4
Geological survey	2	1	Flood season hydrometry	8	7
Hydrometry (stream-gauging)	4	6	Computation of hydrological design data	8	10
Meteorology	4	1	Pre-thesis practice	8	4
Hydrometry (under ice)	5	1			
Hydrogeology	6	2			
Hydroforecasting (night shifts of students in hydroforecasting centres)	8, 9	–			

TABLE 3.2. Study plan of the hydrological specialization of the hydrometeorological institutes of the hydrometeorological service of U.S.S.R. (Leningrad and Odessa)

Subject	Total hours					Hours per week								
						1	2	3	4	5	6	7	8	9
						(semesters)								
	Total	Lectures	Laboratory	Exercices	Seminars	18	15	18	15	18	14	13	11	18
						(weeks)								
Mathematical analysis	480	250		230		6	5	5	6	5	2			
Computer and programming	45	30		15					3					
Fluid mechanics	42	28	14								3			
Special (open channel) hydraulics	166	102	64						4	3		4		
Theoretical mechanics	90	60		30				5						
Physics	300	150	110		40	5	8	5						
Hydrophysics	39	26	13									3		
Introduction to electronics and automation	90	45	45											2
Cybernetics	36	36				5							5	
Chemistry and hydrochemistry	140	60	80			4	4							
Geophysics, geology, geomorphology	132	66	66			2	2							
Engineering drawing and projective geometry	66	18	48			3	5							
Surveying geodesy and photogrammetry	129	63	66					3	2	2				
General climatology and meteorology	120	84	36						4	4				
Synoptic meteorology	132	66	66					6	5		5	5	2	
Hydrometry	340	190	150							3	6			
General and special hydrogeology	140	90	50			1				3	4	3	3	
General hydrology	200	120	80								4	6	7	
Hydrological analysis	210	100	110										2	4
Water resources management and analysis	94	38	56										3	7
Hydrological forecasting	160	90	70											5
Water balance computation	36	24	12									3		
Hydrological data collection and surveys	39	26	13										3	
Dynamics of channel flow and erosion	120	60	60									4		
Hydraulic structures	52	39	13											3
TOTAL	3 398	1 861	1 222	275	40	26	24	24	24	20	24	28	25	21

TABLE 3.3. Curricula and selected syllabi 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 ground water								3
Preparation of geological reports								2
Hydrologic systems								3
TOTAL	15	16	16	16	18	18	24	17

4 Selected detailed syllabi of undergraduate and post-graduate courses in hydrology and related fields

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, sanitary engineering, water resources engineering, geology, geography, forestry, agronomy. Those programmes are not aimed at training hydrologists. However, those attending a sufficient number of courses in hydrological subjects may build up a sufficient base for working in hydrology.

Most of the syllabi of courses in hydrology and related topics which are included in various programmes of education are included in the curricula listed in Chapters 3 and 5. The syllabi were not prepared by the IHD Working Group on Education, but were taken, practically unchanged from catalogues of various schools in an attempt to present examples of how the various hydrological topics listed in Chapter 2 are presented in specific courses.

Because of the variability in local conditions, objectives of educational programmes within the framework of which the courses are taught, the length of time available and the personal motivations and interests of the instructor, courses dealing with the same subjects (e.g. ground-water hydrology or surface-water hydrology) may have different syllabi. Obviously, even identical syllabi do not guarantee that the emphasis, the way of presentation, etc., will be the same. Hence an attempt was made to present more than one example for each subject. Each syllabus is followed by an indication of the country in which the course is taught. This will enable the reader to relate the syllabus to the type of hydrological problems which are of interest in that country.

In general, the syllabi are presented in a brief form. However, several syllabi are given in more detail because it was felt that a fuller coverage of the suject may be helpful to some readers.

There is no indication of the number of hours allocated to each course, as that information was not available. However, with a few exceptions, the courses listed are intended to be taught in fifteen to forty hours.

No distinction is made between undergraduate and professional post-graduate courses and special post-graduate training-schools. The difference among courses taught at the various levels of education as well as among courses taught in different educational programmes (in engineering departments, in non-engineering departments, for the training of professional hydrologists, etc.) lies in the depth and extent of coverage of the various topics. It also lies in the different reference to mathematics, statistics, etc. One should note that, in general, exercises, numerical problems and field trips are not mentioned. However, they should be considered as an integral part of every syllabus.

Although the primary objective of this work is to deal with hydrology, one cannot handle this subject without considering related subjects. Such subjects are of two types. On the one hand there are subjects which are considered complementary to hydrological education. Among these one may list: geology, meteorology, fluid mechanics, flow in open channels, sediment transport, flow through porous media, soil physics, soil science, systems analysis, operations research, statistics, etc. On the other hand, for such subjects as hydraulic engineering, development planning and management of water resources, hydrological information is an essential input. Examples of both, therefore, are included (see Appendix 3).

Before concluding these introductory remarks, the IHD Working Group on Education wishes

again to emphasize that the syllabi presented in the appendixes should be considered only as examples which may be used as guidelines. By no means should this list be considered as complete or comprehensive.

5 Post-graduate education in hydrology

There are two general types of post-graduate education of specialists in hydrology. The first is part of regular university programmes, predominantly geared to obtaining a higher degree. In general each student follows an individual programme in one or more departments which offer courses in hydrology and related topics as part of their curriculum, and he also does some research work. In some systems of education, the highest degree does not require additional formal course work.

The second type of education involves special courses (schools) for groups of students, whether within or outside the framework of a university. These are designed specifically for the training or mid-career education of hydrologists. They may or may not lead to a higher degree. The Unesco-sponsored international courses (see 5.5) are examples of this type of education.

5.1 Individual post-graduate study for obtaining a higher degree

University graduates may become specialized by pursuing individual studies, which, according to their character, may be divided into three basic types:

1. The education based on the Anglo-Saxon tradition, after which a Bachelor's degree is accorded. The possibility of obtaining the degree of Master of Science and eventually that of Doctor of Philosophy also exists. This system is established in the British Commonwealth and in the United States.
2. The traditional system which provides the university graduates with a 'Licence' or Doctor's degree on the basis of individual studies and a dissertation (thesis).
3. The Eastern European system in which university graduates study individually according to curricula for the degree of Candidate of Science. On the basis of a dissertation (thesis), the degree of Candidate or usually later Doctor of Sciences is awarded.

The Candidate of Science corresponds to the Anglo-Saxon Ph.D. The degree of Doctor of Sciences in Eastern Europe does not involve study according to a curriculum and the thesis submitted for this degree is often a work either published or prepared by the author during his previous activity in the field. It is, however, most difficult to establish a general equivalence or comparison because of variations among individual subjects and universities.

In the following paragraphs examples are indicated of compulsory and elective curricula for obtaining: (a) the degree of Master of Science; (b) the degree of Ph.D.; (c) the degree of Candidate of Science.

Syllabi for the compulsory and elective subjects indicated in the curricula are similar to those indicated in Chapter 4. The subjects are, however, often studied in greater depth.

5.2 Master of Science

Example a: Compulsory

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

7. Geology.

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

Example b: Compulsory
1. General hydrology.
2. Meteorology.
3. Statistical hydrology.
4. Stochastic hydrology.
5. Hydrological models.
6. Ground-water hydrology.
7. Open channel flow.
8. Water quality.

Example c: Eight of the following subjects have to be chosen
1. Hydrodynamics.
2. Advanced hydraulic engineering.
3. Flow through porous media.
4. Advanced ground-water 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.

5.3 Doctor of Philosophy

1. All courses required for Master of Science.
2. Six courses in minor areas to support major field of interest (i.e. mathematics, economics, operations research, meteorology, etc.).
3. Porous media flow.
4. Dissertation.

5.4 Candidate of Science

Compulsory
1. Hydrology and water management.
2. Applied mathematics.
3. Specialized subject.

Elective
4. Meteorology and climatology.
5. Hydraulics.
6. Hydrogeology.
7. Hydrotechnical study.
8. Dissertation.

5.5 International post-graduate courses

These courses, usually lasting six to twelve months, are intended for selected graduates in a field related to hydrology who, after graduation, have acquired some practical experience. A number of these courses are organized within the framework of the IHD. Among those sponsored by Unesco are those held in Budapest, Delft, Jerusalem, Madrid, Padova and Prague. To be largely accessible, lectures in Budapest, Delft, Haifa and Prague are held in English, in Padova in French and English, and in Madrid in Spanish. The curricula and syllabi are given in Appendix 4. The courses include lectures, practical training, individual work by the participants and study tours.

Unesco also sponsors a number of shorter educational activities, e.g. the summer schools for hydrology teachers in the U.S.S.R., the United States and the Netherlands, and the one-month programme on tracing techniques in Graz (Austria).

5.6 Post-graduate courses in hydrology of surface water and ground water

Examples of curricula of other post-graduate courses in hydrology are presented below.

5.6.1 *Engineering hydrology (Venezuela)*
Computer programming I
Hydrology I
Hydrology II
Hydrogeology
Engineering economy
Water chemistry
Computer programming II
Sedimentation
Open channel flow
Ground-water hydraulics
Hydrological simulation

Statistics
Economy
Systems analysis
Water poliution control
Pumps and pipelines
Water resources planning.

5.6.2 *Surface-water hydrology (Iran)*
Hydrogeology
Hydrology
Mathematics
Water chemistry and physics
Pedology
Meteorology and climatology
Statistics and probability
Planning for water resources development
Computers
Use of radio-isotopes in water sciences
Water economics and water laws
General geology, geomorphology, cartography, photogeology
Irrigation
Topography and photogrammetry
Engineering concepts
Hydraulic engineering
Soil–water relationship
Field experience.

5.6.3 *Engineering hydrology (Australia)*
Hydrodynamics
Advanced hydraulics
Hydromechanics
Hydraulic design
Irrigation and drainage
Hydrology I
Hydrology II
Engineering hydrology
Ground-water hydrology
Water resources development
Design of water resources systems
Water-supply and treatment
Sewage treatment and disposal
Mathematics.

5.6.4 *Ground-water development (United States)*
Basic considerations
Geologic aspects of ground water
Ground-water occurrence and movement
Hydrology
Ground-water exploration
Well hydraulics
Well design
Well construction
Well maintenance
Sand analysis
Pumping equipment.

5.6.5 *Ground-water exploration (Israel)*
Introduction to geology
Introduction to ground-water geology
Surface and subsurface methods in ground water
Introduction to ground-water hydrology
Methods of ground-water hydrology
Elements of applied hydrometeorology
Introduction to flow in porous media and model experiments
Isotopes in ground water
Chemistry of ground water
Interpretation of ground-water chemistry
Drilling and construction of wells, testing and development
Geophysical methods in ground-water exploration
Interpretation of geophysical data-well log analysis
Elements of surface-water observations and recharge problems
Planning ground-water survey
Ground-water occurrence in arid and tropical regions
Introduction to water-supply planning.

6 Forward look

6.1 Continuous scientific development

Although hydrology as a science is based on such classical disciplines as mathematics, physics (especially atmospheric physics, thermodynamics and the mechanics of fluids), chemistry and geology, and the study of the distribution of water over and under the earth's surface, it may be regarded as part of classical geography. The experience of recent decades has shown it to be in a stage of rapid change. As changes have been far-reaching both in the pure science and in its applications, inevitably there have been correspondingly large and almost continuous changes in hydrological education so that the curricula and syllabi of existing courses, as recorded here, may be expected to be superseded by the time this report is published. They are none the worse for that, for it is generally recognized that courses are designed both to meet the needs of their students and to utilize to the full the talents and interests of their teachers; hence no originator of a new course is likely to follow old patterns slavishly—he will instead use such information as is contained in the earlier chapters to stimulate his own creative plans for meeting the needs of his own time and conditions.

At the same time, the designer of courses must be aware of the need of his students for a sound preparation of hydrological work over two, three or even four decades, and a tentative look into the future will, therefore, be useful to him, even if he disagrees with some of the forecasts attempted here.

6.2 The hydrological cycle

The qualitative terms, the view of the hydrological cycle has changed little over half a century, and it is difficult to foresee fundamental future changes.

However, there has been a tendency to bring together the branches of hydrology which up to the beginning of the twentieth century appear to have been treated in complete isolation, and to consider hydrometeorology and surface- and ground-water hydrology in a unified manner. Modern hydrology increasingly turns to conceptual models of the whole hydrological cycle and this tendency should be strongly emphasized in education.

The mathematical models representing hydrological concepts are still grossly simplified, partly because of man's scientific ignorance and partly because more complicated mathematics have proved intractable. Both faults may be expected to yield, to some extent, to the ever-increasing hydrological research effort and to the computational powers of mathematicians and their machines, and all courses should leave students with a clear understanding of the significance of the results of future research. It is also important that practising hydrologists appreciate the quantitative implications of any simplifications inherent in their conceptual and mathematical models of the hydrological cycle; for 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, students need a fundamental understanding both of the whole cycle and of the 'sensitivity' of their results to any errors in their assessment of any one phase.

In general, hydrologists in the past were primarily concerned 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 fuller utilization of water resources over the globe. The influence of man on nature has already caused major changes in water quality and great local changes in quantitative régimes; it may soon be expected to include some artificial modification of such phases of the cycle as precipitation and evaporation.

6.3 Measurement

A qualitative understanding of the hydrological cycle is of educational value in the study of those parts of physics, geology, geography, forestry, agriculture and engineering affected by natural waters, but for a fuller understanding and for hydrological application a quantitative knowledge of each phase of the cycle is needed. This requires measurements and recording, and demands the study of the principles and methods of measurement.

It is difficult to forecast which principles of measurement, used in which kind of instruments and in which design and density of networks, will appear in the next stage, but it seems highly likely that: (a) measurement will continue to play an important role, whether in basic hydrological assessments or in connexion with water management (for yield or for flood warning); (b) the instruments and the methods of their use will become more accurate, more robust and less dependent on field observers and technicians; (c) powerful sensors, recorders and transmitters of hydrological quantities will be as appropriate for use in the hydrologically less-developed areas as in advanced ones; (d) the collection, processing, analysis, storage and retrieval of data over large regions will be performed by automatic equipment and will make it necessary to re-examine what is to be measured and how data are to be evaluated; and (e) measuring instruments, etc., are not likely to need (or indeed to be designed for) field maintenance and repair (i.e. hydrologists need not be expected to have a detailed mechanical and electrical acquaintance with equipment, but should be highly skilled in the proper siting of instruments and in the full utilization of results).

Traditionally the measurements of precipitation, evaporation, surface run-off and ground-water levels have been undertaken independently, but there is likely to be a tendency (due to the basic similarity of recorders and transmitters and the unity of analytical approaches) for the various sensors to be linked to common apparatus. Hence measurement, like the theoretical study of the hydrological cycle, may well see a merging of its hitherto autonomous branches.

6.4 Hydrological analysis

Dynamic and deterministic (or 'parametric') analysis

The classical approach to the understanding of the hydrological cycle has been to analyse the physics (fluid mechanics and thermodynamics) of every phase and to link the results of successive analyses together with the aid of the general laws of conservation, chiefly that of mass. (Probably the continuity equation will lose its local name, 'hydrological equation', as energy and force considerations are increasingly recognized to be important.) This research trend may be expected to continue and to reduce the areas of pure empiricism and 'black-box' analysis. However, until a full physical theory is established, the practising hydrologist should not only acquire a mastery of the methods of empiricism (including 'systems engineering'), but be prepared to replace the interim results so obtained by those of subsequent physical research.

Stochastic analysis

The history of the physical sciences shows that, with every discovery, the area of uncertainty (in which, possibly, some randomness was postulated to be inherent) is first narrowed and later, with further investigations, again extended.

Hydrology is no exception. However the 'inputs' of precipitation and evaporation (with the energy variables affecting them) may be expected to become more clearly predictable and the mechanisms linking such 'inputs' with the hydrological 'outputs' of run-off more inherent in the hydrological cycle for as far ahead as one can see at the time of writing. Hence a study of stochastic hydrology seems indispensable: but the student

must be led to a clear understanding of the distinction between the treatments of uncertainties by stochastic techniques: first, those arising from our present ignorance (either lack of a theory or shortage of factual data), and, second, those inherent in hydrology as part of the physics of a random universe and as an observational science with random errors of observation.

Hence the student must be able to combine a willingness to consider novel mathematical models and criteria of hydrological 'success' with a mastery of existing stochastic techniques.

6.5 Regional hydrology

For several centuries there have been attempts to generalize the findings of the various physical sciences (ranging from the branches of geophysics to geology) with the aid of the concept of regional and phenomenological homogeneity. Especially in unexplored regions the techniques based on this concept promise to bear valuable fruit. Hence the IHD Working Group on Education recommends a study of the parameters on which homogeneity is based.

6.6 Conclusion: the need for flexibility

All this leads to the conclusion that the underlying philosophy of all courses should be to give students an understanding of the best current theories and acquaint them with the best current techniques whilst, at the same time, preparing them for a full review of their theoretical and methodological understanding and skills at frequent intervals. Hence both teacher and student must be prepared for a continuous process of re-education, and Unesco's policy will remain one of furthering this process by the support of symposia or conferences and of publications designed to contribute to a general raising of hydrological standards. Attendance at such symposia and study of the resulting publications are strongly recommended throughout the educational process and subsequent professional career of any hydrologist.

Appendixes

1 Selected syllabi prepared by the IHD Working Group on Education

A. Syllabus on determination of characteristic discharge data

1. *Mean annual discharge*
1.1 Water balance equation
1.2 Factors influencing the mean annual run-off
1.3 Climatic formulae
1.4 Significance and essence of the analogy method

2. *Variations in annual discharge*
2.1 Study of variations of annual run-off
2.2 Study using precipitation and other meteorological data
2.3 Long-term characteristics

3. *Annual distribution of run-off*
3.1 Statistical and genetical methods of calculating the annual distribution
3.2 Character and types of river feeding
3.3 Climatological and physiographical factors affecting annual run-off distribution
3.4 Recession curves; drying-up of rivers
3.5 Methods of estimating when data are lacking

4. *Flood discharges*
4.1 General theory of flood formation
4.2 Empirical formulae
4.3 Genetical methods of establishing flood hydrographs (rainfall, snow melt)
4.4 Methods of estimating a design flood
4.5 Application of flood frequency analysis method

5. *Minimum discharge*
5.1 Methods of calculating the minimum discharge
5.2 Application of the analogy method considering physiographical conditions

B. Syllabus on hydrological forecasting

1. *Introduction. Objectives. Importance. Historical development of hydrological forecasts.*

2. *Types, classifications and forms of hydrological forecasts and warnings,* including classification according to period covered, elements of the régime, forecasting methods, and purpose of forecast.

3. *Forecasting methods.*
3.1 Short-range forecasts of flow and stage. Rainfall–run-off computations. Estimating inflow rates on the basis of hydrometric data. Methods of hydrograph computation. Estimating snow melt rates. Stream-flow routing.
3.2 Annual, seasonal and monthly river forecasts. Seasonal snow melt forecasting for lowland and mountain rivers. Long-term forecasts of seasonal peak flow and stage. Seasonal low flow forecasts.
3.3 Forecasts of lake levels.
3.4 Ice forecasts. Appearance of ice. Formation of ice cover. Break-up of ice cover.
3.5 Ground-water forecasts. Water-levels and discharge of springs.

4. *Hydrological forecasting services.* Organization. Operation. Accuracy and checking of forecasts.

C. Syllabus on ground water and ground-water development

PART I—GROUND WATER

1. *Introduction*
1.1 Unity of natural water on the earth. Role of ground water in nature. Hydrogeology, the science of ground water. Aim and subject-matter of this science. Relation between hydrogeology and the other disciplines, especially hydrology. Brief historical review of the development of hydrogeology as a science.
1.2 Basic questions relating to hydrogeology. Importance of applied hydrogeology. Close connexion between practical needs and the theoretical development of the study of ground water.
1.3 Role of the study of ground water in relation to the supplying of water to inhabited areas and industrial districts, the improvement of transport, the construction of hydrological stations, the improvement of agricultural output, the exploitation of mineral wealth and the improvement of public health.

2. *Classification of rocks and their physical properties*
2.1 Classification of rocks, igneous, metamorphic, sedimentary and alluvial deposits. Physical properties. Exogenous, endogenous, and erosion processes by

wind and water. Methods of locating the presence of potential water-bearing formations. Grain characteristics, methods of determining grain size and porosity. Size distribution curve, effective grain diameter, uniformity coefficient. Influence of the shape, size, size distribution and arrangement of particles on porosity. Influence of the physical, chemical properties of formation on porosity. Permeability, transmissibility, storage coefficient, specific yield.

2.2 Thermal properties of rocks and their role. Conductivity, thermal resistance and heat capacity. Principles of geothermic gradient.

3. *Occurrence of ground water*

3.1 Vapour phase.

3.2 Fixed or hygroscopic water and its physical properties. Hygroscopy of various rocks.

3.3 Pellicular water, its physical properties and the mechanism of its run-off. Power of pellicular or molecular retention. Capacity of maximum molecular retention and methods of determining it.

3.4 Water in capillaries and its physical properties. Factors in the balance of capillary humidity. Laws of the capillary phenomena of rocks. Level and rate of capillary ascent in rocks. Principles of the capillary zone. Methods of determining capillarity.

3.5 Free vadose water. Hydraulic relation of water in capillaries to vadose water. Differentiation between rocks by their permeability. Capacity for total and absolute retention. Principles of the humidity of rocks and methods of determining it.

3.6 Principles of permafrost. Interstitial ice.

3.7 Crystallized water. Chemically bound water.

4. *Physical properties, chemical composition, bacteriological properties and radioactivity of ground water*

4.1 Physical properties of ground water (colour, transparency, odour, taste) and methods of determining them. Temperature of ground water. Influence of ground-water temperature on conditions governing ground-water formation, its circulation and intake. Methods of determining the temperature of ground water. Classification of ground water according to temperature.

4.2 Basic elements contained in ground water (gases, elements in the form of ions, elements in suspension, colloids, organisms). Chemical analysis of water. Principle of hard water. Classification of ground water according to degree of hardness.

4.3 Geochemistry of ground water and factors influencing its chemical composition. Action of rocks on the chemical composition of natural water. Alkalinization of rocks. Phenomena of the salinization of rocks. Chemical classification of ground water. Coefficients characteristic of the chemical composition of ground water.

4.4 Bacteriological composition of ground water and its role. Nature and intensity of biochemical processes in ground water. Principles of the colitrite. Classification of ground water according to its bacteriological composition.

4.5 Radioactivity of ground water. Principles of radioactivity. Classification of ground water according to its degree of radioactivity.

5. *Origin and classification of ground water*

5.1 Theory of the origin of ground water by infiltration, condensation and inflow. History and present state of theory of the formation of ground water by condensation. Deep water and its origin. Juvenile water, trapped sea water. Present classification of ground water. Varieties of water according to their genetic, hydrological and stratigraphical characteristics.

6. *Water in aeration zones, soil and marshes and temporarily suspended aquifers*

6.1 Water in aeration zones—its formation and situation. Water-table aquifers—their formation. Geological conditions governing aquifers. Nature of movement and chemical characteristics of water-table aquifers. Régime of water-table aquifers and influence of meteorological factors on this water.

6.2 Marsh water—formation and intake. Classification of marsh water according to intake. Hydrogeological peculiarities of marshes.

6.3 Temporarily suspended aquifers—types and conditions needed for their formation. Physical properties and chemical composition of temporarily suspended aquifers. Régime of such aquifers. Temporarily suspended aquifers as a source of water-supply.

7. *Unconfined aquifers*

7.1 The boundaries of an unconfined aquifer. Phreatic watercourses and phreatic basins. Surface of the water-table and its gradients. Correlation between the surface of the unconfined aquifer and contour of the soil surface. Special features of the unconfined aquifers, their régime and intake. Influence of meteorological factors. Influence of the soil contour, forests and unconfined aquifers on the régime of phreatic water. Dynamics of the chemical composition of phreatic water. Hydrological role of unconfined aquifers.

7.2 Division of unconfined aquifers into climatic zones (horizontal). Factors governing this division into zones. Special cases of unconfined aquifers resulting from glacial deposits, steppes, arid steppes, desert or semi-desert zones, water from the sandy sea coast.

7.3 Ground water from permafrost regions. Types of permafrost ground water, its nature and régime. Dividing line between the principal types of permafrost.

7.4 Water and pressure—conditions governing its formation and characteristics. Levels of unconfined aquifers, conditions governing their formation and their régime.

7.5 Current theories concerning the formation of aquifers.

8. *Confined and semi-confined aquifers*

8.1 Artesian water. Artesian wells and their component parts. Piezometric faces of artesian wells. Isopiezic maps and their practical use. Influence of pressure changes on aquifer characteristics.

8.2 Régime of artesian water. Distinctive characteristics of the physical properties and chemical composition of artesian water. Hydrodynamic zones of artesian water.

8.3 Hydrological role of artesian water.

8.4 Current theories on artesian water.

9. *Ground water in rock fissures and karst*

9.1 Fissure water—its formation and conditions governing its circulation. Free and confined fissure water. Régime of fissure water.

9.2 Karstic water. Process of karstic formations and their origin. Development of karstic phenomena. Hydrological peculiarities of karst. Contemporary theories concerning zones of circulation of karstic water. Relation between the formation of karst and epirogenetic movements of the earth's crust. Régime of karstic water. Karstic rivers. Peculiarities of the chemical composition of karstic water. Principal karstic regions in the world. Special features of the study of karstic water and its régime.

10. *Springs, mineral water and thermal water*

10.1 Formation, recharge and régime of springs. Classification of springs.

10.2 Principles of mineral and thermal water. Origin of its mineral content, sources of heat. Classification of principal types of thermal water (carbonic sulphurous, radioactive).

10.3 Methods of investigating mineral and thermal springs and wells. Role of the study of their régime.

PART II—GROUND-WATER DEVELOPMENT

11. *Ground water of a country*

11.1 Regional hydrogeology and its aims. Principles determining ground-water deposits, distribution and formation. Study of the hydrogeological conditions which exist in different regions and are of importance from the point of view of hydraulic development works or are of interest theoretically. Identification of ground-water resources and prospects of utilizing them. Determination of means of managing the ground-water régime for water-supply purposes; construction of engineering works; prospecting and development of mineral deposits; irrigation and other economic development measures. New ideas in regional hydrogeology.

12. *Ground-water dynamics*

12.1 Dynamics of ground water. Geological, geomorphological, hydrological and meteorological factors determining the various forms of ground-water movement. The role of ground-water run-off in the total run-off.

12.2 Principles of ground-water movement and limits of their applicability. Laminar, turbulent and transitional ground-water movement. Concept of uniform or non-uniform, steady or unsteady ground-water flow. Underground movement of waters differing in composition. Influence of density, viscosity and dissolved gases on velocity of flow.

12.3 Real and nominal velocity of ground-water movement in aquifers, real and nominal velocity in fissured rocks. Concept of the coefficient of permeability. Criteria for determining the transition from laminar to turbulent flow. Laboratory methods for determining the coefficient of permeability. Field methods for determining permeability pumping-tests using one or more wells, effect of boundary conditions and other limiting factors, use of tracers. Graphical and analytical methods for describing the cone of depression. Determination of aquifer coefficients.

12.4 Ground-water movement in homogeneous aquifers. Steady and unsteady, uniform and non-uniform ground-water flow. Ground-water movement in non-homogeneous aquifers, including the effect of aquicludes.

12.5 Characteristics of wells, relation of yield and draw-down (specific capacity). Interference of wells.

12.6 Seepage losses from reservoirs and their effects on hydrology of the adjacent areas.

12.7 Fluctuations of the water-table as affected by irrigation with imported water, pumping, or drainage. Application of the water balance principle to natural and artificial conditions.

12.8 Precision of calculations. Analysis to determine probable errors and significance of measurements.

13. *Ground-water exploration*

13.1 Hydrogeological surveys. Geomorphological features, age and structure of geological formations. Extent of recent alluvial formations. Location of brackish and saline strata.

13.2 Geophysical methods.

13.3 Drilling of test holes and interpolation of drilling samples. Electrical logs.

D. SYLLABUS ON HYDROMETRY

1. *Introduction*

2. *Measurement of river stage*

2.1 Stream levels. Observation of stream levels. Recording of stream levels.

2.2 Classification and processing of stream level data.

3. *Measurement of discharge (gauging)*

3.1 Traditional methods (current meters) Gauging technique

Equipment
Analysis of readings
3.2 Other methods
Gauges (weirs, jumps, etc.)
Floats
Radioactive tracers
Chemical gauging
Power stations.

4. *Stage-discharge variations. Test reaches*
4.1 Stations with a single stage-discharge ratio.
4.2 Stations with two or more stage-discharge ratios.
4.3 Unstable stations.
4.4 Stations with rapidly varying water stages.
4.5 Mathematical adjustment of stage-discharge laws.
4.6 Extrapolation from test discharges readings.

5. *Processing of hydrometric data (discharge)*
5.1 Various ways of representing discharge (graphs, tables, etc.) basic data.
5.2 Calculation of frequency values.
5.3 Classification and publication.

6. *Transport of solids*
6.1 General remarks
6.2 Techniques for measurement of transported solids. Equipment. Analysis of readings.

7. *Snow and ice measurements. Special methods. Equipment*

8. *Measurement of the physical and chemical properties of water*
8.1 Temperature readings.
8.2 Chemical composition.

9. *Laboratory hydrometry*

10. *Hydrometric measurement of ground water*

2 Curricula and syllabi prepared by the WMO Working Group on Training in Hydrometeorology

Recognizing the need for detailed syllabi for instruction in hydrometeorology, the World Meteorological Organization's Commission for Hydrometeorology, at its second session (Warsaw, 1964), decided to establish a Working Group on Training in Hydrometeorology. This group was requested to prepare detailed syllabi for the three main levels of the hydrometeorological staff, i.e. the professional, technical assistant and observer levels.

The Working Group consisted of E. F. Brater, United States, K. A. Hzmaljan (U.S.S.R.), Z. Mikulski (Poland), C. H. Munro (Australia) and M. Podani (Romania). The final report of the Working Group was submitted to the President of the Commission for Hydrometeorology.

The president, as authorized by the commission, approved the report on behalf of the commission. In view of the importance of its contents, the president also recommended that the report be published as soon as possible in the most appropriate manner. The report has, accordingly, been included in the series of WMO pubications intended for training purposes and is included in the WMO technical publication mentioned on page 14.

The recommended curriculum and syllabi are in the nature of optimum programmes. They provide for the study of special subjects as well as of a large number of general subjects (mathematics, physics, chemistry, etc.). For this reason, whenever students have a good basic education (for example, incomplete higher education or a higher education in another technical field) the duration of training can be reduced by the elimination from the curriculum of subjects which they have previously studied.

In the compilation of curricula and syllabi account was taken of the fact that hydrology is associated with the natural and engineering sciences, which require a thorough basic education in physics and mathematics. It was also borne in mind that in order to be able to satisfy the requirements of water management organizations and hydraulic engineering enterprises, hydrologists must also have adequate engineering training.

Curricula subjects[1]

A. Higher mathematics (500)
B. Physics (300)
C. Principles of descriptive geometry and technical drawing (50)
D. Theoretical mechanics and fluid mechanics (200)
E. General chemistry and hydrochemistry (140)
F. Principles of geophysics, geology, geomorphology and soil science (160)
G. Surveying (180)
H. Hydraulics and open channel flow dynamics and channel processes (river-bed formation) (260)
I. General meteorology and climatology (260)
J. Synoptic meteorology (130)
K. General hydrology (200)
L. Streamflow and hydrological calculations (180)
M. Hydrometry (600)
N. Hydrological forecasts (160)
O. General and special hydrogeology (170)
P. Principles of hydraulic engineering, water management and water management calculations (110)

A. Syllabus on higher mathematics

1. *Analytical geometry*
1.1 Analytical geometry in plane
1.2 Determinants and systems of linear equations
1.3 Vectorial algebra
1.4 Analytical geometry in space

2. *Introduction to mathematical analysis*
2.1 Value and number
2.2 Functions
2.3 Limits. Continuity

3. *Differential calculus of functions with one variable*
3.1 Derivative and differential
3.2 Application in functional analysis
3.3 Application in geometry

4. *Integral calculus of functions with one variable*
4.1 Indefinite integral
4.2 Definite integral
4.3 Use of definite integral

5. *Series*
5.1 Numerical series
5.2 Power series
5.3 Numerical and power series with complex number terms

1. The duration (in hours) of each course is given in parentheses (total duration: 3,600 hours).

5.4 Fourier series

6. *Differential equations*
6.1 First-order equations
6.2 Second- and higher-order equations
6.3 Linear equations of the second and higher orders

7. *Differential calculus of functions with several variables*
7.1 Functions with several variables
7.2 Derivatives and differentials
7.3 Application of several variables
7.4 Double and triple integrals
7.5 Surface and curvilinear integrals

8. *Theory of fields*
8.1 Scalar field
8.2 Vector field

9. *Theory of probability*
9.1 Direct determination of probability
9.2 Various conditions of probabilities
9.3 Law of large numbers

10. *Mathematical statistics*
10.1 Laws of mathematical statistics
10.2 Theory of correlation

11. *Equations in mathematical physics*
11.1 Equation of heat conductivity
11.2 Laplace equation
11.3 Diffusion equation
11.4 Wave equation
11.5 Elements of operator calculus

12. *Numerical calculus methods*
12.1 General rules of approximative calculations
12.2 Interpolation and approximative functions
12.3 Numerical differentiation and integration
12.4 Calculation methods in linear algebra
12.5 Methods of grids

13. *Computers and programming*
13.1 The operation of electronic computers and principles of programming
13.2 Methods of automatic programming

B. Syllabus on physics

1. *Physical basis of mechanics*
1.1 Mechanics of the solid phase
1.2 Mechanics of liquids and gases

2. *Molecular physics and thermodynamics*
2.1 Physical basis of the molecular-kinetic theory
2.2 Physical basis of thermodynamics
2.3 States of aggregation and phase transitions

3. *Electricity and magnetism*
3.1 Electrostatics
3.2 Direct current
3.3 Electromagnetism

4. *Oscillations and waves*
4.1 Mechanics of oscillations and waves
4.2 Electromagnetic oscillations and waves

5. *Optics*
5.1 Elements of the wave theory of light and geometric optics
5.2 Elements of electronic optics
5.3 Interference and diffraction of light
5.4 Polarization and dispersion of light
5.5 Optics of moving bodies and the theory of relativity
5.6 Thermal radiation. Photo-electric effect and pressure of light

6. *Physics of atoms and molecules*
6.1 Electronic shell of the atom and Bohr's theory
6.2 Elements of quantum mechanics
6.3 Periodic system of elements and spectra
6.4 Molecules and polymers

7. *Physics of solid bodies*
7.1 Elements of the lattice theory
7.2 Elements of the zone theory of solid bodies

8. *Physics of the atomic nucleus and elementary particles*
8.1 Natural radioactivity
8.2 Composition of the atomic nucleus
8.3 Gamma rays and neutrons
8.4 Nuclear reactions

C. Syllabus on principles of descriptive geometry and technical drawing

1. *Principles of descriptive geometry*
1.1 Point
1.2 Straight line
1.3 Planes
1.4 Methods of conversion of projections
1.5 Axonometric projections

2. *Technical drawing*
2.1 Technique of constructing geometrical figures
2.2 Principles of projection drawing
2.3 Principles of topographical drawing

D. Syllabus on theoretical mechanics and fluid mechanics

1. *Statics*
1.1 Composition of forces
1.2 Parallel forces; theory of couples on a plane surface
1.3 Plane system of forces
1.4 General system of forces
1.5 Centre of parallel forces and centre of gravity

2. *Kinematics*
2.1 Kinematics of a point
2.2 Translation and rotation motion of a solid body
2.3 Complex motion
2.4 Plane-parallel motion of a solid body

3. *Dynamics*
3.1 Differential equations of the motion of a material point
3.2 Dynamics of a relative motion of a material point
3.3 Theorems of the amount of motion of a material point and system
3.4 Theory of shocks
3.5 Theorems on the moment of the amount of motion of a material point and on the kinematic moment of a system
3.6 Theorems on the variation on the kinetic energy of a material point and system; general law of energy conservation
3.7 D'Alembert's principle and principle of virtual displacements

4. *Fluid mechanics*
4.1 Kinematics of a liquid
4.2 Hydrostatics
4.3 Hydrodynamics of an ideal liquid
4.4 Wave theory
4.5 Dynamics of a viscous liquid

E. SYLLABUS ON GENERAL CHEMISTRY AND HYDROCHEMISTRY

1. *General chemistry*
1.1 Atomic-molecular theory
1.2 Structure of the atom and the periodic system of elements
1.3 Chemical combination and the structure of molecules
1.4 Kinetics and chemical equilibrium
1.5 Theory of solutions
1.6 Basic principles of electrochemistry
1.7 General properties of metals; alloys
1.8 First group of the periodic system of elements
1.9 Second group
1.10 Third group
1.11 Fourth group
1.12 Organic combination
1.13 Fifth group
1.14 Sixth group
1.15 Seventh group
1.16 Eighth group
1.17 Zero group

2. *Hydrochemistry*
2.1 Water as a solvent; its properties
2.2 Electrolyte solutions
2.3 Principles of physico-chemical analysis
2.4 Surface phenomena and adsorption
2.5 Basic problems of colloidal chemistry
2.6 Chemical composition of natural water
2.7 Chemical composition of atmospheric precipitation
2.8 Chemistry of rivers, lakes and reservoirs
2.9 Chemistry of ground water
2.10 Chemistry of seas and oceans

3. *Water pollution*

F. SYLLABUS ON PRINCIPLES OF GEOPHYSICS, GEOLOGY, GEOMORPHOLOGY AND SOIL SCIENCE

1. *Principles of geophysics and general information about the globe*
1.1 Shape, dimensions and types of motion of the globe
1.2 Layers surrounding the globe; atmosphere, hydrosphere, biosphere, lithosphere and bathysphere; their composition, structure, thermodynamic conditions and state of aggregation
1.3 Terrestrial magnetism, density of the earth and distribution of gravity forces over its surface
1.4 Distribution and relationship of water and land on the earth's surface

2. *Principles of geology*
2.1 Composition of the earth's crust, distribution of chemical elements in the earth's crust
2.2 Minerals and rocks
2.3 Geological processes, tectonics and mountain formation phenomena
2.4 Historical geology methods

3. *Principles of geomorphology*
3.1 Classification of types of relief—morphological, orographic and genetic
3.2 Action of flowing water and erosion. Rivers and climate
3.3 Water-accumulation forms of relief
3.4 Karst and glacier forms of relief; forms of relief in deserts and mountain areas

4. *Principles of soil science*
4.1 Soil formation; soil as polydispersion systems
4.2 Physics of soil
4.3 Chemistry of soil
4.4 Classification of soils
4.5 Soil and water
4.6 Movement of soil water
4.7 Hydrological properties of soils
4.8 Soil water balance

G. SYLLABUS ON SURVEYING

1. Plan and map
2. Principles of theory of errors in measurements
3. Measurement of lines in the field
4. Optical parts of geodetic instruments
5. Theodolite and theodolite survey
6. Levelling
7. Combined planimetric/altimetric surveys
8. Approximation surveys
9. Geodetic network

10. Geodetic applications in stationary and field hydrological surveys
11. Principles of aerial photography
12. Principles of cartography

H. SYLLABUS ON HYDRAULICS AND OPEN CHANNEL FLOW DYNAMICS AND CHANNEL PROCESSES (RIVER-BED FORMATION)

1. *General hydraulics*
1.1 Hydrostatics
1.2 Principles of hydrodynamics
1.3 Flow through small and large orifices at constant and variable pressure
1.4 Steady flow in open channel
1.5 Pressure flow of a liquid in pipes
1.6 Non-steady flow
1.7 Spillways and flow over structures
1.8 Hydraulic jump and energy dissipators

2. *River hydraulics*
2.1 Non-uniform flow in channels
2.2 Flow with a variable discharge
2.3 Unsteady flow in open channels
2.4 Hydraulics of bifurcations and estuaries

3. *Principles of similitude*

4. *Principles of the dynamics of streams with a non-erodable bed*
4.1 Mechanics and structure of two-dimensional flow
4.2 Hydromechanical analysis of two-dimensional turbulent flow
4.3 Non-rectilinear flow and additional resistance of channel to flow

5. *Physical and hydromechanical basis of the theory of flow in an eroding channel*
5.1 Main mechanical and hydraulic characteristics of river-beds and sediments
5.2 Mechanism of sediment transport

6. *Channel processes*
6.1 Hydrodynamic and hydromorphological approach to the channel processes theory
6.2 Basic river-bed processes by the construction of hydraulic structures

I. SYLLABUS ON GENERAL METEOROLOGY AND CLIMATOLOGY

1. *General properties of the atmosphere*
1.1 Composition and structure of the atmosphere
1.2 Basic gas laws applicable to the atmosphere
1.3 Principles of atmospheric statics

2. *Radiant energy in the atmosphere*
2.1 Solar radiation
2.2 Effective radiation and radiation balance

3. *Heat exchange in the soil, water and atmosphere*
3.1 Heat régime of the soil and bodies of water
3.2 Principles of atmospheric thermodynamics
3.3 Heat transfer in the atmosphere; air temperature
3.4 Vertical distribution of air temperature

4. *Water cycles in the atmosphere*
4.1 Evaporation and methods of measurement
4.2 Air humidity and methods of measurement
4.3 Condensation of water vapour; international cloud classification
4.4 Precipitation and methods of measurement, including radar
4.5 Snow pack and snow surveys

5. *Wind measurement methods*

6. *Climatological problems and investigations methods. Relationship with meteorology and hydrology*
6.1 Climatological data processing methods
6.2 Basic factors of climate formation
6.3 Influence of relief on climate
6.4 Influence of snow and ice cover on climate
6.5 Geographical distribution of climatic elements over the globe
6.6 Classification of climates
6.7 Microclimate and local climate
6.8 Changes in climate and climatic fluctuations
6.9 Climates of the world

7. *Network of meteorological stations; observation times and the transmission of information*

J. SYLLABUS ON SYNOPTIC METEOROLOGY

1. *General information on synoptic meteorology and short-range weather-forecasts*
1.1 Basic synoptic codes; prospects of using meteorological satellite data; elements of World Weather Watch
1.2 Compilation and analysis of weather-charts
1.3 Analysis of the fields of meteorological elements
1.4 Air masses—their classification and properties
1.5 Atmospheric fronts
1.6 Cyclone activity
1.7 Analysis and short-range forecasts of the synoptic position and weather conditions

2. *Macrosynoptic processes and long-range weather-forecasts*
2.1 Laws of general atmospheric circulation
2.2 Peculiarities of circulation in various areas of the globe and types of macrosynoptic processes
2.3 Methods of long-range weather-forecasts covering long and short periods

3. *Quantitative precipitation forecasts*

4. *Radar precipitation measurement*

K. Syllabus on general hydrology

1. *Role of water in economic activities*
1.1 Bodies of water on the globe; general information on oceans, seas, large lakes and rivers
1.2 The water cycle on the globe; the general principles of water balance
1.3 General information on the structure of water, ice, snow and water vapour

2. *River systems and basins*
2.1 Definition of rivers; formation of river system; watershed divides
2.2 Definition of a basin; boundary and configuration of basins; measurement of basins
2.3 Morphological and physico-geographical characteristics of basins
2.4 Characteristics of river systems; classifications of tributaries

3. *River valleys and channels*
3.1 River valleys and their types
3.2 River-beds and flood plains
3.3 Plane formation of river channels; formation of bed cross-section
3.4 Types of movement of water in river-beds; circulation currents and vortex motion

4. *Sources of run-off*
4.1 Run-off from rainfall
4.2 Run-off from snowfall, glaciers and permanent snow
4.3 Run-off from ground water
4.4 Influence of climate, relief, soil, geological and other factors on run-off processes

5. *Water stage and run-off régime*
5.1 Typical hydrographs
5.2 Phases of the hydrologic year
5.3 Regulated régime (natural and artificial)
5.4 Floods—their development and laws governing their movement

6. *General principles of streamflow and water balance*
6.1 Water balance equation and its analysis
6.2 Characteristics of streamflow; discharge, volume, depth of run-off discharge in seconds; litres per square kilometre and run-off coefficient
6.3 Average annual run-off; long-term average annual run-off; seasonal run-off

7. *Thermal and winter régimes of rivers*
7.1 Temperature variations in rivers
7.2 River freezing processes and ice formation
7.3 Ice break processes

8. *Sediment transport*
8.1 Energy of running water; erosive action of rivers
8.2 Suspended load and its transport; relationship of suspended load to water stage and discharge
8.3 Sediment transport of rivers and factors governing the degree of it
8.4 Bed load, its formation and régime
8.5 Deformation of the river channel; channel formation processes and their variation in time and along the length of the river; influence of hydraulic structures on channel formation processes
8.6 Chemical sediment; basic elements of chemical régime of rivers

9. *River estuaries and hydrological peculiarities*

10. *Hydrology of lakes and reservoirs*
10.1 Lake formation processes and the inflow–outflow balance of lakes
10.2 Temperature variations in lakes; calculations of the heat balance of lakes
10.3 Salinity, chemical and gaseous composition of lake water
10.4 Waves on lakes and reservoirs; calculations of wave height; erosion banks
10.5 Current in lakes and reservoirs
10.6 Lake deposits—their classification and morphology
10.7 Main characteristics of the hydrological régime of reservoirs

11. *Biology of lakes and rivers; relation between the biology of lakes and rivers and the chemical composition of waters*

12. *Notion on hydrology of marshes*

13. *Principles of oceanography*

L. Syllabus on streamflow and hydrological calculations

1. *Run-off process theory*

2. *The use of mathematical statistics and the probability theory in hydrology*

3. *Meteorological conditions governing streamflow*
3.1 Air temperature as a factor in the transformation of water balance elements
3.2 Precipitation—its various types and intensity; calculations of average precipitation in river basins
3.3 Evaporation from free water surface and from the surface of a river basin; instruments for measuring evaporation and evaporation calculation methods

4. *Water and heat balance equations; the use of water and heat balance equations for solving various water management problems*

5. *Mean annual run-off*
5.1 Determination of annual run-off for subsequent hydrological calculations and its accuracy
5.2 Influence of climatic and other physical geographic factors on mean annual run-off
5.3 Compilation of maps of mean annual run-off isolines, their accuracy and importance

6. *Variability of annual run-off*
6.1 Methods of determining variations in annual run-off on the basis of the relationship with precipitation and variations in types of circulation
6.2 Use of frequency distribution curves to determine annual run-off variations
6.3 Coefficients of variations of annual run-off series and their dependence on the size of the drainage basin and other physiographic factors; methods of determining coefficient of skewness

7. *Distribution of flow during the year*
7.1 Statistical and physical methods of calculating this distribution
7.2 Nature and types of river inflow methods of compiling run-off hydrographs
7.3 Run-off isoline maps and their use
7.4 Mass curves of daily flow
7.5 Methods of calculating minimum and maximum discharges; meteorological factors of rain run-off. Methods of calculating the intensity and depth of rainstorms

8. *Flood flow*
8.1 Definition of flood, rainfall and snow-melting floods, maximum probable flood, design flood, recurrence interval flood
8.2 Overland flow of flood, infiltration
8.3 Hydrograph analysis, unit by hydrograph concept
8.4 Flood estimation in small basins, empirical formulae, synthetic hydrograph
8.5 Flood frequency analysis
8.6 Minimum flow, depletion curves

9. *Discharge of suspended and chemical load; methods of calculating this load*

10. *Special aspects of hydrological calculations*
10.1 Methods of calculating run-off in planning drainage and irrigation
10.2 Methods of calculating irrigation requirements on the basis of water and heat balance equations
10.3 Flood routing
10.4 Calculation of maximum water stage of various frequency
10.5 Calculation of evaporation from free water surface and from bare soil
10.6 Other hydrological calculations

11. *Water balance surveys*
11.1 Organization and methods of multipurpose studies of the water balance of basins of rivers and lakes
11.2 Methods of stationary and field surveys of water balance elements

M. Syllabus on hydrometry

1. *Stage régime studies*
1.1 Principles of the stage régime of rivers, lakes and reservoirs; gauges and datum systems; types of gauges
1.2 Choice of reaches for hydrometric observations
1.3 Observation times and their dependence on water level régime; recording of maximum and minimum stage. Measurement of the hydraulic slope
1.4 Instruments for stage observations (including stage recorders)
1.5 Water temperature observations
1.6 Processing of hydrometric observations (stage and temperature)

2. *Soundings*
2.1 Organization of soundings; river soundings by cross-sections, longitudinal sections and diagonals; determination of sounding profiles
2.2 Sounding instruments—manual, mechanical, hydrostatical and acoustical
2.3 Processing of sounding data

3. *Measurement of stream velocity*
3.1 General notions on streamflow régime; basic principles of flow; distribution and pulsation of velocities
3.2 Point and integration methods of measuring velocity; points on the vertical
3.3 Instruments for measuring amount and direction of flow and their classification; gauging-station equipment, calibration of hydrometric instruments
3.4 Processing of velocity data

4. *Determination of discharge; classification of discharge measurement methods*
4.1 Volumetric method
4.2 Slope-area method and its various applications
4.3 Control cross-sections and conditions of their use
4.4 Floats
4.5 Weirs and flumes
4.6 Dilution method
4.7 Use of isotopes
4.8 Processing of discharge data by graphical and analytical methods and processing of integration measurements

5. *Relationship between discharge and stage, and calculations of mean daily discharge*
5.1 Plotting of rating curve, evaluation of its accuracy and extrapolation of it
5.2 Discontinuous rating curves
5.3 Calculation of mean daily discharge and compilation of discharge yearbooks

6. *Sediment discharge computations*
6.1 Basic data on the régime and the movement of sediment in rivers
6.2 Measurement of suspended sediment; methods and instruments
6.3 Measurement of bed load; methods and instruments
6.4 Laboratory analysis of samples of transported suspended sediment and bed load and sedimentation
6.5 Processing of suspended sediment transport and bed load discharge data

7. *Other types of observations; their conduct and processing; use of instruments*
7.1 Thermal régime observations and winter régime observations (snow, ice, ice phenomena)
7.2 Water transparency and colour observations
7.3 Observations of chemical quality of water
7.4 Wave observations

8. *Special work*
8.1 Determination of the discharge of small rivers using hydraulic structures
8.2 Measuring of discharge at hydraulic structures and hydropower plants

9. *Technical instructions for hydrological stations and their inspection*

10. *Method of hydrometrical measurements in laboratory; principles of the similarity theory and modelling methods*

11. *Hydrological field investigations*
11.1 Relationship between investigations, planning and construction; stages of an investigation
11.2 Characteristic features of investigations used as a basis for the planning and construction of hydraulic engineering works (hydro-power plants)
11.3 Characteristic features of investigations for navigation and timber floating
11.4 Characteristic features of investigations for planning and construction of irrigation systems
11.5 Characteristic features of investigations for designing and constructing roads and bridges

12. *Basic safety techniques and labour protection rules to be observed in carrying out hydrological observations on rivers and lakes*

N. Syllabus on hydrological forecasts

1. *General information on hydrological forecasts*
1.1 Organization of a hydrological information network and a hydrological forecast service
1.2 Types of hydrological and meteorological information; codes for transmission of hydrological and meteorological information and forecasts
1.3 Collection of scientific and operational hydrological and meteorological data necessary for the computation of hydrological forecasts
1.4 Evaluation of forecast errors; reliability of specific methods and natural reliability

2. *Short-term flow forecasts (stage and discharge)*
2.1 Classification of short-range hydrological forecasts and forecasting methods
2.2 Physico-empirical relationships
2.3 Correlation relationships
2.4 Isochrone method
2.5 Rainfall loss rate—unit hydrograph method
2.6 Stage forecasting

3. *Long-term flow forecasts*
3.1 Classification of long-term run-off forecasts and forecasting methods
3.2 Methods of corresponding volumes (by volume of water in channel system)
3.3 Water balance method
3.4 Methods of analogy and methods of standard forecasts

4. *Forecasting of temperatures*

5. *Short-term and long-term forecasts of ice phenomena*

6. *Use of computers and models in hydrological forecasts*

O. Syllabus on general and special hydrogeology

1. *General hydrogeology*
1.1 Unity of the natural waters in the world; role of ground water
1.2 Classification of rocks and their physical properties
1.3 Forms of physical state and movement of ground water
1.4 Physical properties, chemical composition and radioactivity of ground water
1.5 Origin and classification of ground water
1.6 Water of the aeration zone and water in the soil
1.7 Non-artesian (ground) and artesian water
1.8 Ground water in fissured rocks
1.9 Mineral waters

2. *Dynamics of ground water*
2.1 Laws of ground-water dynamics
2.2 Determination of percolation coefficient and yield for various types of wells
2.3 Methods of determining velocity and direction of ground-water flow

3. *Hydrogeological investigation*
3.1 Networks of hydrological observation wells
3.2 Hydrogeological calculations for water management

4. *Elementary principles of hydraulic machinery*

P. Syllabus on principles of hydraulic engineering, water management and water management calculations

1. *Principles of hydraulic engineering*
1.1 Construction operations and materials used in hydraulic engineering
1.2 Basic hydraulic engineering structure

2. *Water resources utilization and control*
2.1 Hydro-power development
2.2 Inland waterways
2.3 Transport of timber by water (floating)
2.4 Irrigation

2.5 Drainage
2.6 Water supplies to population and industry
2.7 Hydraulic engineering in the fishing industry
2.8 Soil erosion control
2.9 Hydraulic engineering, bridges

3. *Water resources management*
3.1 Water resources, their evaluation and economic importance
3.2 Water requirements of various sectors of the economy and flow regulation régime
3.3 Average *per capita* consumption for urban water-supply and variations in domestic and industrial consumption

4. *Water management calculations*
4.1 Water resources management installations and reservoirs
4.2 Basic data in water resources management planning
4.3 Basic principles of flow regulation theory; calculations using mass diagrams and demand lines
4.4 Flow regulation calculations using stochastic methods
4.5 Regulation calculations using storage behaviour diagrams for developing release role graphs
4.6 Other applications of statistical methods to water resource problems
4.7 Hydraulic power calculations
4.8 Flood control and flood damage mitigation methods
4.9 Reservoirs in series and compensation regulation and methods of calculation

3(a) Curricula and selected syllabi on education in hydrology in the U.S.S.R.

1. CURRICULA

(See Tables 3.1 and 3.2.)

2. SYLLABI

The full Russian syllabi, with a translation of substantial parts in English, are available at the IHD Secretariat, Unesco, Paris.

2.1 *Fluid mechanics*

2.1.1. 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.

2.1.2 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.

2.2 *General and special (open channel) hydraulics*

2.2.1 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 connexion with upper and lower backwater.

2.2.2 Special (open channel) hydraulics
Non-uniform flow in channels. Flow with changing discharge. Unsteady flow. Hydraulics of bifurcations and of estuaries. Laboratory work problems.

2.3 *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 régime 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.

2.4 *Chemistry and hydrochemistry*

2.4.1 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.

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

2.5 *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, volcanism, earthquakes, historical geology and geomorphology, processes of soil formation, etc. Pedology. Field exercises.

2.6 *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; influence of the snow and ice cover on the climate; classification of climates; microclimate and regional climate; changes in fluctuations of the climate; climates of the globe. Laboratory training.

2.7 *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.

2.8 *Hydrometry*

2.8.1 General hydrometry

Measurement of the water régime; discharge computation; sedimentation; winter and other temperature régimes; 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.

2.8.2 Hydrometric structures and equipment

2.9 *General and special hydrogeology*

2.9.1 General hydrogeology

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

2.9.2 Special hydrogeology

Ground water in the U.S.S.R.; dynamics of ground water; research and investigation of ground water. Laboratory training.

2.10 *General hydrology*

2.10.1 Hydrology of continents

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

2.10.2 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.

2.11 *Hydrological analysis*

Introduction; equations 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.

2.12 *Water resources management and design*

2.12.1 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.

2.12.2 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.

2.13 *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.

2.14 *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 correlations 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.

2.15 *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.

2.16 *Dynamics of channel flow and channel erosion*

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

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

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

2.17 *Hydraulic structures*

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

2.17.2 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.

3(b) Curricula and selected syllabi on education in hydrology in the United States

I. REQUIRED COURSES

1. *Hydrology*

1.1 *Principles of hydrology*
Basic principles of hydrology dealing with the chemical, physical, and biological aspects of water movement and mass transfer. Techniques of measurement of hydrologic variables; relations used by man to develop water supplies.

1.2 *Seminar*

1.3 *Hydrological properties of soils*
Shape and size distribution of soil constituents and structural units of soils as related to the state of soil water and its movement in soil. Individual laboratory projects included.

1.4 *Field hydrology (summer camp)*
Field methods of collection, compilation and interpretation of hydrologic data; geologic and geophysical methods; preparation of hydrologic reports. Laboratory comprises daily field-work. Required of hydrology majors.

1.5 *Hydrology*
Elementary treatment of major topics in hydrology including rainfall, evaporation, ground water and run-off.

1.6 *Hydrogeology*
Geology and hydrologic factors controlling occurrence and development of ground water.

2. *Geosciences*

2.1 *Physical geology*
Principles of physical geology.

2.2 *Elementary structural geology*
Structures resulting from the formation and deformation of rocks. Structural problems.

2.3 *Principles of geomorphology*
Concepts of landform development with emphasis on fluvial processes and climate factors. Field trips.

3. *Mathematics*

3.1 *Analytic geometry and calculus*

3.1.1. Analytic geometry and calculus for mining students, *or*

3.1.2 Analytic geometry and calculus for engineers

3.2 *Introduction to statistics*
Probability, standard distributions, applications of central limit theorem, test of hypotheses, confidence intervals, linear regression and correlation.

3.3 *Intermediate analysis and differential equations*

4. *Chemistry*

4.1 *Fundamentals of chemistry*
Essential concepts and problem-solving techniques. Emphasis on chemical bonding, structure and properties, stoichiometry, kinetics, equilibria, and descriptive organic and inorganic topics.

4.2 *Fundamental techniques of chemistry*
Basic techniques in college chemistry. Emphasis on experimental methods, techniques of measurement, separation, purification and analysis of organic and inorganic substances.

4.3 *Also, one additional course beyond Fundamentals of chemistry*

5. *Physics*

5.1 *Introductory*
Fundamental principles of mechanical, thermal, acoustical, electrical, optical, atomic and nuclear phenomena.

6. *Aerospace and mechanical engineering*

6.1 *Principles and applications of fluid mechanics*
Fundamentals of fluid mechanics covering properties of fluids, fluid statics and dynamics, concepts and definitions.

7. *Biological sciences*

7.1 *Elementary plant physiology*
Functions, nutrition, metabolism and development of higher plants.

8. *Atmospheric sciences*

8.1 *Introduction to meteorology and climatology*
The physical processes in the atmosphere, simple atmospheric motions, elements of climate, climatic types and world distribution of climate types.

9. *Water resource administration*

9.1 *Water, society and the environment*
The role of behavioural sciences (social, legal, economical, political and psychological) in public administration of use, development and management of water resources, and ecological relation of water in the biosphere.

9.2 *Land economics*
Economic principles useful in analysing problems and policies of land and water use, development and conservation; their application to problems of land and water valuation, ownership and control, public and private use, exploitation and conservation.

10. *Systems engineering*

10.1 *Programming for scientific applications*
Introduction to problems analysis and algorithms; basic concepts of digital computers; Fortran programming with applications to typical scientific and engineering problems.

11. *English*

11.1 *Freshman composition*
The equivalent of English 1 for students whose proficiency in English grammar and usage permits advanced placement; theme writing; library paper; collateral reading.

11.2 *Freshman composition*
Continued practice in composition with emphasis upon objective writing; library paper; readings in fiction and non-fiction.

11.3 *Expository writing for scientific and technical students*

12. *Economics*

12.1 *Survey of economics*
Current economic theory and institutions.

13. *Physical education*

13.1 *Physical education for women*

13.2 *Health, physical education and recreation for men*

II. Course offerings in hydrology

1. *Water and the environment*
An integrated course dealing with the principal components of the water cycle. The role of man in water-supply and management and the resultant environmental effects. (Not for hydrology majors.)

2. *Principles of hydrology*
Basic principles of hydrology dealing with the chemical, physical and biological aspects of water movement and mass transfer. Techniques of measurement of hydrological variables; relations used by man to develop water supplies.

3. *Seminar (undergraduate)*

4. *Hydrological properties of soils*
Shape and size distribution of soil constituents and structural units of soils as related to the state of soil water and its movement in soil. Individual laboratory projects included.

5. *Field hydrology (summer camp)*
Field methods of collection, compilation and interpretation of hydrological data; geological and geophysical methods; preparation of hydrological reports. Laboratory comprises daily field-work. (Required of hydrology majors.)

6. *Hydrology*
Elementary treatment of major topics in hydrology including rainfall, evaporation, ground water and run-off.

7. *Hydrogeology*
Geology and hydrological factors controlling occurrence and development of ground water.

8. *Statistical hydrology*
Applications of mathematical statistics and probability theory to measurement, analysis and synthesis of hydrological processes and design and control of water resource systems.

9. *Watershed hydrology*
Application of fundamental principles to quantifying the basic hydrologic processes occurring on watersheds.

10. *Hydrochemistry*
Solute composition of natural-occurring water, chemical reactions affecting the solute content of water, relations and effects of above on water quality criteria and pollution. Analytical procedures used by water testing laboratories.

11. *Water quality control*
Aspects of water quality maintenance; physical, chemical and biological factors in water and waste-water treatment and natural purification.

12. *Hydrological systems*
Major physical processes relating to hydrological systems of the earth; mass and energy flux across hydrological interfaces; the role of the hydrologist in water resource development.

13. *Physical oceanology and limnology for hydrologists*
Origin, distribution and characteristics of oceanic water; advestive and convestive processes; estuarine and shoreline processes; effect on coastal aquifers; classification and hydrological regimen of lakes; oceans and lakes as sources of water-supply.

14. *Snow hydrology*
Physical properties of snow, melt and run-off characteristics, measurement, flood and water yield prediction, forest–snow relationship and management potential.

15. *Water quality dynamics*
Mathematical models are derived to study and predict dispersion of pollutants and water quality changes in streams, lakes and reservoirs, aquifers, soils and estuaries.

16. *Soil water dynamics*
Fluid flow in soils, potential theory and surface phenomena; introduction to modern concepts and theories of physical processes in soils.

17. *Aquifer mechanics*
Mechanics of fluid flow through porous media; flow dispersion quantitative determination of the hydraulic characteristics of geohydrologic systems; principles of well field design and aquifer evaluation. Field trips.

18. *Development of ground-water resources*
Boundary-value problems in geohydrologic system; analysis of cause–effect relationships between streams, lakes and aquifers for management of water resources; planning and design of regional water resources investigations. Field trips.

19. *Dynamics of flow systems of the earth*
The physical and mathematical principle of flow systems as influenced by environmental factors of the earth; application of classical, numerical and computer mathematics and solutions to flow and frictional flow systems manifested by surface water and ground-water movement in and on the earth.

20. *Advanced topics in hydrology*
Content of course to be determined by new developments in the science of hydrology, student interests and faculty availability.

21. *Parametric hydrology*
Linear and non-linear analysis of watersheds, aquifers, soil systems, hydrological instruments. Hydrological signal analysis and model building in presence of noise and in context of decision theory.

22. *Stochastic*
Times series analysis and sampling of hydrologic data. Use of stochastic process models of streamflow, river networks, aquifers, soil and vegetative patterns, evaporation, reservoirs, precipitation.

23. *Seminar*

III. Course offerings in water resources administration

1. *Water, society and the environment*
The role of behavioural sciences (social, legal, economical, political and psychological) in public administration of use, development and management of water resources; and ecological relation of water in the biosphere.

2. *Land economics*
Economic principles useful in analysing problems and policies of land and water use, development and conservation; their application to problems of land and water valuation, ownership and control, public and private use, exploitation and conservation.

3. *Application of operations research to water resources*
Applications of deterministic and stochastic linear programming and dynamic programming techniques to water resources management problems. Survey of other operations research techniques. A knowledge of Fortran programming is required.

4. *Population and resources*
Estimates of present and potential world population; distribution and methods of conserving important resources. Field trips.

5. *Environmental politics*
The role of government in the conservation and development of natural resources; conservation policies and problems in the field of natural resources; some special attention to the South-west.

6. *Forest and range policy*
Application of fundamental principles to quantifying the basic hydrological processes occurring on watersheds.

7. *Water resources administration practice*
A critical examination of institutional setting in which water resources management takes place and the processes by which policies are formed and developments undertaken.

8. *Economics of natural resources*
Advanced application of the tools of economic analysis to the recognition, exploration and solution of problems in natural resources development, use and conservation.

9. *Methodologies in water resources*
Studies of the applications of operations research, econometrics and probability theory to system modelling and management in the context of current research efforts.

10. *Multidisciplinary tutorials*
Examination of civil decision problems from the view point of different disciplines in a context of group study and tutorials. Intended primarily for participants in the civil decision programme.

Conformal mapping, sand models, electric analogies. Estimation of total and available ground-water resources, the concept of safe yield and the mining of ground water.

11. *Hydrology of water storage*
The exploration of storage possibilities of surface as well as of ground water. Hydrological analysis of surface storage. Reservoir operation. Some design and operating problems of surface reservoirs. Use of underground reservoirs for storage.

12. *Sediment transportation in alluvial streams*
Formation, movement and measuring of sediment. Movement of bed load and suspended sediment. Flow in alluvial channels. Current relationships for sediment.

13. *Effect of man's influence on hydrological phenomena*
Principal factors of the hydrological cycle that can be influenced by man. Human activity and its effect along the watercourses in connexion with their training and utilization. Effect of human activity on the catchment area. Evaluation of the efficiency and development of water management.

14. *Hydrology of land drainage*
The hydrology of subsurface land drainage. The hydrology of surface land drainage. A systems engineering approach of the influenced concentration of waters in flat areas. The relationship between land drainage hydrology and feasibility studies concerning land drainage. The aims of research work in the field of hydrology of land drainage.

2. International Course for Hydrologists, Delft

2.1 Curriculum[1]

Hydrology
Hydraulics
Sediment transportation and sedimentology*
Mathematics
Ground-water flow
Ground-water recovery: (a) geophysical aspects; (b) technical aspects
Geophysics†
Soil science
Forest hydrology and watershed management†
Rivers
Reservoir operation†
Hydrometry
Geology
Geomorphology
Urban hydrology†
Hydrology of coastal areas†
Parametric hydrology†
Aerial survey and remote sensing*
Meteorology
Models*
Data processing and computer programming
Numerical methods*
Statistics
Stochastic processes in hydrology
Analogue computation†
Nuclear methods†
Water quality
Water law and management
Engineering operations

2.2 Syllabi

1. *Hydrology*
A. Introduction. The hydrologic 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 evapo-transpiration. 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 hydrologic cycle. Infiltration as a factor in run-off and infiltration as recharge of ground water. 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. Ground-water hydrographs. Synthetic hydrographs. Long-term and short-term forecasting of yield and floods. Flood routing.
G. Physical aspects of erosion. Wind erosion.

2. *Hydraulics*
A. General equations of streamflow continuity. Bernoulli's law, impulse momentum equation.
B. Application to flow over weirs and through orifices.
C. Uniform flow.
D. Gradually varied flow, backwater curves.
E. Long waves. Single translation masses, method of characteristics.

3. *Sediment transportation and sedimentology*
Erosion and production of sediments. Properties of transported material and water. Initiation of particle motion. Transportation mechanism. Calculation of sediment transport. Sampling techniques. Flow characteristics and sediment transportation. Stable channels.

1. In the following list, * denotes subject in which part is facultative, and † denotes facultative subjects.

4. *Mathematics*
A. Partial differentiation. Differential equations. Fourier analysis.
B. Introduction to the theory of complex numbers and to conformal mapping.

5. *Ground-water flow*
Introduction. Physical phenomenon of the flow of viscous liquid through a porous medium. Fundamental laws. Mathematical treatment of a number of frequently occurring flow problems. One-, two- and three-dimensional flow; phreatic, confined and semi-confined ground water; permanent and non-permanent flow.

Other methods of solving the problems: graphical methods; use of images, numerical analysis; conformal mapping; model experiments.

Discussion of some practical problems: seepage through dams; leakage from reservoirs; flow into wells; dewatering of construction sites; upward seepage of ground water in low areas; salt water intrusions.

6. *Ground-water recovery*

Geophysical aspects

A. Introduction. Appraisal of ground-water resources.
B. Recapitulation of geology. Permeability of rocks. Structural geology.
C. Aquifers. Origin and occurrence of ground water. Aquifers in geological structures. Hydrologic properties of various pervious materials. Hydrology of dunes.
D. Prospecting methods. The use of various geophysical exploration methods in geohydrology.

Geoelectrical prospecting; the resistivity method and its use and application in water-supply geophysics, engineering geophysics and structural geophysics.

Location of ground-water reservoirs.
E. Seepage. Prediction of the amount of seepage. Practical consequences of seepage in reclamation works. Seepage of saline ground water.
F. Conservation and use of ground water. Ground-water mapping. Exploitation; safe yield. Purposes of artificial recharge.

Technical aspects

A. Introduction. Theoretical formulae for the drawdown curves of galleries, single wells, well systems and polders, for confined and unconfined flow, with different geohydrological conditions.
B. Practical aspects of the flow of ground water to wells, analysis of test pumpings with steady and unsteady flow.

7. *Geophysics*
Review of the various prospective methods. Seismic refraction method. Electrical resistivity method—its use and application in ground-water studies.

Ground-water quality and mapping of ground-water reservoirs, mathematical and physical interpretation, case histories. Well-logging methods.

8. *Soil science*
A. Chemical and physical properties of soils; soil organic matter; soil organisms; soil moisture relationships; soil structures.
B. Soil formation; soil mapping; soil classification. Land classification.
C. Salty soils.
D. Pedology and agrohydrology.

9. *Forest hydrology and watershed management*
Forest influences and forest hydrology research—aims and methods. Subsurface flow in forested watersheds and its influence on the hydrograph; flow from unsaturated soil.

10. *Rivers*
Introduction, types and dimension of rivers, morphological and régime factors. Water discharge, measuring instruments and methods, two- and three-dimensional flow current pattern, eddies and spiral flow, formulae. Transport of solid matter, measuring instruments and methods, formulae, bed formation and equilibrium. Introduction to river morphology, meandering and braiding of channels.

11. *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 the 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 freeboard above maximum still water-level for design of a dam. Wind waves and set-up in reservoirs.

12. *Hydrometry*
Stage-discharge relationship, selection of measuring site (networks), measurement of stage, measurement of discharge (area-velocity methods, tracer methods, weirs and flumes, other methods. Accuracies and errors, automatic data processing and telemetering systems.

13. *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.

14. *Geomorphology*
Evolution of landforms. Weathering processes. Slopes and their development. Landforms created by river work.

Geomorphology of limestone areas. Landforms developed under arid conditions. Glaciers and glacial landforms. Landform types—a classification.

The use of geomorphological maps. Principles of geomorphological photo-interpretation (static and dynamic aspects). Qualitative and quantitative interpretation. Importance of photoscale, emulsion type, etc. Photogeomorphology and the appraisal of water resources.

15. *Urban hydrology*
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.

16. *Hydrology of coastal areas*
Coastal morphology. Sources of salt. Measures to combat salt intrusion. Reservoirs in coastal areas; water and salt balance.

17. *Parametric hydrology*
Systems approach to hydrology—the systems view point, hydrologic systems, linear time-invariant systems, identification of hydrologic systems. Problem of run-off prediction. Identification of continuous-time systems, identification of discrete-time systems. Simulation of hydrologic systems, hydrologic cycle, conventional catchment model. Methods of simulation-regression and conceptual models, digital and analogue simulation. Linear catchment response. Limiting forms of IUH. General linear synthesis. Error-sensitivity of identification methods—basic problem and data, theoretical analysis, types and level of error, algebraic methods, optimization methods, transform methods. Simulation of non-linear systems—the problem of non-linearity, overland flow, concept of uniform non-linearity.

Linear theory of flood routing—basic of flood routing, linear channel response, simulation of LCR, simulation of IUH.

Infiltration theory—general principles, steady-state solutions, unsteady flow problems, solutions of constant parameters, special solutions, review of solutions.

18. *Aerial survey and remote sensing*
How an area is covered 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. Spatial triangulation principle. Flight planning in connexion with application of the photographs for civil engineering.

19. *Meteorology*
A. Atmospheric physics—subdivision of meteorology, units and accuracy, atmospheric gas laws, phase changes of water, meteorological moisture variables, radiation.
B. Meteorological instruments—general instrumentation problems, instrument response theory, thermometers, radiation meters, hygrometers, precipitation measurement, wind measurement, exposure of surface instruments, upper air measurements and radar.
C. General meteorology—vertical motion in the atmosphere, vertical stability, precipitation formation, artificial control of precipitation, large scale winds and weather.
D. Micrometeorology—meteorological estimation of evaporation, vertical turbulent transport, change of wind speed with height, wind profile evaporation formulae, energy balance evaporation formulae, atmometers and evaporation pans, comparison of estimation methods.

20. *Models*

Model investigations in hydraulics

Short history of experimentation in hydraulics.
Principle of similarity; numbers of Reynolds, Froude, Weber and Mach and related scale factors.
Model distortion, artificial roughness, model tilting.
Movable bed models (bed load, suspended load, local scour).
Some generalities on wave models with and without movable bed.

Hydrological models

A. Modelling physically—design of a rain simulator, measuring of a flow on a model.
B. Digital (mathematical) modelling—basic assumptions of a rainfall—run-off mathematical model construction, simulation of the catchment as a system, solution of the system by the use of the space parameter representation, solution of equation by time parameter representation.
C. Analogue (mathematical) modelling—simulation of the catchment as a system of channel reaches represented by an analogue model, 'method of norms', scaled model components.

21. *Data processing and computer programming*
A. Range of application of digital machines—interaction with over-all design and construction techniques. Integration of computation with sampling, testing and interpretation—design systems.
B. Introduction to a programming language (either Algol-60 or PL1). Exercises and applications.
C. Review of data processing methods.

22. *Numerical methods*
A. Economics of computer applications in engineering practice.

B. Problems of equilibrium, transition and propagation type, as described by elliptic, parabolic and hyperbolic equation systems.
C. Solution of problems governed by elliptic equations. Consistency. Acceleration of convergence.
D. Solution of problems governed by parabolic equations. Explicit schemes; stable and unstable behaviour. A sufficient condition for stability. Implicit schemes—unconditional stability. Truncation errors. The tri-diagonal algorithm.
E. Solution of problems governed by hyperbolic equations. Stability. Optimization of stability and the elimination of truncation errors—the method of characteristics.

23. *Statistics*
Types of hydrological data, classification and graphical representation of data. Elementary theory of probability. Theoretical frequency distributions. Applications of the binominal, Poisson, normal, hypergeometric, multinomial, lognormal, Pearson III, and Gamma-distributions. Plotting of data on probability papers and other types of technical papers.

Sampling theory for large and smaller samples.

Regression and correlation analysis with applications to hydrology.

Testing of hypothesis, the chi-square distribution, maximum likelihood methods.

The theory of extreme values as applied to the study of flood and droughts.

24. *Stochastic processes in hydrology*
Various types of hydrological sequences: periodic series, almost periodic series, ergodic and non-ergodic, stationary and non-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.

25. *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 panel preparation of an analogue machine.

26. *Nuclear methods*
Introduction. Determination of the density of sediments. Gamma-scattering density probes. Use of nuclear techniques in leakage investigations. Use of nuclear techniques in precipitation–run-off relations. Use of environmental isotopes in water balance studies.

27. *Water quality*
Principles of chemistry and microbiology of water.

Water quality in relation to use of water resources. Mechanisms of water pollution. Analysis of polluted water. Prevention and control of water pollution. Case studies.

Four laboratory sessions will be held in order to illustrate relevant chemical and microbiological techniques by practical exercises.

28. *Water law and management*
Water legislation government and administration of water resources. Water laws. Water property. Use of waters. Underground waters, legal system concerning their property, legal régime of their prospection, taxation régime.

29. *Engineering operations*
A. Principles of engineering economy. Comparative cost. Interest rate. Depreciation.
B. Social and economic aims of projects. Economic versus financial analysis. Analysis of cost and benefits. The 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.
D. The work of the United Nations and its Agencies with respect to water resources activities. Development aid policy. Sources of assistance for water development projects in developing countries. The operations of the World Bank, the United Nations Development Programme, the regional organizations and bilateral schemes.

3. International Post-graduate Course in Management of Water Resources with Special Emphasis on Ground-water Exploitation, Haifa

3.1 Curriculum

Principles of flow through porous media
Ground-water hydrology
Principles of surface hydrology
Exploration techniques and interpretation
Drilling techniques
Chemistry of ground water
Radioactive and other tracer techniques
Models and analogues
The use of digital computers
Legislation and administration
Regional geohydrology and aquifer management
Planning of water resources development

3.2 Syllabi

1. *Principles of flow through porous media*
Porous media (the aquifer as an example). The continuum approach. Piezometric head and pressure.

Properties of porous media: permeability, storativity, porosity, hydraulic conductivity. Homogeneity and isotropy. Darcy's law and the solution of one-dimensional flows. The continuity equation and boundary conditions. Method of solutions. Phreatic flows. Unsaturated flows. Fronts. Interface between fluids. Front mixing and hydrodynamic dispersion.

2. *Ground-water hydrology*
Aquifers, classification and properties. Darcy's law. Basic equations of steady and unsteady ground-water flow in aquifers. Phreatic flows. Hydraulics of wells. Techniques of pumping-tests. Coastal aquifers and sea water–fresh-water relationships. Hydrological balances. Interpretation of spring-flow data. Hydraulics of artificial recharge. Underground storage and mixing. The problem of safe yield.

3. *Principles of surface hydrology*
Precipitation. Evaporation and evapotranspiration. Rainfall–run-off relationships. Hydrographs analysis, the unit hydrograph. Flood routing. Statistical techniques of analysis. Synthetic hydrology.

4. *Exploration techniques and interpretation*
Principles of geology. Physical principles, instrumentation and working methods of geoelectric, gravimetric and seismic surveys. The principal methods of well logging. Correlation of geophysical parameters with hydrogeological characteristics. Advantages and limitations of each method in hydrogeological work. Regional hydrogeological reconnaissance.

5. *Drilling techniques*
Mechanical principles of the percussion, rotary and reverse circulation drilling methods. Specifications of bore-holes and casings according to rock types, required depth, depth of water-level and diameter of pump. Types of filters. Specifications for gravel packs. Methods of developing bore-holes for pumping. Mechanical and energy principles of pumping equipment.

6. *Chemistry of ground water*
The more common chemical constituents of ground water and their origin. Various methods of geochemical classification of waters according to natural groups. Application of geochemical classifications to the determination of flow direction and of the origin of ground-water bodies. The problem of base-exchange in a natural environment.

7. *Radioactive and other tracer techniques*
Principles of tracer methods. Advantages and limitations of radioactive tracers. The use of artificial tracers in investigations of surface and ground water. Instrumental methods (snow-gauging and survey, soil moisture, logging). Occurrence and distribution of environmental isotope data in surface- and ground-water investigations. The use of salts and tracers.

8. *Models and analogues*
General. Scaling procedure. The sand box. The Hele–Shaw analogue. The electrolytic tank analogue. The RC-network analogue. Applicability of the various models and analogues.

9. *The use of digital computers*
Computers: types, sizes, speeds, cost, modes of use. Data flow and its organization. Graphics. Statistical analysis of ground-water data. Ground-water budgets. Evaluation of pumping-tests. Steady and unsteady flow problems. Dispersion. Unsaturated flow. Problems in surface flow. Applications to development of water resources, especially ground water.

10. *Legislation and administration*
Water resources and water rights. Allocation of water. Water institutions and administration: government administration, public institutions, water tribunal. Prevention of pollution. Water projects and recharging of water. Prices and other economic problems. Sanctions. Principles of the law for metering water. Principles of the law of drainage.

11. *Regional geohydrology and aquifer management*
The regional approach. Elements of the ground-water balance. Natural replenishment and artificial recharge. Safe yield. Storage and reserves. Management techniques. Quality control.

12. *Planning of water resources development*

4. International Course in General and Applied Hydrology, Madrid

4.1 Curriculum

Climatology
Meteorology
Surface-water hydrology I
Surface-water hydrology II
Applied hydrology
Agricultural hydrology
Forest hydrology
Hydrogeology
Instruments and methods of observation
Geology
Mathematical statistics
Analysis and quality of waters
Applied geophysics

4.2 SYLLABI

1. *Climatology*
General climatology
Temperature
Rainfall
Pressure, wind, humidity and evaporation
Classification of climates
Evapotranspiraiton and evaporation
Aridity, deserts
Microclimatology
Synoptic climatology
Evolution of the climate

2. *Meteorology*
General meteorology
Main concepts of atmosphere dynamics
Kinematical analysis of plane motion of a fluid
Air masses: frontogenesis and frontolysis
Wind alteration by local influence
Sun radiation
Atmosphere thermodynamics
Wet air thermodynamics
Rainfall estimate
Rainfall-duration-area analysis
Meteorology in semi-arid countries
Use and process of rainfall data

3. *Surface-water hydrology I*
Introduction to hydrology
Hydrological cycle
Hydrological balance
Evaporation and transpiration
Basin topography
Basin geography and geology
Hydrographical net
Soil and infiltration
Run-over

4. *Surface-water hydrology II*
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 floods
Short-run forecast for the evolution of flood flows

5. *Applied hydrology*
Mathematical statistics on hydrology
Practice procedures of treatment and processing of hydrological data
Statistic 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

6. *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 requirement for cultivated plants
Measurements of humidity rates and humidity tension in the soil
Water circulation in the soil
Irrigation methods

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

8. *Hydrogeology*
General hydrogeology
Study of porosity
Study of permeability
Study of hydrogeological environment
Water-carrying types
Water-carrying areas
Analysis of ground-water motion
Circulation in a water-carrying layer
Hydraulics of wells
Analogical patterns
Ground-waters intake
Artificial recharge
Karstic hydrogeology

9. *Instruments and methods of observation*
Hydrometeorological instruments and methods of observation
Recording instruments
Rainfall measurement
Flow measurement
Hydrological data statistics
Limnimeters, limnigraphs and mills
Types of stations

10. *Geology*
Cristallography
Knowledge of minerals
Descriptive mineralogy
General petrography
Tectonics
Geochronology

Palaeontology
Stratigraphy
Continental geomorphology
Morphology of limestones and dolomites
Karstical potamology

11. *Mathematical statistics*
General
Theory of probabilities
Alleatory variables
Some classic distributions
Assymptotical distributions
Two-dimensional variables
Sampling theory

12. *Analysis and quality of waters*
Water drinkability
Chemical analysis
Chemical research
Water hardness
Practical studies of water quality
Water biology
Coli group research
Interpretation of results
Applied chemistry and biology

13. *Applied geophysics*
General
Electric method
Geophysical testification
Gravimetrical method
Seismical method
Practical use of geophysical methods

5. International Post-graduate Course in Hydrology, Padova

5.1 Curriculum

Hydrometeorology
Hydrometry
Statistics and probability calculations
Hydrology of surface water
Hydrology of underground water
Open channel hydraulics
River hydraulics
Water resources
Hydraulic models
General culture

5.2 Syllabi

1. *Hydrometeorology*
Analytic and synoptic meteorology
Climatology
Water cycle in the atmosphere
Rainfall
Evapotranspiration
Snowfall
Elements of physical glaciology
Meteorological subsidiaries
World Meteorological Organization

2. *Hydrometry*
Open channels and closed conduits measurements
Particular techniques of measurement especially by means of current meters
Flow measurements by means of dilution methods
Organization of the hydrographic services

3. *Statistics and probability calculations*
Elements of probability theory
Statistical principles and practices in hydrology
Statistics and stochastic processes in hydrology

4. *Hydrology of surface water*
Hydrology of surface water
Hydrogeology of surface water
Elements of physical glaciology
Forest influence on the water régime
New trends in the field of agricultural and vegetable hydrology
Behaviour of lake waters
Tracers and isotopes in the research of surface water

5. *Hydrology of underground water*
Hydrology of underground water
Ground-water flow
Applied techniques in well engineering
Tracers and isotopes in the research of underground water

6. *Open channel hydraulics*
Progress in hydraulics
Uniform flow
Steady or unsteady gradually varied flow in channels
Density currents

7. *River hydraulics*
Principles of river hydraulics
Floods
Mechanics of sediment transportation
Hydraulics, sediment transportation and morphology of river mouths
Continental erosion
Hydrography and hydrology of the Danube

8. *Water resources*
Progress in hydraulics
Evaluation of hydraulic resources of a region
Water-supply and drinking-water distribution
Regulation of hydroelectric power plants with special regard to reservoirs

Irrigation principles and practices
Sewage principles and practices
Hydroelectric power plants
Sea water and brackish water desalination
Water conditioning
Preparation of water development projects
Research methods on hydraulic resources for hydroelectric purposes
Hydroelectric resources and pumping stations in Switzerland

Economics in hydraulic constructions

9. *Hydraulics models*
Hydraulic model analysis
Similitude in sediment transportation

10. *General culture*
Course on the Italian language held in English
Course on the Italian language held in French
Brief history of Italian art

6. Hydrological Data for Water Resources Planning, Prague

6.1 Curriculum

Hydrometeorological and hydrological networks of stations, instruments and methods of measurement
Analysis of hydrometeorological data
Principles of water resources planning
Hydro-power systems development and related hydrological data
Hydrological data for design of water resources projects in agriculture, forestry and soil conservation
Hydrological data for urban water-supply from ground water
Hydrological forecasts
Use of reservoirs for control of river flow
Use of electronic computers in hydrological analysis and processing of data
Principles of radio-isotope techniques and their use in hydrological practices
Model research of river channels and of the run-off process

6.2 Syllabi

1. *Hydrometeorological and hydrological networks of stations, instruments and methods of measurement*
Precipitation
Snow
Evaporation
Soil moisture and infiltration
Streamflow
Water temperature
Freezing of rivers, lakes and reservoirs
Sediment discharge
Ground water and springs
Processing and storage and retrieval of data

2. *Analysis of hydrometeorological data*
Depth area—duration studies
Probable maximum precipitation
Rainfall frequency analysis

3. *Principles of water resources planning*
Economical and technological concept of water management. Institutional arrangements in water management, water management institutions as productive organizations; special features of water management.

Fundamental conditions for planning

Ascertaining of main objectives on water resources development.
Perspective plans of constraints in supply of water resources; perspective plans of water demands; categories of used water, synthesis of available resources and of demands; water-supply for urban purposes; water for agriculture, industry and thermal power production; water for hydro-power production.

Design of water-resources systems

Region of interest; time levels; economic relationship between water demands and water resources; water resources balance; balance of water quality and quantity; water resources development; biological aspects; climatic and technological aspects of water conservation.

Hydrological data needed for planning

Precision, density of networks, qualitative and quantitative analysis.

4. *Hydro-power systems development and related hydrological data*

I. Hydrological data

River categories and their hydrological characteristics; accuracy; potential water power resources and their technical and economic analysis.

II. Design of hydropower systems

Design of hydroelectric power plant parameters; optimum régime of river control in dependence of power systems structure; demand on the degree of flow control in hydroelectric power plants operating in a system with high weight of hydro-plants; with high weight of thermal plants, and approximately equal weights of hydro- and thermal plants; computation techniques of river flow control in a system of storage reservoirs for power purposes; computation scheme for intersystem of flow.

III. Simulation of stochastic hydrological series (generating of data)

Linear dynamic system; frequency characteristics; application of Fourier integral in computing transition

processes; impulse transition function; transformation of input stochastic process to output stochastic process; transformation of white noise.

5. *Hydrological data for design of water resources projects in agriculture, forestry and soil conservation*
Elements of soil-water science; permeability of soils; infiltration; surface run-off from elementary plots; run-off evaluation in small watersheds; water requirements of plants for irrigation purposes.

6. *Hydrological data for urban water-supply from ground water*
Relations between rocks and water; hydrogeological characteristics of the main types of rocks; aquifers and their régime; methods applied in hydrogeological prospecting; protection of ground water; hydrogeological maps.

7. *Hydrological forecasts*
Classification of hydrological forecasts; forecast requirements by different users.

Short-term hydrological forecasts

Hydrometric forecasts. The method of tendencies; linear and non-linear tendencies method of corresponding discharges; division of rivers into forecasting reaches; determination of travel time; relation between corresponding discharges; forecast procedures. Hydrometeorological forecasts. Run-off process; characteristic parameters of the run-off process; computation of parameters; rainfall–run-off relations; graphical and digital presentation; hydrograph forecasts; hydrograph and hyetograph analysis; isochrone method; concentration time; unit run-off areas; run-off distribution curves; time advance of forecast.

Seasonal hydrological forecasts

Snow melt run-off forecasting; discharge forecasts in drought periods.

Long-term hydrological forecasts

Factors influencing the long-term variation of streamflow; relation between precipitation and discharge; effect of geophysical and cosmic factors on variations of rainfall and discharge; use of symmetry of natural phenomena; smoothing of long-term hydrological series of overlapping averages; decomposition of the time series by harmonic analysis; use of sun activity variation.

Forecasts of ground-water levels

Natural changes and interferences in the régime of ground water; classification of forecasts; short-term forecasts; long-term forecasts; hydrological methods; hydraulic methods; laboratory experimental analogue methods; selection of method.

8. *Use of reservoirs for control of river flow*
Selection and processing of hydrological data for the design of reservoirs; water management methods of design of reservoirs according to natural chronological run-off series; water management methods of reservoirs design based on mathematical statistics; reservoirs with short-time run-off control; reservoirs with seasonal (annual) carry-over; reservoirs with carry-over in several years; compensation-type control of the run-off by reservoirs; flood control; safeguarded yield and its influence on the economic effectiveness of reservoirs.

9. *Use of electronic computers in hydrological analysis and processing of data*
Basic information on electronic computers, digital computers, analogue computers, examples of hydrological problems solved with digital computers; elements of programming; use of continuously acting computers for forecasts, solution of non-steady movement.

10. *Principles of radio-isotope techniques and their use in hydrological practices*
Atom and nucleus; radioactivity; interaction of radiation with matter; detection of nuclear radiation; counting statistics; electronic instruments; radio-isotope instruments in field practice.

11. *Model research of river channels and of the run-off process*
Model of river channels and river systems; models of surface run-off in watersheds for forecasting purposes; physical and mathematical models of surface run-off.

5 Examples of syllabi of courses in hydrology

CONTENTS

I. *General hydrology*
  A. Introduction
  B. Surface-water hydrology
II. *Fluid mechanics and hydraulics*
III. *Sediment transport and sedimentology*
IV. *Mathematics in hydrology*
  A. General
  B. Statistics
  C. Stochastic processes
  D. Operation research and systems analysis
V. *Ground-water flow and flow through porous media*
VI. *Ground-water hydrology*
VII. *Geology, hydrogeology, geophysics*
  A. Geology
  B. Hydrogeology
  C. Geophysics
VIII. *Soil science*
IX. *Watershed management and forest hydrology*
X. *Rivers*
  A. General
  B. River hydraulics
  C. Geomorphology
XI. *Reservoir operations and water resources management*
XII. *Hydrometry*
XIII. *Hydrology of special areas*
  A. Urban hydrology
  B. Agricultural hydrology
  C. Coastal areas
  D. Marshes and swamps
XIV. *Special techniques and methods*
  A. Parametric hydrology
  B. Aerial survey
  C. Tracer techniques
XV. *Meteorology*
  A. Meteorology
  B. Climatology
XVI. *Models*
XVII. *Data processing and computer programming*
  A. Data processing
  B. Use of computers
XVIII. *Numerical methods*
XIX. *Water quality and geochemistry*
XX. *Water law*
XXI. *Water engineering*
XXII. *Snow, ice and glaciology*
XXIII. *Man's influence on the hydrological cycle*
XXIV. *Forecasting*

I. GENERAL HYDROLOGY

I. A. INTRODUCTION

I. A. 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 ground water. 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. Ground-water hydrographs. Synthetic hydrographs. Long-term and short-term forecasting of yield and floods. Flood routing.

g. Physical aspects of erosion. Wind erosion.

I. A. 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.

Ground water: 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.

I. A. 3 *Hydrology*
Study of the problems of long-term basin yield and of short-term streamflow prediction from the view point 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.

I. A. 4 *Hydrologic transport processes*
The hydrologic cycle and its interrelations with man; statistical analysis and simulation of hydrologic 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, ground-water recharge, drainage, sea water intrusion in aquifers and estuaries; heat exchange and density stratification in natural waters; thermal pollution control.

I. A. 5 *Applied hydrology*
Hydrologic cycle, meteorology, streamflow, evapotranspiration, hydrographs, run-off relations, run-off hydrographs, ground water, unit-hydrographs, flood routing, frequency and duration studies, and application of hydrologic techniques.

I. A. 6 *Hydrology*
General. Climatology: factors, temperature, pressure, humidity and wind. Descriptive hydrology: precipitation, evapotranspiration, surface water, ground water, water quality, sedimentation, terminology, measurements, classification and generalization). Hydrological studies: principles and methods. Drought and reservoir studies, flood studies, study of the safe yield of a ground-water system, determination and estimation of hydrological losses.

I. A. 7 *Hydrology*
The hydrologic cycle, physics of the air, precipitation, infiltration and soil moisture, run-off, rainfall–run-off relationships and the way that these factors affect utilization and conservation of water resources.

I. A. 8 *Hydrology*
General principles, hydrometeorology, surface hydrology, subsurface water, hydrological cycle. Methods of water resources management. Water balance, precipitation, evaporation, infiltration, run-off; equations for the water balance.

I. A. 9 *Hydrology*
Science of hydrology and application to engineering problems. Hydrologic cycle, evaporation, characteristics of air masses, precipitation, storms, fogs, weather, run-off, unit graph, droughts and flood prediction. Analysis of records in connexion with typical engineering problems, and to recent developments in the hydrologic field.

I. A. 10 *Theoretical hydrology*
Application of mathematical models, theories and analysis to hydrologic problems in hydrometeorology, surface water, ground water and quality of water.

I. A. 11 *Advanced hydrology*
Mechanism, sampling methods and distribution in time and space of precipitation, evaporation, infiltration and water retention.

I. A. 12 *Engineering hydrology*
Study of the hydrologic cycle in its relationship to the development of water resources. Climate, storms, evapotranspiration, river basin mechanics. Run-off, yield, flood analysis and forecasting, soil erosion and sediment transport, quality degradation.

I. A. 13 *Hydrological systems*
A synthesis of the major factors of the atmosphere and lithosphere relating to hydrological systems of the earth. Discussion of the major subdivisions of hydrological systems and their interrelationship and the role of the hydrologist in water resources development.

I. A. 14 *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.

I. A. 15 *Hydrology and climatology*
Relationship between meteorology, surface hydrology and ground-water 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. Ground-water flow and discharge of springs. Darcy's law and applications. Phreatic and piezometric surfaces near wells. Pumping-tests of wells.

I. B. SURFACE-WATER HYDROLOGY

I. B. 1 *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. Hydrograph of precipitation, infiltration, subsurface and surface run-off.

Occurrence of surface run-off. Influencing factors: geographical and geometrical, geographical and physical. Régime 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.

I. B. 2 *Surface-water hydrology*
Theory of the movement and occurrence of water over the surface of the earth. Analysis of hydrologic systems, frequency analysis of rainfall and run-off, flood hydrographs and flood routing, legal aspects of surface water, computer applications.

I. B. 3 *Surface hydrology*
Hydrometeorology, measurement and analysis of precipitation, hydrometry. Rainfall–run-off relations. Statistical analysis of run-off. Storage design, generalizations in surface-water hydrology.

I. B. 4 *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.

I. B. 5 *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.

I. B. 6 *Surface-water hydrology*
Hydrology of surface water. Hydrogeology of surface water. Elements of physical glaciology. Forest influence on the water régime. New trends in the field of agricultural hydrology. Behaviour of lake waters. Tracers and isotopes in research on surface water.

I. B. 7 *Advanced surface hydrology*
Principles of open channel flow (including non-uniform and unsteady flows). Flood routing techniques (in reservoirs and in natural channels). Simulation models on digital computers. Statistical analysis of streamflow (mean, standard deviation, frequency distribution, frequency of peak discharges and of low flows).

I. B. 8 *Advanced surface-water hydrology*
Methods of run-off measurement. Statistical analysis of rainfall and run-off. Methods for estimating design rainfall and design run-off and peak flows. The dimensionless hydrograph. The unit hydrograph and the instantaneous unit-hydrograph. Linear and non-linear rainfall-run-off relationship. The use of the Laplace transform for hydrograph-hyetograph relationships. Synthetic generation of hydrological data.

I. B. 9 *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. Ground water. 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.

I. B. 10 *Estimation of surface-water resources*
Interpretation and classification of surface-water resources, general aspects of inventories. Determination of available water resources of rivers and lakes. Distribution of available water resources over the parts of the catchment area. Interpretation of the dependable and available water resources for sub-catchment areas, importance of the territorial distribution.

I. B. 11 *Floods and droughts*
Flood and droughts. Flood estimation: formulae, frequency analysis, unit-hydrograph method. Flood routing. Flood forecasting. Droughts: distribution, frequency, duration.

II. Fluid mechanics and hydraulics

II. 1 *Fluid mechanics I*
Definitions and properties of fluids. Fluid statics. Kinematics of fluid flow. Basic principles and relations (control volume, control mass analysis, Reynolds' transport theorem, mass and momentum studies at integral and infinitesimal scale, stresses and forces in fluids, Newtonian fluids, Navier–Stokes equations). Dimensional analysis (similitude, analogy). Inviscid flows (Euler's equation, potential flow, complex variables).

Viscous flow (laminar flow, turbulent flow, Reynolds' stresses, flow resistance in closed conduits). Boundary layers (concept, laminar and turbulent boundary layer along flat plates, transition, drag).

II. 2 *Fluid mechanics II*
Free surface flow in rigid channels (classifications, specific energy, hydraulic jump, uniform flow, gradually varied flow). Free surface flow in erodible channels (permissible velocity and tractive force, stable channels). Control sections in open channels (weirs, chutes, spillways, gates). Energy dissipation (stilling basins). Groundwater hydraulics (Darcy's law, flow under structures, steady ditch and well flow, unsteady well flow). Experimentation and model testing in hydraulics.

II. 3 *Fluid mechanics*
Kinematics: particle, mean motion, fluctuations, streamlines, pathlines and types, boundary conditions, material derivative, accelerations, stream function, velocity potential, flux, circulation, vorticity, Kelvin's and Helmholtz theorems, Eulerian and Lagrangean co-ordinates. Theory of functions: analytic function, Cauchy–Riemann theorem, singularities, Laplace equation, conformal mapping, flow net, applications (source, vortex, saddle, flow round cylinder, flow through porous media). Dynamics: Euler's equations, conservation theorems (transport, mass, momentum, angular momentum, energy, generalized Bernoulli), viscous flow, boundary layer, turbulence, Reynolds' stresses, applications. Use of library, periodicals, films, students' seminar.

II. 4 *Unsteady flows of incompressible fluids*
Basic relations. Closed conduits (water hammer and surges). Open channels (small waves, positive and negative surges). Ground water (two-dimensional unconfined flow, confined flow). Boundary layers (boundary layer formation, periodic boundary layers).

II. 5 *Hydraulics*
Principles of the flow of water in open and closed conduits. Steady and unsteady flow. Analysis and design of conveyance and distribution systems. Sediment transport. Hydraulic machinery.

II. 6 *Advanced hydraulics*
Equations of motion of ideal and real fluids. Creeping motion (ground-water flow). Laminar flow in closed conduits. Transition from laminar to turbulent flow. Principles of turbulent flow (Reynolds' stresses, semi-empirical theories of turbulence, universal velocity distribution). Turbulent flow in closed conduits (smooth and rough circular conduits, non-circular conduits). Two-dimensional turbulent free surface flow. Turbulent flow in open conduits. Unsteady flow (navigation locks, surge waves, surge tanks, water hammer).

II. 7 *Advanced hydraulics of open channels*
Steady flow through transitions, obstructions and bends. Unsteady flow in open channels, waves, surges, methods of characteristics and flood routing.

II. 8 *Free surface flow*
The formulation of the free surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels. Theory of small amplitude waves.

II. 9 *Open-channel hydraulics*
Continuity, energy and momentum principles; uniform and non-uniform flow; steady and non-steady flow; friction formulae. Surface profiles including river channels. Flood wave behaviour; flood routing techniques.

III. SEDIMENT TRANSPORT AND SEDIMENTOLOGY

III. 1 *Sediment transportation and sedimentology*
Properties of transported material and water. Initiation of particle motion. Transportation mechanism. Calculation of sediment transport. Sampling techniques. Flow characteristics and sediment transportation. Stable channels.

III. 2 *Sediment transport*
Bed load. Definition. Measurements. Computation of sedimentation and scouring velocities, application in design and practice of reclamation. Context with soil erosion. Computation of bed load discharge and connexion with reservoir silting.

III. 3 *Hydrodynamics of sediment transportation*
A study of the mechanics of the entrainment, transportation and deposition of solid particles by flowing fluids. This will include discussion and interpretation of results of laboratory and field studies of alluvial streams and wind erosion.

III. 4 *Mechanics and sediment transport*
Theories of sediment transport. Transport processes and types of movement. Interrelationship of sediment transport, channel geometry and channel stability in alluvial streams. Applications to river regulation, artificial channels, local scour, deposition in reservoirs, beach processes, etc.

III. 5 *Mechanics of sediment transport*
Measurement and description of sediment characteristics. Mechanics of entrainment, movement, and deposition of sedimentary materials by moving fluids. Analysis of roughness and sediment transport rate of alluvial channels. Design of earth canals. Morphology of rivers.

III. 6 *Sediment transport*
Hydraulics of channels with a movable bed including particle mechanics, critical tractive force theory, the DuBoys problem, the Swiss formulae, Einstein's bed load theory, the suspension and saltation theory, calculation of total sediment loads. Interesting problems in fluvial hydraulics will be included.

IV. Mathematics in hydrology

IV. A. General

IV. A. 1 *Mathematics for hydrology*
a. Partial differentiation. Differential equations. Fourier analysis.
b. Introduction to the theory of complex numbers and to conformal mapping.

IV. A. 2 *Linear systems solutions by transform methods*
Formulation of equations for linear electrical and mechanical systems; application of the Laplace transform for their solution; introduction to the theory of a complex variable and contour integration; the inversion formula and application to partial differential equations.

IV. A. 3 *Mathematics of engineering*
Applications of mathematical methods to engineering problems are considered, involving systems whose mathematical formulation leads to the solution of ordinary differential equations. Topics include infinite series, matrix calculus, ordinary differential equations and special functions.

IV. A. 4 *Mathematics of engineering*
Applications of mathematical methods to engineering problems are considered. Elementary theories and methods of linear partial differential equations are presented. Basic techniques in solving boundary value problems involving potential, heat and wave equations are emphasized.

IV. A. 5 *Mathematics of engineering*
Practical introduction to non-linear differential equations; representative applications; presentation of various analytical methods employed in solution of technical problems taken from fields of electrical, mechanical and civil engineering. Topological, operational, Poincaré, van der Pol, and Kryloff–Bogoliuboff methods; technical problems.

IV. B. Statistics

IV. B. 1 *Statistics in hydrology*
Types of hydrological data, classification and graphical representation of data. Elementary theory of probability. Theoretical frequency distributions. Applications of the binominal, Poisson, normal, hypergeometric, multinomial, lognormal, Pearson III, and Gamma-distributions. Plotting of data on probability papers and other types of technical papers. Sampling theory for large and smaller samples. Regression and correlation analysis with applications to hydrology. Testing of hypothesis, the chi-square distribution, maximum likelihood methods. The theory of extreme values as applied to the study of flood and droughts.

IV. B. 2 *Statistics*
Observation and measurement of hydrological phenomena. Possibilities and methods of their processing. Statistical variables and statistical series. Empirical and theoretical frequencies, probability of occurrence of hydrological phenomena. Theoretical frequency distributions. Numerical methods of computations. Correlation. Graphical interpretation and anamorphosis.

IV. B. 3 *Statistics*
Statistical variables; frequency and probability; measures of central tendency, skewness and variability; moments; probability distribution; correlation and regression; mass curves; tests of significance; degree of freedom; introduction to frequency analysis, correlation analysis and the analysis of variance.

IV. B. 4 *Engineering probabilistics and stochastics*
Sets and set algebra: sample spaces; combinatorics; absolute and conditional probability; discrete and continuous random variables; probability distribution, increment and density functions; Chebychev's inequality; Laplace–Fourier transforms; law of large numbers; central limit theorems; discrete and continuous stochastic processes.

IV. C. Stochastic processes

IV. C. 1 *Stochastic processes*
Various types of hydrological sequences: periodic series, almost periodic series, ergodic and non-ergodic, stationary and non-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.

IV. C. 2 *Stochastic processes in linear systems*
Formulation and solution of equations of behaviour of lumped and distributed linear electrical, rigid- and fluid-mechanical, and thermal systems with stochastic (i.e. chance) excitation, or system change, and response. Emphasis on functional transform methods and on duality.

IV. D. Operation research and systems analysis

IV. D. 1 *System simulation and synthesis*
Theory and methods applicable to the simulation and synthesis of a wide range of systems characterized by deterministic and inherent stochastic elements. Microscopic simulations, macroscopic simulations. Simulation languages. System identification techniques. Applications to simulation and synthesis of representative systems.

IV. D. 2 *Techniques of system optimization*
Theory, evaluation and computer applications of mathematical techniques for optimization with and without constraints. Advanced linear, quadratic and non-linear programming and stochastic processes. Applications to systems optimization problems.

IV. D. 3 *Environmental systems analysis*
Structuring and solution of mathematical programming models with emphasis on linear programming and its extensions. Introduction to Lagrangean multipliers, dynamic programming, queuing theory and game theory. Application of systems analysis techniques to the solution of complex environmental engineering-economic problems.

IV. D. 4 *Dynamic elements of operational systems*
Basic theoretical models applicable to general large-scale stochastic systems. Linear-system approximations, applications to a wide range of system types.

IV. D. 5 *Simulation of water resource systems*
Simulation of hydrologic inputs to water resource systems and the physical and economic response of such systems. Use of simulation as a complement to analytic techniques in the design and operation of water resource systems. Examination of the net-benefit response surfaces by random and uniform grid sampling, method of steepest ascent and other optimizing techniques.

V. GROUND-WATER FLOW AND FLOW THROUGH POROUS MEDIA

V. 1. *Principles of flow through porous media*
Porous media (the aquifer as an example). The continuum approach. Piezometric head and pressure. Properties of porous media: permeability, storativity, porosity, hydraulic conductivity. Homogeneity and isotropy. Darcy's law and the solution of one-dimensional flows. The continuity equation and boundary conditions. Methods of solutions. Phreatic flows. Unsaturated flows. Fronts. Interface between fluids. Front mixing and hydrodynamic dispersion.

V. 2 *Flow through porous media*
The continuum approach. Porosity and saturation. Motion and mass conservation equations. Flow of incompressible fluids. Permeability and hydraulic conductivity. Anisotropy. Wettability. Capillary pressure. The sharp interface approximation for miscible and immiscible fluids. Initial and boundary conditions. Mathematical statement of single and multiphase flow problems. The Buckley–Leverett approximation. Inhibition. Miscible displacement. Instability and fingering.

V. 3 *Flow through porous media*
Introduction. Physical phenomenon of the flow of viscous liquid through a porous medium. Fundamental laws. Mathematical treatment of a number of frequently occurring flow problems. One-, two- and three-dimensional flow; phreatic, confined and semi-confined ground water; permanent and non-permanent flow. Various methods of studying problems: graphical methods; use of images, numerical analysis; conformal mapping; model experiments. Discussion of some practical problems: seepage through dams; leakage from reservoirs; flow into wells; dewatering of construction sites; upward seepage of ground water in low areas; salt water intrusion.

V. 4 *Theory of flow through porous media*
Theory of miscible and immiscible fluid displacement processes within porous media; derivation and solution methods for equations describing flow; appropriate linearization of flow equations, representation as a hyperbolic system, numerical solutions, problems in stability of fingering, statistical hydrodynamics, capillarity.

V. 5 *Flow in porous media*
Hydrodynamics of flow through porous media with emphasis on physical processes involving resistance and dispersion. Basic media characteristics in relation to transport phenomena. Analysis of steady and unsteady flow problems in confined and free surface aquifers. Multiple phase flow, miscible fluid displacement and mixing. Applications in the field of ground-water flow including seepage in embankments, extraction and recharge of ground water, water quality and saline intrusion.

V. 6 *Flow through porous media*
Treatment of steady and unsteady flow through porous media from a theoretical point of view; examination of the assumptions underlying the development of the governing field equations; emphasis on solutions by complex variables, matrix mathematics and experimental models and analogue.

V. 7 *Porous media flow*
Mechanics of flow through porous solids. General equations of single phase and multiphase flow and methods of solving the differential form of these equations. Hydraulics of wells, of infiltration and of ground-water recharge and of other steady state and transient seepage problems in fully and partially saturated materials.

V. 8 *Flow in porous media*
Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, of infiltration and of ground-water recharge, and of other steady state and transient seepage problems.

V. 9 *Flow of permeable media*
Fluid mechanics of subsurface flow. Basic concepts, Darcy's law, potential flow theory with application to ground water and seepage flow. Formulation of boundary value problems and solution by analytical and computer techniques.

V. 10 *Saturated flow in porous media*
Hydrostatics and hydrodynamics in porous media. Darcy's law and its extensions. Flow net. Equations of flow, continuity and compressibility. Boundary and initial conditions. Hodograph of solution: direct, indirect, theory

of functions, numerical and graphical methods, models and analogies, one-, two-, three-dimensional and axi-symmetric examples. Approximations of Dupuit and Boussinesq; homogeneous, heterogeneous, layered, anisotropic, unsaturated media. Applications in hydraulic engineering (dams, seepage), agriculture, soil mechanics.

V. 11 *Unsaturated flow in porous media*
Water retention in soils. Measurement of potential. Flow processes and the differential equations of continuity. Applications to front movement. Field capacity. Drying. Drainage of water in various transport phenomena. Kinetic principles of flow in soils.

V. 12 *Unsaturated flow in porous media*
Multiphase flow through homogeneous and stratified porous media: similitude for flow of fluids in multiphase systems: applications to flow above the water-table in earth materials.

V. 13 *Laboratory for flow through porous media and ground-water hydrology*
Determination of rock properties (porosity, permeability, dispersitivity, pore-size distribution). Capillary pressure. Relative permeability (for unsaturated flow). Use of models and analogues (sand-box model, Hele–Shaw analogues, electrolytic tank analogue, RC-network analogue).

VI. Ground-water hydrology

VI. 1 *Geophysical aspects of ground-water hydrology*
a. Introduction. Appraisal of ground-water resources.
b. Recapitulation of geology. Permeability of rocks. Structural geology.
c. Aquifers. Origin and occurrence of ground water. Aquifers in geological structures. Hydrologic properties of various pervious materials.
d. Prospecting methods. The use of various geophysical exploration methods in geohydrology. Geoelectrical prospecting; the resistivity method and its use and application in water supply geophysics. Location of ground-water reservoirs.
e. Seepage. Prediction of the amount of seepage. Practical consequences of seepage in reclamation works. Seepage of saline ground water.
f. Conservation and use of ground water. Ground-water mapping. Exploitation; safe yield. Purpose of artificial recharge.

VI. 2 *Ground-water hydrology*
Definitions. Occurrence. Advantage as a water resource. Classification of aquifers. Ground-water movement. Darcy's law. Anisotropy. Continuity equations. Boundary conditions. Mathematical statement of ground-water 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 ground-water balances. Artificial replenishment of aquifers. Surface and subsurface exploration methods. Sea-water intrusion and hydrology of coastal aquifers.

VI. 3 *Ground-water hydrology*
Theory of the movement and occurrence of water in subterranean aquifers, hydrodynamics of flow through porous materials, quality of ground water, legal aspects of ground water and computer applications. Conjunctive management of ground-water basins.

VI. 4 *Ground-water hydrology*
Occurrence of ground water. 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.

VI. 5 *Ground-water hydrology*
Ground-water hydrology and hydraulic occurrence, distribution and movement of ground water; exploration; well construction and development, legal and economic aspects.

VI. 6 *Ground-water hydrology and hydraulics*
Occurrence and movement of ground-water, determination of hydraulic characteristics of the ground-water reservoir with emphasis on non-equilibrium methods, interrelationship of surface-water bodies and the ground-water reservoir, and evaluation of ground-water problems, including salt-water encroachment, depletion of ground-water reserve, temperature rise due to recirculation of spent cooling water, river infiltration, and industrial contamination.

VI. 7 *Advanced ground-water hydrology*
The aquifer. The continuity approach. Equations of motion and continuity. Anisotropy and directional permeability. Inhomogeneity. Boundary and initial conditions. The phreatic surface. Mathematical statement of ground-water flow problems. Methods of solution. The description of boundaries in the hydrograph plane. The aquifer flow approximation. The Dupuit approximation. Pumping-tests in leaky and confined aquifers. Hydrologic boundaries. Partially penetrating wells. Multiple well systems. The ground-water contour map. Ground-water exploration techniques. Regional ground-water balances. The interface in coastal aquifers. Artificial recharge: objectives; techniques; front movements, mixing. Hydrodynamic dispersion. Models and analogues. Aquifer management as part of a water resource system.

VI. 8 *Estimation of ground-water resources*
Interpretation and classification of ground-water resources, ground-water investigations. Applied hydrology, geophysical aspects, surface and subsurface investigation of ground water. Well hydraulics. Theory and experiment in the study of ground-water movement. Conformal mapping, sand models, electrical analogues. Estimation of total and available ground-water resources, the

concept of safe yield and the mining of ground water.

VI. 9 *Technical aspects of ground-water hydrology*
a. Introduction. Theoretical formulae for the drawdown curves of galleries, single wells, well systems and polders, for confined and unconfined flow, with different geohydrological conditions.

b. Practical aspects of the flow of ground water to wells, analysis of test pumpings with steady and unsteady flow.

VII. Geology, hydrogeology, geophysics

VII. A. GEOLOGY

VII. A. 1 *Geology*
Cristallography. Knowledge of minerals. Descriptive mineralogy. General petrography. Tectonics. Geochronology. Palaeontology. Stratigraphy. Continental geomorphology. Morphology of limestones and dolomites. Karst potamology.

VII. A. 2 *Physical geology*
An introduction to the basic principles of the earth sciences, geology, geochemistry and geophysics in relation to materials and processes acting upon and within the earth. Consideration is given to: rocks and minerals; structure and deformation of the earth's crust; earthquakes; volcanism; and the work of wind, running water, the oceans and glaciers upon the earth's surface.

VII. A. 3 *Geology for the hydrologists*
Composition and texture of rocks in relation to the processes which lead to their origin, transformation and destruction. Description of 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, faultering, jointing. Influence of various processes on strength and permeability of rocks. Some aspects of hydrogeology are reviewed, in particular with respect to geochemistry. Test cases which illustrate various hydrogeological features.

VII. B. HYDROGEOLOGY

VII. B. 1 *Ground-water geology and prospect for ground water*
Pervious, impervious and semi-pervious rocks. The influence of sedimentation on the distribution of porosity. Primary and secondary porosity. Fissured rocks, karstic aquifers. The influence of structure on the formation of aquifers. Considerations in selecting well sites. Methods of ground-water prospection. Discussion of case histories.

VII. B. 2 *Hydrogeology*
Hydrological properties of various rocks. The influence of geological structure on the flow of ground water. Bore-holes (siting, execution, supervision). The problem of karstic erosion. Hydrogeological surveys. Ground-water balances. The problem of the 'safe yield'. Exploitation of reserves. Artificial replenishment and underground storage. Salinization by sea-water encroachment and by other factors. Regional hydrogeology.

VII. B. 3 *Hydrogeology*
General hydrogeology. Study of permeability. Study of hydrogeological environment. Water-carrying types. Water-carrying areas. Analysis of ground-water motion. Circulation in water-carrying strata. Hydraulics of wells. Ground-water intakes. Artificial recharge. Karstic hydrogeology.

VII.B. 4 *Hydrogeology*
Occurrence of ground water. Ground-water flow. Techniques of assessing water resources. Examples of specific aquifers. Hydrochemistry. Recharge. Ground-water development. Arid zone problems.

VII. B. 5 *Drilling techniques*
Mechanical principles of percussion, rotary and reverse circulation drilling methods. Specifications for bore-holes and casings according to rock types, required depth, depth of water-level and diameter of pump. Types of filter. Specifications for gravel packs. Methods of developing bore-holes for pumping. Mechanical and energetic principles of pumping equipment.

VII. C. GEOPHYSICS

VII. C. 1 *Geophysics*
Review of the various prospecting methods. Seismic refraction method. Electrical resistivity method, its use and application in ground-water studies. Ground-water quality and mapping of ground-water reservoirs. Mathematical and physical interpretation, case histories. Well-logging methods.

VII. C. 2 *Exploration techniques and interpretation*
Principles of geology. Physical principles, instrumentation and working methods of geoelectric, gravimetric and seismic surveys. The principal methods of well-logging. Correlation of geophysical parameters with hydrological characteristics. Advantages and limitations of each method in hydrogeological work. Regional hydrogeological reconnaissance.

VIII. Soil science

VIII. 1 *Soil science*
a. Chemical and physical properties of soils; soil organic matter; soil organisms; soil moisture relationships; soil structures.

b. Soil formation; soil mapping; soil classification. Land classification.

c. Conservation of soil fertility; erosion control, soil improvement.

d. Pedology and agrohydrology.

VIII. 2 *Soil science I*
Soil formation and composition, and the chemistry and physics of soils in relation to soil fertility. Topics considered include: soil genesis, distribution of the major soil types of the world; composition of the inorganic and organic fractions of soils; clay mineralogy; chemistry of the plant nutrients in soils· the nitrogen cycle; air and water movements in soils; the physics of irrigation and drainage; soil erosion.

VIII. 3 *Soil science II*
The genesis and composition of clay minerals in different soil types; the reaction of ions and water at the surface of colloidal particles, and the influence of these reactions on the physical and chemical properties of soils, particularly the potential and capacity of the soil to provide the major plant nutrients and trace elements; the diffusion of ions in soils and the chemistry of nutrient uptake by plants; the composition of the organic colloids and the kinetics and biochemistry of organic matter transformations; soil organisms; theories of the flow and diffusion of air and water in porous materials, and their application to infiltration, permeability and other irrigation and drainage problems, mechanisms of aggregate formation and breakdown in soils in relation to soil fertility.

VIII. 4 *Soil physics*
Soil structure, compaction, tilth, tillage; water infiltration, retention, availability, movement, and evaporation; heat capacity, flow; air porosity, diffusion, deficiency effects on plants, drainage requirements.

VIII. 5 *Soil mechanics*
Introduction. Index properties and classification of soils. Soil compaction. Soil structure. Soil moisture. Effective stress concept. Capillarity and shrinkage. Water flow in soils and permeability. Compressibility and consolidation of soils. Shear strength of soils.

VIII. 6 *Seepage and consolidation*
Steady and unsteady seepage of water through porous incompressible media. Analytical, numerical and graphical methods for solution of practical problems. One-dimensional consolidation of clays. Non-homogeneous strata. Moving boundary problems. Three-dimensional consolidation; theories of Terzaghi and Biot. Design of sand well installations. Secondary consolidation.

VIII. 7 *Seepage and capillarity*
Detailed analysis of water movement problems associated with gravity and capillary flow. Topics include flow nets, pore water pressures, creep and piping, critical gradients, capillarity, sorption pressures, soil moisture tension, frost-forming processes and theoretical approaches to ice crystal growth.

VIII. 8 *Soil properties*
The principle of effective stress in saturated and partly saturated soils. Deformation and pore-pressure changes in soil under stress. The measurement of pore pressure, shear strength and deformation in the laboratory; the triaxial apparatus, shear box, torsion shear and vane tests. Failure criteria in terms of total and effective stress.

VIII. 9 *Physical chemistry of soils*
Selected topics in physical chemistry as related to soils. Electrokinetic phenomena, colloidal behaviour, interactions of organic and inorganic soil materials.

VIII. 10 *Physics and chemistry of soils*
Applications of developments in soil physics, soil chemistry, clay mineralogy, particle mechanics and soil mechanics. Particle dynamics, size frequency relations, packing, pressure, diffusion, thermo transport phenomena and weathering.

VIII. 11 *Site investigation and field measurements*
Ground-water conditions. The response time of piezometers and the *in situ* measurement of permeability and consolidation characteristics. The instrumentation of earth and rockfill dams, and the measurement of pore pressure, total stress and deformation in the field.

IX. Watershed management and forest hydrology

IX. 1 *Hydrology and watershed management*
Importance of water. Historical review. Relation of hydrology and watershed management with other sciences. The hydrological cycle. Water in the air (air humidity, condensation, precipitation, interception, evaporation). Water on the surface (surface run-off, channel run-off). The subsurface water (hygroscopic water, capillary and gravity water). Measurement methods and means in hydrological works. Water losses and floods. Relations of hydrology to the vegetation, especially forest vegetations. Present land use and land capability classification. Ranges, forests, cultivated lands and waste lands. Causes of deterioration of watersheds. Planning of watershed development with examples and applications, especially in arid regions.

IX. 2 *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.

IX. 3 *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.

IX. 4 *Applied watershed management*
Techniques of managing wildlands for increases in usable water yields, protection of watershed values, and rehabilitation of depleted watershed lands.

IX. 5 *Applied watershed management laboratory*
Field observation and planning relating to application of watershed management techniques for increasing water yields, watershed protection and rehabilitation of depleted watershed lands.

IX. 6 *Watershed analysis*
Techniques, information sources, and field collection of data for a comprehensive analysis of a small watershed.

X. Rivers

X. A. General

X. A. 1 *Introduction to rivers*
Introduction, types and dimensions of rivers, morphological and régime factors. Water discharge, measuring instruments and methods, two- and three-dimensional flow current pattern, eddies and spiral flow, formulae. Transport of solid matter, measuring instruments and methods, formulae, bed-formation and equilibrium. Introduction to river morphology, meandering and braiding of channels.

X. B. River hydraulics

X. B. 1 *River hydraulics*
Principles of river hydraulics. Floods. Mechanics of sediment transportation. Hydraulics, sediment transportation and morphology of river mouths. Continental erosion. Hydrography.

X. B. 2 *Advanced hydraulic engineering*
Selected topics in morphology of natural channels. Flood control. Multiple purpose dams. Sediment transport. Sedimentation basins. Design of earth dykes. Protection of channels and streams against erosion. Scouring around structures. Control structures. Integral planning of waterworks.

X. C. Geomorphology

X. C. 1 *Geomorphology*
Evolution of landforms. Weathering processes. Slopes and their development. Landforms created by rivers. Geomorphology of limestone areas. Landforms developed under arid conditions. Glaciers and glacial landforms. Landform types, classification. The use of geomorphological maps. Principles of geomorphological photo-interpretation (static and dynamic aspects). Qualitative and quantitative interpretation. Importance of photo-scale, emulsion type, etc. Photogeomorphology and the appraisal of water resources.

X. C. 2 *Catchment characteristics*
Geological factors and their effect on surface and subsurface water. Genesis and development of drainage networks. Geomorphological characteristics. The geology of the country. Soils—origin, composition, classification and structure. Soil moisture—retention; movement. Soil profiles and their effect on water movement. The soils of the country. Vegetation—hydrological aspects of the plant–water relation. The vegetation patterns of the country.

XI. Reservoir operations and water resources management

XI. 1 *Reservoir operations*
Assignment, types and main characteristics of water storage reservoirs. General requirements for the design of flood control and the water conservation reservoirs. Characteristic water-levels and their maintenance. Analysis of factors affecting the operation of reservoirs. Basic hydrological data for computation of reservoir operation, water management and economical considerations. Variability of flow, its presentation by hydrograph and change of flow. Use of the computation of reservoir operation if none is available. Ice, temperature, water quality and currents in the reservoir. Influence of heat storage into the reservoirs on the surroundings. Sedimentation of reservoirs. Yield of suspended bed load. Calculation of siltation and dead volume. Calculation of distance from entrance into the reservoir of the transported material to the point of settling. Water losses from the reservoir. Evaporation, losses due to the formation of ice. Infiltration losses. Effect of reservoirs on flood waves. Numerical and graphical presentation of hydrographs, duration curves and mass inflow and mass outflow curves. Mass curve in rectangular co-ordinate system, reduced mass curve and skew co-ordinate system.

Graphical procedure for mass curve construction from a kown hydrograph. Reservoir operation for the design purposes by analysis of hydrograph, duration curve and mass curve. Numerical procedure for reservoir operation in both cases where water surface area is either constant or variable in size. Reservoir operation by statistical methods for single and multiple purpose reservoirs. Constant and variable draft of water. Probability of water-supply and flood protection. Analysis of potentialities and requirements. 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. Duration–area curve. Pondage problems. Determination of time needed for filling a reservoir. Water-supply along the natural river-bed from the compensating reservoir to the intake structure during summer and winter periods. Design of the freeboard above maximum still water level for design of a dam. Wind waves and set-up in reservoirs.

XI. 2 *Hydraulic engineering and hydrology*
Precipitation, measurements and analysis. Relationships between precipitation and run-off. Evaporation, evapotranspiration. Infiltration into the ground. Surface run-off. Determination of discharge and flood flow. Flow

measurement in watercourses. Hydrographs and their analysis. Underground water sources and their use. Ground-water balance. Exploration methods for ground water. Flow of ground water. Wells and well discharge. Pumping-tests. Lowering of ground-water level. Sea water intrusion. Dynamics of watercourses. Principles and methods of wa rcourse development. Erosion, movement and deposition of material in watercourses. Principles of reservoir design. Purposes of dam building. Hydrological, geological and other considerations. Types of dams. intakes and spillways. Examples of hydraulic works.

XI. 3 *Water resources development*
Definition of resources, water and related resources, over-all and general considerations and principles in water resources development, phases of development, techniques of river basin planning, multiple purpose use concept, techniques of river-development schemes, allocation of cost, repayment, organizational set-up of water resources development, operation and maintenance.

XI. 4 *Ground-water systems*
Characteristics of complex combined ground-water/surface-water systems: deterministic and stochastic imputs and responses; error and sensitivity analyses; application of optimization techniques.

XI. 5 *Water resources systems engineering*
Deterministic and probabilistic analysis of hydrologic, water-supply and waste-water treatment systems using mathematical techniques such as simulation, linear and dynamic programming and queuing theory. Conjunctive utilization of surface-water and ground-water systems.

XI. 6 *Water resource systems*
General principles of the application of system analysis to problems in water resource engineering. Water resource 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.

XI. 7 *Environmental systems analysis*
Advanced topics in the application of mathematical programming and probability theory to the solution of environmental engineering problems. Special emphasis on water resource systems planning and management.

XI. 8 *Water resources engineering*
Basic concepts of water resources planning; water inventories, use and control; water conservation measures and legislation; multiple purpose project planning, domestic and foreign water-development projects; simulation optimization and dynamic programming studies.

XI. 9 *Analytical methods in water resources engineering*
Classical methods of optimization. Queuing theory and its application in water storage. Markov chains and their use in operation of reservoirs. Application of linear programming in the design of water resource systems. Use of PERT. Dynamic programming and its applications to the design and operations of complex resource systems.

XI. 10 *Water resources engineering*
Probability analysis of hydrological data. Theory of storage and operation of reservoirs. Generation of hydroelectric power. Economic factors affecting the design of water resources systems. Operation of water resources systems. Multipurpose projects. Water laws.

XI. 11 *Hydrology of land drainage*
Hydrology of subsurface land drainage. Hydrology of surface land drainage. A systems engineering approach of the influenced concentration of waters in flat areas. The relationship between land drainage hydrology and feasibility studies concerning land drainage. The aims of research work in the field of hydrology of land drainage.

XI. 12 *Irrigation engineering*
a. Introduction: necessity and importance of irrigation; types of irrigation; water requirements of crops; duty.

b. Hydrology: rainfall and run-off; rain-gauges; run-off calculation by empirical methods; run-off tables; flood discharge and its estimation by gauges; estimation of peak flood; hydrograph; unit-hydrograph.

c. Water losses: percolation and seepage; evaporation and absorption losses in canals and in storage systems; evaporation reduction.

d. Silt and scour: Kennedy's theory; Lacey's theory; prevention of silt deposition in canals and reservoirs; silt vanes; scour and protection from scour.

e. Head works: weirs; weirs on pervious foundations uplift and piping; Blight's creep theory; Khosla's theory; effect of construction of hydraulic structures on the régime of a river.

f. Storage works: masonry dams; foundation treatment; overflow and non-overflow sections; simple design problems; earth dams; selection of site; method of construction; causes of failure; surplusing arrangements; tank bunds; tank weirs.

g. Distribution systems: canals; design and alignment; main canals and distributaries; lining of canals; construction of masonry works in canals; canal drops; cross drainage and surplus works; aqueduct; syphon aqueduct; superpassage; syphon; level crossing; bridges.

h. River training works: spurs; groynes; Bell's bunds; mattresses and aprons.

XI. 13 *Engineering operations*
a. Principles of engineering economy. Comparative cost. Interest rate. Depreciation.

b. Social and economic aims of projects. Economic versus financial analysis. Analysis of cost and benefits. The 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 resources activities. Development aid policy. Sources of assistance for water development projects in developing countries. The operations of the World Bank, the United Nations Development Programme, the regional organizations and bilateral schemes.

XI. 14 *Economics of natural resources*
Analysis of natural resources development and utilization. Project evaluation, water rights, land ownership, taxation, land use controls, planning; organizational decision-making—resource institutes and public policy. Concepts of economic efficiency applied to natural resource problems, emphasizing the activities of government agencies; use of operations research techniques and economic welfare criteria in estimating project benefits and costs.

XII. Hydrometry

XII. 1 *Hydrometry*
Open channel and closed conduit measurements. Measuring techniques especially by current meters and with a dilution method. Organization of the hydrographic services.

XII. 2 *Instruments and methods of observation*
Hydrometeorological instruments and methods of observation. Recording instruments. Rainfall measurement. Flow measurement. Hydrological data statistics. Limnometers and limnographs. Types of gauging stations.

XII. 3 *Stream-flow measurement*
Measurement of stage—methods and instruments. Gauging stations; controls; site selection. Measurement of flow—methods and equipment; site selection. Current meter gauging—types, procedures; recording and processing of observations. Other methods of determining discharge—orifices, weirs, gates, spillways, venturi meters, flumes, slope-area, contracted opening, floats, headrod, tracer methods. Stage-discharge relation—construction; correction; extrapolation; rating tables. The processing and tabulation of streamflow data.

XII. 4 *Hydrometry*
Hydrometrical stations. Measurement of water stages, measurement of discharges. Current meters, theory and practice of measurement. Rating curve. Computation of discharges by means of formulae.

XIII. Hydrology of special areas

XIII. A. URBAN HYDROLOGY

XIII. A. 1 *Urban hydrology*
To indicate the special features of urban run-off and to give a background for the design of urban drainage systems. 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 graph of the Chicago method.

XIII. A. 2 *Urban hydrology*
Urban climate, urban development and its effect on water resources; design of storm-water drainage systems; sewers and storm-water inlets.

XIII. B. AGRICULTURAL HYDROLOGY

XIII. B. 1 *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.

XIII. C. COASTAL AREAS

XIII. C. 1 *Hydrology of coastal areas*
Hydrology of coastal areas. Sources of salt. Measures to combat salt intrusion. Reservoirs in coastal areas; water and salt balance.

XIII. D. MARSHES AND SWAMPS

XIII. D. 1 *Stagnant water and marshes*
Stagnant water and marshes. Definition. Temperature and dynamical phenomena in reservoirs. Connexion with melioration works, irrigation and drainage works. Physical properties of water in ponds. Marshes and peat banks. Hydrological data for their drainage.

XIV. Special techniques and methods

XIV. A. PARAMETRIC HYDROLOGY

XIV. A. 1 *Hydrologic and hydraulic system analysis*
Theory and application of the methods and techniques of modern system analysis to hydrologic and hydraulic systems; emphasis on current developments in parametric hydrology and on application of control theory to water-supply and distribution projects.

XIV. A. 2 *Dynamics of the flow systems of the earth*
Systematic study of the physical and mathematical principles of flow systems as influenced by environmental factors of the earth. Application of classical, numerical and computer mathematics and solution to flow and frictional flow systems manifested by surface-water and ground-water movement in and on the earth.

XIV. A. 3 *Parametric hydrology*
Rainfall–run-off relationships. The systems engineering approach; catchment modelling and parameter fitting. Flow forecasting.

XIV. B. AERIAL SURVEY

XIV. B. 1 *Aerial survey*
How an area is covered 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. Spatial triangulation principle. Flight planning in connexion with application of the photographs for civil engineering.

XIV. B. 2 *Airphoto-interpretation*
Principles and practice of using aerial photographs to obtain information about natural features of the earth's surface, with emphasis on earth materials. Relationships of landforms, geological processes, rocks and soils. Use of stereoscopic photographs; elements of photogrammetry.

XIV. C. TRACER TECHNIQUES

XIV. C. 1 *Radioactive and other tracer techniques in hydrology*
Principles of tracer methods. Advantages and limitations of radioactive tracers. The use of artificial tracers in investigations of surface and ground water. Instrumental methods (snow gauging and survey, soil moisture, logging). Occurrence and distribution of environmental isotope data in surface- and ground-water investigations. The use of salts and other tracers.

XIV. C. 2 *Nuclear hydrology*
Applications of nuclear methodology and techniques to hydrologic investigations and measurement devices in hydrology; radiotracer investigations of surface- and ground-water flow and transport; future of nuclear explosives in water resource development; transport of radioactive materials in water.

XV. METEOROLOGY

XV. A. METEOROLOGY

XV. A. 1 *Meteorology*
a. General survey; accuracy, unit systems.

b. Composition of the atmosphere; basic thermodynamics of dry and moist air; adiabatic motion, potential temperature, conservatism; condensation and evaporation of droplets, condensation nuclei, latent heat; moisture variables; radiation.

c. Meteorological instruments; response theory, thermometers, radiation meters, hygrometers, rain-gauges, wind meters; instrument exposure. Cloud radar; radiosonde; pressure meters.

d. Vertical structure of the atmosphere; dry- and moist-adiabats; p-T-diagram. Condensation level; vertical stability; formation of precipitation; stratiform and cumuliform clouds, thunderstorms; artificial precipitation.

e. Horizontal air motion and pressure gradient; temperature effect, sea breeze; convergence and divergence; Coriolis acceleration, Buys–Ballow law; general atmospheric circulation; fronts, depressions generation; weather map; orographic effects; monsoons, climatology; tropical cyclone, tropical weather.

f. Vertical transport of water vapour: turbulent motion; averaging periods; Reynolds stress, turbulent flux; eddy viscosity, drag coefficient, Richardson number, logarithmic wind profile, roughness length, power law; evaporation formulae of Thornthwaite–Holzman, Deacon-Swinbank, Dalton and Langbein; Bowen ratio-energy balance; Penman; use of atmometers and evaporation pans; practical comparison of methods.

XV. A. 2 *Meteorology*
General meteorology. Main concepts of atmosphere dynamics. Kinematical analysis of plane motion of a fluid. Air masses: frontogenesis and frontolysis. Wind alteration by local influences. Sun radiation. Atmospheric thermodynamics. Wet-air thermodynamics. Rainfall estimate. Rainfall-duration–area analysis. Meteorology in semi-arid countries. Use and processing of rainfall data.

XV. A. 3 *Meteorology*
Atmosphere, air humidity, evaporation. Evaporation from free water surface—definition, measurement, computations based on evaporation and meteorological elements. Soil evaporation. Plant evaporation and transpiration. Evapotranspiration. Measurements. Computations for irrigation needs. Evaporation control from free water surface and restriction of irrigation water losses.

XV. A. 4 *Meteorological hydrology*
Meteorology: the atmosphere and atmospheric moisture; forms of water in the troposphere; formation of precipitation. Major weather types producing precipitation. Physics of evaporation: radiation; transport mechanisms; formulae.

Applied hydrometeorology: measurement of precipitation, design of precipitation networks, precipitation data processing, total precipitation on an area.

Climatology: world distribution of precipitation with special reference to seasonal variation and duration; rainfall intensities.

Trends and reliability. Classification of climates.

Special topics: intensity-duration-frequency relationships; depth–area–duration analyses, storm maximization.

XV. A. 5 *Hydrometeorology*
Analytic and synoptic meteorology. Climatology. Water cycle in the atmosphere. Rainfall. Evapotranspiration. Snowfall. Elements of physical glaciology. Meteoro-

logical agencies. World Meteorological Organization.

XV. A. 6 *Agrometeorology*
General meteorology: energy exchange by radiation, solar radiation and energy balance of the earth; air flow; cyclones and anti-cyclones; air masses and fronts; atmospheric stability, climatic regions of the world. Micrometeorology: long-wave radiation; radiation balance, wind profile; Richardson number; turbulent transfer of heat and mass. Energy balance. Application: evaporation; frost; wind-breakers.

XV. A. 7 *Precipitation*
Formation, forms and types. Rainfall: measurement; description and installation of gauges; collection of data. Analysis: mass curves, mean depth, depth–area–duration and intensity–duration–frequency relation. Snow: characteristics; measurement; surveying; analysis. Precipitation in the country.

XV. A. 8 *Precipitation*
Definition, occurrence, classification. Measurements. Rainfalls. Processing of storms, determination of supplementary intensities. Dew, snow. Processing of precipitation at one station. Processing of precipitation within the catchment area and in the network. Distribution of precipitation in the country and its relation to land management.

XV. A. 9 *Evapotranspiration*
Analysis and prediction of evapotranspiration. Influence of climate, vegetative cover and soil on crop water use. Field and laboratory techniques of measuring evaporation radiation, sensible heat fluxes, and determination of profiles of temperature, humidity and wind.

XV. B. CLIMATOLOGY

XV. B. 1 *Climatology*
General climatology. Temperature. Rainfall. Pressure, wind, humidity and evaporation. Classification of climates. Evapotranspiration and evaporation. Aridity, deserts. Microclimatology. Synoptic climatology. Evolution of the climate.

XV. B. 2 *Climate*
Composition, properties and structure of the atmosphere, atmospheric processes and patterns of circulation with factors affecting them; temperature, wind and moisture in the atmosphere. Introduction to climate; the climate of the country.

XVI. Models

XVI. 1 *Models*
a. Model investigations in hydraulics. Short history of experimentation in hydraulics. Principle of similarity; numbers of Reynolds, Froude, Weber and Mach and related scale factors. Model distortion, artificial roughness, model tilting. Movable-bed models (bed load, suspended load, local scour). Some generalities on wave models with and without movable bed.
b. Hydrological models.

XVI. 2 *Hydraulic models*
Methods of simulation, historical development, physical fundamentals. Principles of similarities, different methods of obtaining analogues. Application and limits of analogues. Measurements.

XVI. 3 *Porous media modelling*
Development of model laws and analogies; techniques for modelling porous media systems; limitations of methods and theories; applications of results to prototype conditions.

XVI. 4 *The use of models and analogues in groundwater hydrology*
General. Scaling procedure. The sand box. The Hele–Shaw analogue. The electrolytic tank analogue. The RC-network analogue. Applicability of the various models and analogues.

XVII. Data processing and computer programming

XVII. A. DATA PROCESSING

XVII. A. 1 *Data processing and computer programming*
a. Range of application of digital machines: interaction with over-all design and construction techniques. Integration of computation with sampling testing and interpretation: design systems.
b. Introduction to a programming language: exercise and applications.
c. Review of data processing methods.

XVII. A. 2 *Data processing*
Data quality control; preparation of records for computer analysis; handling of punched tape and magnetic-tape records. Derivation of rainfall normals, average flows; compilation of data for publication.

XVII. B. USE OF COMPUTERS

XVII. B. 1 *Use of computers*
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 show and repetitive working. Applications to reservoir lag, surge chamber, flood routing and soil consolidation computation. Patch panel preparation of an analogue machine.

XVIII. Numerical methods

XVIII. 1 *Numerical methods*
a. Economics of computer applications in engineering practice.

b. Problems of equilibrium, transition and propagation type, as described by elliptic, parabolic and hyperbolic equation systems.

c. Solution of problems governed by elliptic equations. Consistency. Acceleration of convergence.

d. Solution of problems governed by parabolic equations. Explicit schemes: stable and unstable behaviour. A sufficient condition for stability. Implicit schemes: unconditional stability. Truncation errors. The tridiagonal algorithm.

e. Solution of problems governed by hyperbolic equations. Stability. Optimization of stability and the elimination of truncation errors: the method of characteristics.

XVIII. 2 *Numerical methods and computer applications*
Introduction to numerical methods, finite difference techniques, relaxation methods, analogue methods, digital computers and programming language.

XIX. Water quality and geochemistry

XIX. 1 *Water quality*
Principles of chemistry and microbiology of water. Water quality in relation to use of water resources. Mechanisms of water pollution. Analysis of polluted water. Prevention and control of water pollution. Case studies. Laboratory sessions to illustrate relevant chemical and microbiological techniques by practical exercises.

XIX. 2 *Analysis and quality of waters*
Water potability. Chemical analysis. Chemical researches. Water hardness. Practical studies of water quality. Water biology. Coli group determination. Interpretation of results. Applied chemistry and biology.

XIX. 3 *Water quality in water resource development*
Effects of organic, nutrient and thermal pollution on the ecology and chemical quality of streams, lakes, reservoirs and estuaries; cause and control of eutrophication; in-place control of natural water quality; quality requirements for various beneficial uses.

XIX. 4 *Ground-water and surface-water quality*
Water resources quality. Water quality as related to various beneficial uses. Physical, chemical, and microbiological characteristics of pollutional components. Pollution and recovery characteristics of surface and ground waters.

XIX. 5 *Applied chemistry of natural water sysyems*
Detailed considerations of the application of chemical principles to the analysis of actual natural water systems and to the understanding and solution of specific chemical problems in areas such as water purification technology, water pollution control, and aquatic sciences. Among the topics dealt with are the chemical properties of streams, lakes and ocean waters; colloidal phenomena in natural waters; chemical aspects of coagulation and flocculation; heterogeneous chemical processes of various kinds, such as adsorption from solution; corrosion and corrosion control processes and the chemistry of water purification processes such as softening, ion-exchange, stabilization and desinfection.

XIX. 6 *Chemistry of ground water*
The more common chemical constituents of ground water and their origin. Various methods of geochemical classification of waters according to natural groups. Application of geochemical classifications to the determination of flow direction and of the origin of groundwater bodies. The problem of base-exchange in a natural environment.

XIX. 7 *Geochemistry*
A geochemical study of the earth emphasizing sedimentary rocks and their depositional environments, and including the geochemistry of the hydrosphere, atmosphere and biosphere.

XIX. 8 *Water resources microbiology*
Fundamental aspects of microbiology and biochemistry as related to stream pollution and water quality control; the ecology of streams, lakes and other water resources; kinetics and energetics of microbial growth; identification and control of micro-organisms in water and wastes.

XIX. 9 *Microbiology of water and waste water*
Introduction to the characteristics of micro-organisms, their interaction with the environment, and their effect on water quality. Their role in the oxidation of organic substances in waste-water treatment and in receiving waters. Bacteriological, biological and limnological parameters of water quality and their measurement.

XIX. 10 *Assimilation of wastes in water*
Capacity of water resources to assimilate gaseous, liquid and particulate wastes. Phenomena pertinent to the dispersion and stabilization of wastes in water. Analogue and digital computer methods.

XIX. 11 *Chemistry of water and waste water*
Principles of chemistry applicable to the understanding, design and control of water and waste-water treatment processes and to reactions in receiving waters. Analytical methods applicable to the measurement and control of air and water quality.

XIX. 12 *Theory of waste treatment*
Description and analysis of physical, chemical and biological processes for the treatment of domestic sewage and industrial wastes. Discussion in detail of waste surveys, characteristics of sewage and industrial waste, ultimate disposal and pollution control.

XIX. 13 *Theory of water treatment*
An intensive study of the principles of water treatment, covering not only conventional processes employed in treating domestic water-supplies but also water conditioning for industrial water supplies. Emphasis on chemical

and biological water quality and the synthesis of treatment operations to produce water of a specified quality.

XIX. 14 *Water quality control I*
Natural and man-made characteristics of water quality; effect of quality on the use of water; unit operations and processes of water quality control, including desalination, for municipal and industrial use.

XIX. 15 *Water quality control II*
Characteristics of waste waters; chemical and biological unit processes for the treatment of sewage and industrial wastes; water quality requirements in stream pollution control.

XIX. 16 *Water and waste-water treatment processes*
Study of the microbiological, chemical and physical phenomena underlying the treatment of water and of municipal and industrial waste water. Application of these principles to the analysis and design of unit treatment processes. Laboratory studies of water quality and of unit treatment processes.

XX. Water law

XX. 1 *Legislation and administration of water resources*
Water resources and water rights. Allocation of water. Water institutions and administration: government administration, public institutions, water tribunal. Prevention of pollution. Water projects and recharging of water. Prices and other economic problems. Sanctions. Principles of the water metering law. Principles of the drainage law.

XXI. Water engineering

XXI. 1 *Hydraulic engineering design*
Hydraulic engineering design: elements of the economic analysis of a hydrotechnical design project. The combined design of a pipeline and a pumping station. Optimal diameter of pipelines. Mechanical design of pipes. Types of pumps. Use of characteristics of pumps. Factors in the choice of pumps. Hydraulic design of earth channels. Considerations of permissible velocity and shear stress. Seepage losses in channels. Economical considerations. Open channel structures, drops, stilling basins, inverted siphons, flow measuring devices, intake structure, reservoir.

XXI. 2 *Engineering hydrology*
Engineering hydrology as applied to water project planning, illustrated by hydrologic analysis of an actual project. Covers meteorology, hydrologic data, precipitation, evapotranspiration, stream-flow, run-off relations, unit-hydrographs, flood routing, frequency analysis and computer simulation. The relation of hydrology to project purposes and economic analysis is considered.

XXI. 3 *Engineering aspects of ground-water flow*
Emphasis on the applied aspects of ground-water flow and seepage, including permeability determination, flow net construction, filter design, construction dewatering, slope stabilization and road and airfield drainage.

XXI. 4 *Irrigation and drainage*
Irrigation: The plant requirements—food, water, air. The osmotic suction. Transpiration: the process, rate of transpiration. The water requirement: *brutto* and *netto* requirement. Estimate of requirement according to the depth of roots and the crop yield. Method based on climatologic data. Water losses: run-off, deep infiltration, evaporation. Irrigation requirements: effective rain, water deficiency, efficiency of irrigation. Division of the quantity of irrigation water: yearly, monthly, irrigation rate, irrigation cycle. The quality of irrigation water: physical, chemical and bacteriological requirements. Irrigation methods: gravity methods by stagnant water, gravity methods by flowing water, sprinkler irrigation. Drainage: the purposes of drainage—sanitation, communication, agriculture. Field investigations for determination of water surplus: augerholes, piezometers, water-table contour lines, measurement of hydraulic conductivity. Surface drainage: soil and hydrologic investigation. Estimate of the surface run-off. Protection against intrusion of 'foreign waters': border channels, diversion of watercourses, retention. The surface drainage network. Determination of the quantity of subsoil drainwater, calculation methods. Determination of the depth and spacing of drains. Structures in drainage. Soil salinity and leaching.

XXI. 5 *Irrigation and drainage*
Fundamentals of reclamation: the need for correcting the natural distribution of water. Principles of system lay-out. Capacity determination. Design principles of conduits. Form of development: land preparation, farm irrigation and drainage systems. Economic evaluation: goals, criterial and principles. Operation and maintenance: principles, organization, repayment.

XXI. 6 *Drainage*
Reclamation of waterlogged and salted lands. Design of drainage systems, tile-drain theories, drainage by pumping, ground-water movement.

XXII. Snow, ice and glaciology

XXII. 1 *Hydrology*
Snow properties, interception, erosion, wind transport, redeposit, metamorphism, ablation and melting; avalanche genesis and control; snow melt run-off prediction.

XXIII. Man's influence on the hydrological cycle

XXIII. 1 *Effect of man's influence on hydrological phenomena*
Principal factors of the hydrological cycle that can be

influenced by man. Human activity and its effect along the watercourses in connexion with their training and utilization. Effect of human activity on the catchment area. Evaluation of the efficiency and development of water management.

XXIV. FORECASTING

XXIV. 1 *Hydrological forecasting*
General considerations on hydrological forecasting, efficiency of the forecasts, organization of forecasting services. Forecasts of the water régime of rivers and lakes. Methods of forecasts of ice régime. Forecasts of ground-water régime.