Hydrology MSc

VU University Amsterdam - Fac. der Aard- en Levenswetenschappen - M Hydrology - 2015-2016

The Hydrology master's programme provides the student with sound scientific knowledge of how water cycles through the Earth’s atmosphere, surface and groundwater systems and how water quantity and quality are modified due to natural processes, or in response to human interference with the water cycle (e.g. pollution, land use change, etc.). This knowledge is a prerequisite for the sustainable use of our water resources that are being threatened by the continuous increase in the world’s population and the associated increase in water use and agricultural and industrial pollution. As water issues are often not restricted to a single country, the Master’s programme is strongly oriented to provide an international perspective.

The programme is strong in both hydrogeology and ecohydrology. Hydrogeology deals with (un)saturated groundwater and surface water flows on a local to regional scale (0-500 km), groundwater exploration and water quality issues in relation to the geology and land-use. Groundwater and surface water flow patterns and associated variations in the chemical composition of water due to interaction with the environment are assessed using a combination of lectures, field studies and hydrological and hydrochemical modelling workshops. Exploration and water resources assessments are made through application of water balance techniques, geophysical techniques and chemical and isotope tracer methods. Ecohydrology focuses on processes regulating the hydrological cycle and how these are affected by changes occurring at the land surface in response to human activities (e.g. deforestation, climate change). It combines micro-meteorology, (forest) hydrology, Quaternary geology, and environmental sciences to study processes that regulate how water, nutrients, sediment and gases are exchanged between the soil, water, vegetation and the atmosphere. These transfers are studied mostly on small catchment scales. A range of field measurement and sampling techniques are used including micro-meteorology, hydrology, plant physiology, soil physics, chemical isotope tracer methods, in combination with detailed, process-based models.

The year schedule can be found at the FALW-website.
Further information about the MSc programme Hydrology.
A complete programme description can be found at the FALW-website.

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Expired programme components Hydrology

The course programme components presented in the list below will no longer be part of the examination programme in academic year 2014-2014.

Courses:

Name	Period	Credits	Code
Environmental Remote Sensing		6.0	AM_450145
Field Course Hydrology Portugal	Ac. Year (September)	15.0	AM_1013
Field Course Netherlands (Measurements Techniques)	Ac. Year (September)	3.0	AM_450126
Global Biogeochemical Cycles	Ac. Year (September), Period 4	6.0	AM_450332
Groundwater Flow Modelling	Ac. Year (September)	6.0	AM_450008
Groundwater Hydraulics	Ac. Year (September)	6.0	AM_450009
Hydrochemistry	Ac. Year (September)	6.0	AM_450052
Hydrological Systems and Water Management	Ac. Year (September)	3.0	AM_1012
Isotope Hydrology	Ac. Year (September)	3.0	AM_450148
Transport Processes in Groundwater	Ac. Year (September)	6.0	AM_450131

MSc Hydrology year 1

Courses:

Name	Period	Credits	Code
Catchment Response Analysis	Period 1	6.0	AM_450003
Ecohydrology	Period 1	6.0	AM_450014
Field Course Hydrology	Period 5+6	12.0	AM_1169
Groundwater Processes	Period 4	6.0	AM_1164
Integrated Modeling in Hydrology	Period 3	6.0	AM_1165
Measuring Techniques in Hydrology	Period 5	6.0	AM_1168
Unsaturated Zone and Near Surface Hydrological Processes	Period 2	6.0	AM_450021
Water Economics	Period 2	6.0	AM_1167
Water Quality	Period 4	6.0	AM_1166

MSc Hydrology, year 2

Programme components:

- MSc Hydrology year 2 elective options
- MSc Hydrology year 2 compulsory modules

MSc Hydrology year 2 elective options

Courses:

Name	**Period**	**Credits**	**Code**
Basics in Geographical Information Systems	Period 5	3.0	AM_450226
Climate and Policy	Period 3	6.0	AM_450188
Climate Modelling	Ac. Year (September), Period 3	6.0	AM_450004
Ecotoxicology and Water Quality	Period 2	6.0	AM_1054
From Source to Sink: Chemical and Physical Cycles	Period 2	6.0	AM_450146
Geothermal Energy		6.0	AM_450409
Global Biogeochemical Cycles	Ac. Year (September), Period 4	6.0	AM_450332
Groundwater Microbiology and Geochemistry (Geomicrobiology)	Ac. Year (September)	6.0	AM_450132
Modern Climate and Geo-ecosystems	Period 1	6.0	AM_1124
Reflection Seismic for Geologists	Period 4	6.0	AM_450170
Scientific Writing in English	Period 2, Period 5	3.0	AM_471023
Water and Policy	Period 1	6.0	AM_468023

MSc Hydrology year 2 compulsory modules

Courses:

Name	**Period**	**Credits**	**Code**
Advanced Groundwater Processes	Period 1	6.0	AM_1171
Master Thesis Hydrology	Ac. Year (September)	36.0	AM_1170

Advanced Groundwater Processes

Course code	AM_1171 ()
Period	Period 1
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. ir. Y. van der Velde
Examinator	dr. ir. Y. van der Velde
Teaching staff	dr. ir. Y. van der Velde
Teaching method(s)	Seminar
Level	400

Course objective
The goal of this course is to deepen the understanding of groundwater processes for which the Groundwater Processes course laid the fundamentals. The objective is to make the student thoroughly familiar with the modelling of groundwater flow processes and the transport of solutes and heat through groundwater systems.

Course content
Hydrogeology is to a large extent concerned with the flow of water in the subsurface. Groundwater flow models are powerful tools to study this movement of water in the subsurface. Hence, they are widely used in research and consultancy, and thus a key skill for hydrologists. This course you will deepen your understanding of groundwater flow modelling and develop basic programming skills to investigate these processes. Moreover, fundamental transport processes taking place in groundwater bodies will be included in this (advection, diffusion, dispersion, first-order reactions) using numerical methods.

Form of tuition
The course consists of a set of lectures supplemented with practicals.

Type of assessment
Written examination

Target group
Hydrology MSc students and other earth sciences related MSc programs

Basics in Geographical Information Systems

Course code	AM_450226 ()
Period	Period 5
Credits	3.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. ir. J. van Vliet
Examinator	dr. ir. J. van Vliet
Teaching method(s)	Computer lab
Level	400

Course objective
To build a high level of practical skills and experience in the use of professional GIS software for data collection, integration, visualization, database design, mapping and automated analysis and management for a couple of specific earth science related case studies.

Course content
This course consists of a theoretical part and a practical part. In the theoretical part the principles of GIS are explained (database management, data acquisition and integration, spatial analysis, Web-based GIS, Mobile GIS and visualization). The practical part focuses on the use of the software package ArcGIS and is mostly applied to earth scientific study themes. The student will be trained in the use of GIS and special attention will be paid to the use of mobile GIS systems.

Form of tuition
8 hours of lectures, 24 hours of practical (computer) exercises. Self study, including literature study.

Type of assessment
Written exam (ca. 50%) and practical computer exam (ca. 50%).

Course reading
Lecture notes, chapters from Longley et al., (2001) GIS and Science, John Wiley, selected articles

Recommended background knowledge
Advice regarding previous course taken: AB_!076: GIS and digital geographical data

Remarks
The course coordinator for this course can still be subject of change

Catchment Response Analysis

Course code	AM_450003 ()
Period	Period 1
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	drs. E.J. Moors
Examinator	drs. E.J. Moors
Teaching staff	drs. E.J. Moors
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective
The objectives of the course are to provide the student with scientific theory, tools and methods for understanding and evaluating the response of a catchment to precipitation in terms of surface water flows. This requires knowledge about processes regulating the flow of water on the land surface and in river channels, the techniques for quantification of surface water flows and statistical methods for predicting extreme runoff events. In addition, experience with surface water flow modelling for predicting the behaviour of rivers under different land use or

climate conditions should be acquired.

The course contributes to the Knowledge and Understanding and Application of Knowledge and Understanding final attainment levels of the Msc Hydrology Programme. Knowledge and understanding is obtained through the studying of theory as provided in the reader, during the oral lectures and through self-study of scientific papers on rainfall-runoff response topics. Knowledge and understanding is applied in the setting up and execution of a rainfall-runoff model and the critical evaluation of the model simulation with measured data.

Course content

The course consists of three main topics. We start with an overview of hydrodynamic and hydraulic theory that governs flow in open channels. This is followed by lectures on discharge measurement techniques, catchment response analysis and runoff statistics. Topics are hill slope hydrology, hydrograph analysis, reservoir and flow routing and statistical methods to describe and quantify spatial and temporal variation in catchment runoff. The spectrum of available models for runoff modelling, from classical lumped models to data-demanding distributed, physically-based hydrological models, will also be discussed. Finally, theory and understanding will be applied in a series of modelling exercises applying the HBV-light rainfall – runoff model to simulate runoff of the Dinkel River in East Netherlands.

Form of tuition

The tuition consists of ten classroom lectures and four computer modelling workshop sessions. The number of contact hours is in the order of 42.

Type of assessment

The assessment is through a written exam (75%) and assessment of the modelling workshop report (25%).

Course reading

Bishop et al. 2008. Aqua Incognita: the unknown headwaters, Hydrological Processes 22: 1239–1242. doi: 10.1002/hyp.7049.

A,.A. van der Griend and M.J. Waterloo (2013), Catchment Response Analysis. Course Reader, VU University, Amsterdam.

B.L. McGlynn, J.J. McDonnel and D.D. Brammer. A review of the evolving perceptual model of hillslope Flowpaths at the Maimai catchments, New Zealand. Journal of Hydrology 257 (2002) 1-26.

J. Seibert, 2002. HBV light version 2 User’s Manual. Environmental Assessment SLU, Sweden.

Seibert, J. and M.J.P. Vis 2012. Teaching hydrological modeling with a user-friendly catchment-runoff-model software package, Hydrology and Earth System Sciences 16: 3315-3325, doi:10.5194/hess-16-3315-2012, 2012.

I. Tromp-van Meerveld and M. Weiler. Hillslope dynamics modeled with increasing complexity. Journal of Hydrology (2008) 361, 24-40.

Links to other papers are provided on Blackboard.

Entry requirements
The student should be familiar with the subjects of the BSc course Introduction to Hydrology and Climatology (AB_1074) as detailed in the Introduction to Hydrology and Climatology (2013) course reader by M.J. Waterloo, V.E.A. Post and K. Horner.

Recommended background knowledge
The student should have a good background knowledge of mathematics and physics at BSc level and have basic computer skills. In addition, the student should have basic knowledge of Earth Science, as provided by the System Earth course (AB_450067).

Target group
First-year M.Sc. Hydrology students, students from Earth Sciences, Earth and Economy or Natural Sciences M.Sc. programmes.

Remarks
The course is open for participation to students from alternative M.Sc. programmes at the VU University Amsterdam, or from other universities. If you are a professional and wish to attend this course you can also participate on a contract basis. In both cases please do contact the course coordinator to find out if you fulfill the background knowledge requirements and for enrollment procedures.

Climate and Policy

Course code	AM_450188 ()
Period	Period 3
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. P.H. Pattberg
Examinator	prof. dr. P.H. Pattberg
Teaching staff	prof. dr. P.H. Pattberg
Teaching method(s)	Seminar
Level	400

Course objective
After studying this course, students should be able to define and explain key concepts of relevance to the climate change governance issue; understand the causes, impacts and effects of climate change and the key scientific controversies in the regime; be able to identify, explain and analyze the various policy options for mitigation and adaptation at different levels of governance; be able to understand and analyze the key political challenges in the climate change regime, the common problems facing all countries, the coalitions in the regime, the North-South, North-North, South-South, European and domestic political issues; be able to explain and assess the long-term objective, the principles, the commitments of countries and other key elements of the Climate Change Convention, the quantified commitments of developed countries, and the flexibility mechanisms under the Kyoto Protocol; be able to explain, analyze and form a judgment on the role of forestry in the climate change regime, and the various aspects of policy with respect to deforestation and land degradation; be able to define and explain the role of market mechanisms in the climate change regime,

their advantages and disadvantages, and their potential in addressing the climate change problem; be able to integrate the information learnt thus far to assess and identify possible long term solutions to the climate change problem and the research questions that emerge from a study of the climate change regime; and be able to make a judgment about which principles, policy instruments and approaches are likely to be most efficient, equitable and/or effective in addressing the climate change problem.

Course content
International policy on human-induced climate change and its mitigation is a hotly debated subject. Current (international) climate policy is the result of a complex and long-lasting negotiation process at multiple levels of governance. In this process, the science of the complex earth and climate system is closely linked to questions on the socio-economic effects of climate change, the options for global environmental governance as determined by the structure of international organizations, international economic and political relations and environmental law. These close relations between earth system research and economic/political questions make this course an interesting subject for students with a bachelor's degree in different subjects . The course includes:
- an overview of the science of climate change, its impacts (IPCC Fifth Assessment Report) uncertainties, mitigation, adaptation; - climate change policy options at multiple levels of governance; - analysis of the political challenges in climate change and the positions of different countries and actors; - assessment of the international legal instruments including the Climate Change Convention and the Kyoto Protocol, - assessment of the economics of climate change including analysing the flexible mechanisms (Emission trading, Clean Development Mechanisms, Reducing Emissions from Deforestation and Forest Degradation) and options for Post Kyoto measures; and paper discussions on a topical area of climate governance.

Form of tuition
The course consists of 7-8 interactive lectures including class presentations and uses modern didactic approaches, films, and role play to help the students internalize many of the concepts and theoretical approaches developed.

Type of assessment
The students will be examined on the basis of a paper (50%) and a closed book written examination (50%). Students must get a grade of 5.5 in each to pass in the examination.

Course reading
Reader

Recommended background knowledge
Basic knowledge of social science concepts such as governance

Target group
Students with an interest in governance and policy

Climate Modelling

Course code	AM_450004 ()
Period	Ac. Year (September), Period 3

Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. H. Renssen
Examinator	prof. dr. H. Renssen
Teaching staff	prof. dr. H. Renssen, prof. dr. A.J. Dolman, dr. D.M.V.A.P. Roche
Teaching method(s)	Seminar, Computer lab
Level	400

Course content
Geological archives show convincingly that the climate system experiences variability on a wide range of time-scales. For Quaternary studies, climate variations at the following time-scales are most important: glacials-interglacials, millennia and centuries-decades. This course focuses at the mechanisms behind these variations, thereby using climate models as a tool, i.e. numerical computer models in which the dynamics of the climate system are calculated. The combination of these models and geological data will be treated extensively. The course consists of lectures giving an overview of climate models and their application (different types for different time-scales) and of discussion meetings, in which students discuss the recent literature in detail. In this way the course considers case studies for the different time-scales and deals with recent developments in climate modelling. The following two questions are central to the course: 1) What is the driving mechanism behind climate change at a particular time-scale? 2) How can we optimise the combination of climate models and geological data in order to increase our understanding of climate evolution?

Form of tuition
Lectures, discussion meetings and computer exercises.

Type of assessment
Compulsory participation in discussion meetings, computer exercises, oral presentation and written exam.

Course reading
Lecture notes and selected papers (made available through Blackboard).

Remarks
The course is open for participation to students from alternative M.Sc. programmes at the VU University Amsterdam, or from other universities. If you are a professional and wish to attend this course you can also participate on a contract basis. In both cases please do contact the course coordinator to find out if you fulfill the background knowledge requirements and for enrollment procedures.

Ecohydrology

Course code	AM_450014 ()
Period	Period 1
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen

Coordinator	prof. dr. A.J. Dolman
Examinator	prof. dr. A.J. Dolman
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective

Ecohydrology is a combination of ecology (study of how organisms interact with each other and with the natural environment) and hydrology (study of how water cycles in terrestrial environments). It focuses on the role of ecosystems in the water cycle of terrestrial landscapes. The objectives of the course is to provide understanding of the functioning of ecosystems in relation to water availability and the movement of water in terrestrial ecosystems under different climates. This ecohydrological knowledge forms the basis for supporting decisions on sustainable land use from a water resources point of view. It requires fundamental theoretical knowledge on plant physiology and on the exchange of water between the soil, vegetation and the atmosphere. As such, limitations to ecosystem functioning posed by water availability in relation to evaporation and transpiration by different plant communities is a central theme in this course. In addition, the student needs to learn basic computer programming for meteorological data processing and analysis.

Course content

This course describes and discusses basic interactions between the vegetated land surface, the atmosphere and the hydrosphere. Basic questions dealt with include: what determines the broad vegetation patterns of the world, and how do these in turn determine the ecohydrological behaviour of different vegetation types? This requires understanding of primary ecohydrological processes (rainfall and cloud water interception, transpiration, soil moisture dynamics) and feedback mechanisms between the vegetation and the atmosphere as well as insight into the measurement, data analysis and modelling of these processes. The ecohydrological aspects of Dynamic Vegetation Models (DGVMs) will be discussed. Tropical and temperate deforestation impacts on catchment hydrological functioning and climate as well as desertification processes are considered. Ecohydrological processes in boreal and tundra regions, as well as in montane cloud forests will be discussed in some detail. Emphasis throughout the course is on a combination of process understanding, interpretation of experimental results, and modelling. Finally, a computer programming workshop is included to become familiar with the basics of computer programming, meteorological data processing, analysis and rainfall interception modelling.

Form of tuition

The tuition consists of nine classroom lectures, a half-day student presentation session and a computer workshop (five half-days).

Type of assessment

Written test on lecture notes and selected literature (65%), attendance of workshops (15%), and a presentation to be given on a pre-determined topic (20%).

Course reading

Readers, scientific papers and handouts are provided during the course via Blackboard

Entry requirements
The student should be familiar with the subjects of the BSc course Introduction to Hydrology (450024) as detailed in the Introduction to Hydrology (2012) course reader by M.J. Waterloo, V.E.A. Post and K. Horner.

Recommended background knowledge
The student should have a good background knowledge of mathematics and physics at BSc level and basic computer skills

Target group
First-year MSc Hydrology students, students from alternative Earth Sciences, Earth and Economy or Natural Sciences MSc programmes

Remarks
The course is open for participation to students from alternative M.Sc. programmes at the VU University Amsterdam, or from other universities. If you are a professional and wish to attend this course you can also participate on a contract basis. In both cases please do contact the course coordinator to find out if you fulfill the background knowledge requirements and for enrollment procedures.

Ecotoxicology and Water Quality

Course code	AM_1054 ()
Period	Period 2
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. ir. T.H.M. Hamers
Examinator	dr. ir. T.H.M. Hamers
Teaching method(s)	Lecture, Practical

Course objective
At the end of this course, students will have:
1. Gained theoretical knowledge of contaminants in the environment, their effects on organisms and ecosystems, and the assessment of water quality
2. Learned to determine the ecotoxicological effects of chemicals with laboratory toxicity testing
3. Developed a critical academic attitude in environmental management issues by combining scientific information and socio-economic arguments

Course content
This course focuses on the effects of contamination of aquatic ecosystems, from the molecular chemistry of major groups of toxicants to their impacts at the molecular, cellular, individual, population, and ecosystem level.

The first part of the course is a laboratory practical, in which students gain hands-on experience in ecotoxicity testing using methods from bacteria, aquatic invertebrates and fish. Both whole-organism and molecular biological techniques are taught. Students will evaluate scientific literature and the results of their experimental research to assess the risk of environmental contaminants for ecosystem health. At the end of the practical, students will present the results of their experimental work in a poster presentation.

The second part of the course is theoretical and will teach the student the state of the art in ecotoxicology. It is designed as a scientific symposium with invited lectures by internationally renowned guest lecturers as well as PhD candidates who present their PhD research in ecotoxicology. Students take the role of chairperson during the symposium and introduce the speakers, ask questions and discuss critical issues. Topics include emerging compounds, molecular mechanisms of toxicity, community effects, global environmental problems, and chemical regulation. Scientific literature will be given as background information on each topic. The symposium is finalized with oral presentations in which students present a critical evaluation of the topics presented.

Form of tuition
• Laboratory practical course: 56 hours
• Lectures (introduction to practicals + scientific symposium): 36 hours
• Independent study: 68 hours

Type of assessment
1. Participation in laboratory practical course, including lab journal (15%)
2. Poster presentation of the laboratory practical course (35%).
3. Oral presentation of scientific symposium (15%)
4. Written exam of 10 open questions (35% of mark)

The student has passed if each of the components has received a minimum of 5.0, and the final mark is equal to or higher than 5.5, in a range from 1-10.

Course reading
Protocols for the laboratory practical will be provided.
For the theoretical part of the course, scientific articles will be provided by guest lecturers including:
Thomas KV, et al. Comparing illicit drug use in 19 European cities through sewage analysis. Sci
Total Environ. 2012 Aug 15;432:432-9.
van Boxtel AL, et al. Microarray analysis reveals a mechanism of phenolic polybrominated diphenylether toxicity in zebrafish. Environ Sci Technol. 2008 Mar 1;42(5):1773-9.
Roessink I, et al. Impact of triphenyltin acetate in microcosms simulating floodplain lakes. II. Comparison of species sensitivity distributions between laboratory and semi-field. Ecotoxicology. 2006 Jul;15(5):411-24.
Boivin ME, et al. Algal-bacterial interactions in metal contaminated floodplain sediments. Environ Pollut. 2007 Feb;145(3):884-94.
Zweers, PGPC et al. Verification of a REACH Environmental Prioritization System against Regulatory Risk Indices. Human and Ecological Risk Assessment. 2012

Entry requirements
BSc in Biology, Ecology, Biomedical Sciences, Health Sciences, Earth Sciences, Chemistry or related fields

Recommended background knowledge
BSc course in Environmental Toxicology (e.g. AB_1020) is recommended but not mandatory.

Target group
Open to all MSc students in Biology, Ecology, Biomedical Sciences, Health Sciences, Earth Sciences, Chemistry or related fields. Compulsory course for MSc Ecology, ECT specialization. Optional course for UvA MSc Biology, L&O track.

Remarks
For more information, please contact: Prof. dr. ir J. Legler, Room A-645, 020-5989516, juliette.legler@vu.nl

Environmental Remote Sensing

Course code	AM_450145 ()
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. R.T. van Balen
Examinator	prof. dr. R.T. van Balen
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective
This course will make the student more familiar with remote sensing and the main objectives of this course are: (i) To understand the fundamental characteristics of electromagnetic radiation and how this interacts with vegetation, soil, rock and water. (ii) To understand and master the methodology behind a large variety of remote sensing applications related to land surface observations, including a clear understanding of the limitations of these observations. (iii) To develop practical computer skills to use remote sensing products in environmental studies. During the lectures the physical basics and mathematical principles of remote sensing will be discussed. During the practical exercises we will use a suite of remote sensing-derived environmental data (i.e. geology, soil, water, and vegetation). The focus point of the course is dual; on the one side it will be focussed on the elementary knowledge and techniques and on the other site it will be focussed on the integration of several remote sensing. At the end of the course Environmental Remote Sensing the student should have:

• Knowledge of the basic principles of the electromagnetic spectrum and the operation systems for satellite and airplane remote sensing (aerial photography, multi-spectral, and thermal scanning, microwave sensing) and the environmental applications;

• Understanding of the technology to derive reliable remote sensing products over land including vegetation products, water quality products, soil moisture, temperature and evapotranspiration.

• Knowledge of remote sensing data collection from different formats (i.e. hdf, .tif, .mat .nc) and the skills to use them in environmental studies.

• Adequate knowledge to criticize the quality of spatial data, to detect data errors, and to understand the usefulness of given datasets.

Course content
Remote sensing is a scientific technology that can be used to measure and monitor land surface processes from space. This course is designed to introduce students to:

• the fundamental characteristics of electromagnetic radiation, and;
• the interaction of electromagnetic radiation with materials such as vegetation, soil, rock, water, and the atmosphere, and;
• how this interaction can be used to study the Earth.

The lectures will focus on a large variety of remote sensing observations in different parts of the electromagnetic spectrum, each having its own application. Besides a thorough understanding of the theoretical basis, you will also learn how to use satellite data in both scientific and applied studies on scales ranging from detailed local case studies to global applications.

Form of tuition
16 hours of lectures, 24 hours of practical (computer) exercises and literature study

Type of assessment
Written Exam

Course reading
Readers, scientific papers and handouts are provided during the course via Blackboard

Recommended background knowledge
The student should have a good background knowledge of mathematics and physics at BSc level and basic knowledge of Geographical Information Systems.

Target group
First-year MSc Hydrology students, students from alternative Earth Sciences, Earth and Economy or Natural Sciences MSc programmes

Field Course Hydrology

Course code	AM_1169 ()
Period	Period 5+6
Credits	12.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	S.F. Stofberg MSc
Examinator	S.F. Stofberg MSc
Teaching staff	S.F. Stofberg MSc
Teaching method(s)	Seminar, Computer lab
Level	500

Course objective

This course main objective is to instill “hydrological system thinking” in the student's mind. This is done through a combination and practical application of the earth scientific and hydrologic theory given in the period before the field course to solve hydrological questions in the field. The objectives include planning and making decisions about research strategies, learning to make relevant measurements of all the components of the hydrological cycle (surface water, ground water storage, soil moisture, vegetation, and the atmosphere) and use these measurements to make realistic qualitative and quantitative interpretations regarding the hydrological processes and conditions in the field and their relation to local and regional issues related to water resources.

Course content

This course covers the practical side of hydrological research through application of geological and hydrological knowledge to solve the water balance of target areas and to study water quality issues. Students are first familiarized with the geology and hydrology of coastal areas in Portugal and with the relations between geology, land use, vegetation and water (quantity and quality). The focus then shifts to hydrogeological mapping, the collection of field data and their integration to develop qualitative and quantitative conceptual hydrological models for solving the water balance and to address water quality processes and concerns (salinization, agricultural pollution).
The field work will be carried out in an area with relatively high precipitation. The relation between hydrology and geology, vegetation, land use, and climate will be studied and the practical and societal aspects will be addressed. Students perform an independent catchment and groundwater hydrology study. The field period is immediately followed by three weeks during which collected field data are analyzed and reported in the form of an individual scientific paper.

Form of tuition

The course is subdivided in two parts. Before the fieldwork a preparatory workshop will be organised. In the fieldwork region, each group will be assigned a study catchment in which a hydrological observation network (surface water, ground water, meteorology, etc.) will be installed. Students are expected to work independently and make their own decisions regarding planning and research strategy. Data processing, analysis and modelling are an integral part of the field course to scale up the measurements and link their findings to water resources issues in the region. An individual scientific paper-style report will be written in Amsterdam during the final part of the course. Staff members will be present during the whole course period for supervision and for consultation by students.

Type of assessment

Execution of field campaign
Publication of scientific paper on results

Course reading

Boris M. van Breukelen, Michel M.A. Groen, Koos Groen, Ko van Huissteden, Richard A.M. de Jeu, Vincent E.A. Post, Jaap Schellekens and Maarten J. Waterloo (2014). Handbook for Field Hydrological Measurements. VU University Amsterdam.

Entry requirements
Admission to this field course is granted to students who have been admitted to the Hydrology MSc Programme. Furthermore, students must have completed the course Measuring Techniques in Hydrology and, before mid-April, must have passed at least two of the courses Catchment Response Analysis, Groundwater Processes, Water Quality and Unsaturated Zone and Near Surface Hydrological Processes.

Recommended background knowledge
The student should have a good general knowledge of the subjects discussed in the basic theoretical courses M.Sc. Hydrology master, i.e. Catchment Response Analysis, Ecohydrology, Groundwater Processes, Water Quality, Unsaturated Zone and Near Surface Hydrological Processes. Participants will need to work with GIS for analysing and displaying spatial spatial data and will need to be familiar with field methods.

Target group
First year MSc Hydrology Programme students

Remarks
The course coordinator will send you an e-mail asking for information about your participation in this course in January. Besides registering for this course via the VUnet portal for this course please respond to the e-mail request of the coordinator before 31 January. The course is partly subsidized by the faculty and the students are obliged to pay for the other part of the course (travel, residence costs, etc.).

Field Course Hydrology Portugal

Course code	AM_1013 ()
Period	Ac. Year (September)
Credits	15.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Teaching staff	drs. M.M.A. Groen
Teaching method(s)	Fieldwork, Computer lab
Level	600

Course objective
This course main objective is to instill "hydrological system thinking" in the student's mind. This is done through a combination and practical application of the earth scientific and hydrologic theory given in the period before the field course to solve hydrological questions in the field. The objectives include planning and making decisions about research strategies, learning to make relevant measurements of all the components of the hydrological cycle (surface water, groundwater, soil moisture, vegetation, and the atmosphere) and use these measurements to make realistic qualitative and quantitative interpretations regarding the hydrological processes and conditions in the field.

The course contributes to 1) Application of Knowledge and Understanding, 2) Critical Judgement, 3) Communication and 4) Learning Focus final attainment levels of the Hydrology MSc Programme. In particular, at the end of this course the student should be able to:

• independently set up and execute a new hydrological field experiment, be able to analyse existing hydrological research projects with respect to the planning, execution and evaluation of the results,
• know the limitations of hydrological instruments and measurement techniques and how to take these into account when critically evaluating his/her own measurements
• think in a multidisciplinary way and recognise the importance of other (sub)disciplines for his/her own specialisation and combine different types of factual information, complete a report on trainee work, subject matter studied, or research carried out,
• clearly present information, both written and orally to a public of specialists from the same subject area on an independently studied topic (in English),
• read publications and reports in his/her native language and in English,
• actively and constructively participate in discussions on hydrological issues and meetings,
• work together with one or more colleagues with different scientific backgrounds,
• independently collect information on hydrological subjects and analyse, summarise and critically evaluate this information,
• recognise the continued need to keep in touch with relevant developments in his/her discipline, and is prepared to take the appropriate action to realise this,
• recognise cultural and gender-related aspects of water issues.

Course content
This course covers the practical side of hydrological research through application of geological and hydrological knowledge to solve the water balance of target areas and to study water quality issues. Students are first familiarized with the geology and hydrology of coastal areas in Portugal and with the relations between geology, land use, vegetation and water (quantity and quality). The focus then shifts to hydrogeological mapping, the collection of field measurements and their integration to develop qualitative and quantitative hydrological models for solving the water balance and to address water quality concerns (salinisation, agricultural pollution). The field work will be carried out in two areas with a different climate: a semi-arid area (Algarve) and an area with high precipitation (Aveiro region). The relation between hydrology and geology, vegetation, land use, and climate will be studied and the practical and societal aspects will be highlighted. In Aveiro, students perform an independent catchment and groundwater hydrology study. The field period is immediately followed by three weeks during which colected field data are analysed and reported in the form of an individual scientific paper.

Form of tuition
The course is subdivided in three parts. Before the fieldwork a one-day preparatory workshop will be organised. The first part (2 weeks) in the Algarve has an introductory character. During the first four days there will be an excursion devoted to (a) field observation and conceptual model development, (b) field measurements and (c) the hydrological systems in the Algarve region. The excursion is followed by a five- day field survey carried out by students in small groups and supervision limited to a few days. These surveys serve as training for the second part of the field course (4 weeks), which is near the city of Aveiro. Here, each group will be assigned a study catchment in which a hydrological observation network (surface water, ground water, meteorology, etc.) will be installed. Supervision is less intense than

during the first part of the field course as students are expected to work independently and make their own decisions regarding planning and research strategy. Data processing, analysis and hydrochemical modelling are an integral part of the field course. A scientific paper-style report will be written in Amsterdam during the third and final part of the course (3 weeks).

Staff members will be present during the whole course period for supervision and for consultation by students.

Type of assessment
- Performance and oral presentation evaluation Algarve excursion and field campaign (30%)
- Execution of field campaign Aveiro (40%)
- Publication of scientific paper Aveiro (30%)

Course reading
J.J. De Vries and J. Schwan. Groundwater flow and geological structure of the Algarve, Portugal. VU University Amsterdam.

Boris M. van Breukelen, Michel M.A. Groen, Koos Groen, Ko van Huissteden, Richard A.M. de Jeu, Vincent E.A. Post, Jaap Schellekens and Maarten J. Waterloo (2014). Handbook for Field Hydrological Measurements. VU University Amsterdam.

Entry requirements
Admission to this field course is granted to students who have been admitted to the Hydrology MSc program. Furthermore, students must have completed the Field Course Netherlands (AM_450126) and, before mid-April, must have passed at least two of the courses Catchment Response Analysis (AM_450003), Groundwater Hydraulics (AM_450009), Hydrochemistry (AM_450052) and Unsaturated Zone and Near Surface Hydrological Processes (AM_450021).

Recommended background knowledge
The student should have a good general knowledge of the subjects discussed in the basic theoretical courses M.Sc. Hydrology master, i.e. Catchment Response Analysis (AM_450003), Ecohydrology (AM_450014), Groundwater Hydraulics (AM_450009), Hydrochemistry (AM_450052), Unsaturated Zone and Near Surface Hydrological Processes (AM_450021).. Participants will need to work with ARCGIS for analysing and displaying spatial spatial data (Basics in Geographic Information Systems course (AM_450226)) and will need to be familiar with geophysical methods (geo-electrics) and other field methods as demonstrated in the Field Course Netherlands (Measurement Techniques, AM_450126).

Target group
First year MSc Hydrology Programme students

Remarks
The course coordinator will send you an e-mail asking for information about your participation in this course in January. Besides registering for this course via the VUnet portal for this course please respond to the e-mail request of the coordinator before 31 January. The course is partly subsidized by the faculty and the students are obliged to pay for the other part of the course (travel, residence costs, etc.).

Field Course Netherlands (Measurements Techniques)

Course code	AM_450126 ()
Period	Ac. Year (September)
Credits	3.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Teaching method(s)	Seminar, Fieldwork
Level	500

Course objective
This course module will no longer be offered. It has been replaced by Measuring Techniques in Hydrology.

The objective of this course is to familiarize students with measurement methods and techniques that are commonly used in hydrology and environmental sciences.

At the end of the course the student should be able:
1. to select the appropriate field measurement methods and techniques for a certain hydrological question
2. to operate the equipment
3. to evaluate and interprete the results
4. to carry out the fieldwork in Portugal, which directly follows this course, and other research projects independently.

Course content
This course deals with a broad range of field measurement aspects of hydrological studies. The course starts with a one-day excursion to familiarize the participants with the geology and geomorphology of the Dinkel River watershed and practical research experience is subsequently gained through a study of the water balance and hydrochemistry of the area. This part of the course includes instructions in geophysical, geohydrological, meteorological, soil physical, and hydrochemical measurement techniques that are commonly used in surface and groundwater movement studies and in water quality investigations. Spatial data collection and processing methods are practiced through the use of portable geographic information systems. The last few days of the course are used for the analyses of data and the preparation of presentations. At this time, combining the results of different methods for estimating the water balance components solves the water balance for the area and an overview is prepared of the regional hydrochemistry. Key course subjects are installation of
hydrological equipment, rainfall, water level and discharge measurements, installation of piezometers, geodetic surveys and groundwater gradient assessment, soil and aquifer permeability measurements (pumping test, auger hole method), automatic weather station operation, geo-electrical measurements (Schlumberger, Wenner array methods), soil moisture and tension measurements, water sampling and chemical analysis, datalogger programming, data processing and analyses, and finally, presentation techniques.

Form of tuition
The 10 day course takes place at Camping Meuleman at the De Lutte, Overijssel and the direct surrounding carried out in the field. During 6 days students are in the field, receive instructions and carry out measurements in the direct surroundings of the camping and along the Dinkel River. Students work in groups of 4 to 5. In the evenings and

the last two days students attend presentations by staff members on various subjects, interpret the data acquired in the field and prepare a presentation for the final evening according to a prescribed format. During the presentation every individual group member presents a part of the data and interpretations. Students have a total of 77 contact hours (days and evenings).

Type of assessment
Students are evaluated on the basis of:
1. Individual performance in the field (33 %)
2. Individual presentation (33 %)
3. Group performance (33 %)

Course reading
Course reader: Breukelen et al., 2009. Handbook for Field Hydrological Measurements. VU University Amsterdam. Reader is available on Blackboard.

Target group
1. Dutch and foreigns students of VU Hydrology Masters program
2. Students from other universities in the Netherlands following an elecive course
3. Studenst from other European countries on Erasmus scholarships following an elective course

Remarks
Participants work in groups of three to four persons.

From Source to Sink: Chemical and Physical Cycles

Course code	AM_450146 ()
Period	Period 2
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. M. ter Voorde
Examinator	dr. M. ter Voorde
Teaching staff	dr. M. ter Voorde
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective
After having attended this course, the student should have gained knowledge and understanding about
- The interplay of (physical) mechanisms responsible for landscape evolution
- The relative importance and the mutual interaction between these processes
- The methods to put constraints on these processes from geological data, and the strength and limitations of these methods
as well as the skills to
- Read and critically assess significant literature about these subjects
- Actively participate in (oral) discussions about these subjects
- Judge research methods applied on this subject critically on their merits and weak points

- Compare and/or combine the results of different studies.

This implies that the course is not mainly focused on acquiring new knowledge, but especially on using, integrating and reflecting on the things you may have learned before.

Course content
This course deals with the parameters regulating the production, transfer and storage of sediments and solutes from their sources to their sinks, addressing short-term and long-term landscape evolution and sustainability. It covers the linked processes of tectonics, weathering, erosional systems (fluvial, glacial, marine) and climate changes, including ‘real-world’ examples on the SE Netherlands, the Ardennes, the Pyrenees and western Scandinavia, as well as the methods to constrain these processes (e.g. provenance studies and thermochronology). Lecturers from a variety of disciplines will teach the student how to view these topics from various backgrounds.

Form of tuition
Lectures, exercises, literature study. A selected set of papers will be used for a 'PhD- defense'-role play. In addition, numerical modelling of topography development will be carried out by the students.
Aantal contact-uren: 45 (inclusief tentamen)

Type of assessment
Exam (45%), essay (20%), computer-practicum report (10%) PhD-defense-"game"(25%).

Course reading
• Book:
Tectonic Geomorphology, D.W. Burbank and R.S. Anderson, 2nd edition, 2011. John Wiley & Sons, 320 pp.

Additional papers, which will be made available via Blackboard

Target group
Masterstudents GBL, Earth Sciences Solid Earth, Earth Sciences AEG, Earth Sciences Paleoclimate and Geo-ecosystems

Geothermal Energy

Course code	AM_450409 ()
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. M.P. Bokhorst
Examinator	dr. M.P. Bokhorst
Teaching method(s)	Lecture, Computer lab
Level	500

Course objective
• To provide students with an overview of the current status and future outlook of geothermal exploration and production (heat/cold and electricity)
• To assess its impact in the energy-transition challenge, being a

major alternative source for renewable energy.
• To provide insight into the energetical and economical aspects of different ways to supply thermal energy to buildings and processes.
• To review main categories of operational geothermal systems, the governing processes and relevant boundary conditions, linking hydrogeology to subsurface understanding
• To assess exploration concepts of geothermal prospecting and see how they can be applied to future subsurface analysis and energy supply prediction
An additional practical aim is to improve your communication and writing skills.

Course content
This course provides a comprehensive overview of existing systems that are used to supply thermal energy to buildings and/or industrial processes. The course starts with a general introduction to the history of geothermal exploration and production, what kind of geothermal systems exist, and how these are linked to particular subsurface and economical conditions. In addition it is explained what benefits of geothermal energy exist compared to other energy resources.
Subsequently different aspects are explained in more detail. We will first
concentrate on the demand side, by showing how the heat and cold demand of a building can be provided by different types of energy systems and how the economical aspects of the different options relate. Later on we will focus on the hydrogeological parameters that contribute to successful geothermal systems. This is achieved through a review of several such systems, including borehole heat exchangers (closed loop systems), aquifer thermal energy storage (ATES or open loop systems) and systems for the production of deep geothermal heat for heating and/or electricity production (enhanced geothermal systems). Special emphasis is placed on the relation of subsurface conditions and operational excellence.
During the course the students are put in the role of consultants that have to choose an optimal solution for the customer. A business case is build in which different geothermal options have to be considered and compared to a conventional solution for climate control in the buildings concerned.

Form of tuition
The course uses two different methods:
Oral lessons in the form of lectures and tutorials/seminars (distributed equally) where various topics are presented by the lecturer and discussed in common with the students. Students must be aware that the content of this course is difficult to find in one-two textbooks. Therefore, understanding the handouts is essential. Our advice is to attend the oral lessons during class hours. Further students are expected to read and present material from selected papers in a short presentation and abstract.
Practical lessons: this course includes a number of practical exercises and a few case studies. Exercises and case studies will be worked out individually and in small groups and discussed in class. The rule of thumb: this is individual work, unless otherwise specifically noted.

Type of assessment
The final mark is made up of assignments (10%), a presentation, an excursion(10) and a 1-page abstract of relevant paper(s) (10%) and case studies (70%).
The practicals and case studies will cover the topics presented

during the course.

Course reading
All materials will be digitally provided through Blackboard

Entry requirements
To facilitate a rapid in- depth study at MSc level, students are required to know in advance basic notions of hydrogeology (groundwater flow, impact of wells on hydraulic head) which were already studied during their BSc curriculum. Furthermore sufficient knowledge of mathematics and MS Office (Excel) is required.

Global Biogeochemical Cycles

Course code	AM_450332 ()
Period	Ac. Year (September), Period 4
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. G.R. van der Werf
Examinator	prof. dr. G.R. van der Werf
Teaching staff	dr. J. van Huissteden
Teaching method(s)	Computer lab, Lecture
Level	400

Course objective
To understand and quantify the role of biogeochemical cycles (Carbon, Nitrogen, Phosphorus, Water) in the Earth system.

Course content
The course starts with an overview of the major global biogeochemical cycles, their role in the Earth system, and how they are modified by humans. The main subject is exchange of C, N, P, and S between the soil, water, atmosphere, and biota on global and local scales in different climatic zones (tropics, temperate, boreal and arctic zone) and environments. We address the relation of biogeochemical cycles with the climate system. Each week consists of two lectures where the first one serves as a more introductory lecture and the second a more in-depth view of a theme in global biogeochemical cycles. The themes include: 1) the global terrestrial carbon cycle, 2) forests, 3) the nitrogen cycle, 4) the oceanic carbon cycle, 5) oceanic cycles of N, P, and S, 6) the arctic region, and 7) disturbances including deforestation and forest fires.

Form of tuition
12 Lectures, assistance with essay writing

Type of assessment
Written exam (50%) and essay (50%)

Course reading
W.H. Schlesinger: Biogeochemistry: An analysis of Global Change, 3th edition (Academic Press), lecture notes and literature made available during the course.

Target group
MSc students Earth Sciences, Hydrology, Environment and Resource management

Groundwater Flow Modelling

Course code	AM_450008 ()
Period	Ac. Year (September)
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective
This course module will no longer be offered. It has been replaced by Advanced Groundwater Processes.

The student: (1) has knowledge and insight in the terminology and the conceptual and mathematical theory of groundwater flow modelling; (2) is able to build and program basic groundwater models using the finite-difference technique and is able to apply professional groundwater modelling software packages; (3) understands a range of professional literature, can judge its quality and (4) shows awareness of the limitations of models.

Course content
Groundwater flow models are a powerful tool to study the movement of water in the subsurface. They are so widely-used in both research and consultancy that every hydrology graduate should have the skills to understand and use groundwater flow models. This course deals with the simulation of groundwater flow using numerical methods. The topics covered include the fundamentals of numerical solution schemes (finite-difference and finite-element methods), conceptual model development, model design, model calibration, controlling error, various types of model use. Computer laboratories are an integral part of the course. Students learn to create simple models themselves (Python, spreadsheets) and build more complicated models using existing, dedicated groundwater modelling software (MODFLOW) and more generic modelling codes (FlexPDE).

Form of tuition
The course consists of 12 sessions. The first part of each session (~ 1.5 hr) comprises the following elements: lecture and discussion of studied text from the course notes. Starting from session 3, each session a small team of students also presents/evaluates a studied paper. During the second part of each session (~ 2 hr) students can work individually on computer laboratories/tutorials in a computer room. Supervision is available from session 4. The remaining time (~126 hr) should be devoted to self-study including preparation study for the sessions and for the written exam and finalizing the computer assignments.

Type of assessment
Written exam (60%) + modelling assignments (40%).

Course reading
Course notes and online materials referred to therein:

Chiang and Kinzelbach [1998] Processing modflow: a simulation system for modeling
groundwater flow and pollution
http://www.pmwin.net/programs/prevpm/pm4/doc/pmwin41.pdf

Konikow, L.F. [2000] Use of numerical models to simulate groundwater flow and
transport. In: Environmental isotopes in the hydrological cycle – principles and
applications; Volume IV Groundwater: unsaturated and saturated zone. W.G. Mook, Editor.
IAEA Vienna. http://www-naweb.iaea.org/napc/ih/documents/global_cycle/vol%20VI/VI_Ch4.pdf

Reilly, T.E. [2001] System and boundary conceptualization in ground-water flow
simulation. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Applications of Hydraulics, Chapter B8
http://pubs.usgs.gov/twri/twri-3_B8/

Reilly, T.E., and A.W. Harbaugh [2004] Guidelines for evaluating ground-water flow
models. U.S. Geological Survey Scientific Investigations Report 2004-5038 http://pubs.usgs.gov/sir/2004/5038/

Additionally: paragraphs 7.2-7.4 of Domenico, P.A. & F.W. Schwartz, 1998, Physical and chemical hydrogeology, 2nd edition, Wiley.

Entry requirements
Successful participation requires a thorough background in Groundwater Hydraulics (450009). A good conceptual understanding of groundwater flow systems and its relationship with catchment hydrology is also recommended. Courses which contribute to the latter understanding are several 1st year MSc courses, notably Catchment Response Analysis (450003) and Field Course Hydrology Portugal (AM_1013).

Target group
2nd year students in the Hydrology Master

Groundwater Hydraulics

Course code	AM_450009 ()
Period	Ac. Year (September)
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Teaching method(s)	Seminar
Level	400

Course objective
This course module will no longer be offered. It has been replaced by Groundwater Processes.

The student has profound knowledge and insight in the terminology and the theory of groundwater hydraulics; in particular the mathematical notion and its physical meaning. The student can apply the theory to a range of basic/classical problems using graphical and analytical solution methods and has knowledge of the limitations of applicability of the methods used.

Form of tuition
The course consists of 12 working lectures of about (~ 4 hr) each. The sessions comprise the following elements: lecture, discussion of studied theory, and desk exercises. The practicing with exercises is supervised; answers to exercises are published on blackboard after each session. The remaining time (~120 hr) should be devoted to self-study including preparation study for the sessions and for the written exam.

Recommended background knowledge
Successful participation requires a good background in mathematics (notably algebra, vectors, differentiation, (partial) differential equations and integral calculus) and physics (in particular dimensional analysis and working with units) at the level of the BSc course Wis- en Natuurkunde (450073). Familiarity with basic groundwater hydrology (e.g., Inleiding Hydrologie 450024 / Inleiding Hydrologie en Klimatologie AB_1074) is also recommended.

Target group
Students in the Hydrology Master

Groundwater Microbiology and Geochemistry (Geomicrobiology)

Course code	AM_450132 ()
Period	Ac. Year (September)
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	U. Nunes da Rocha
Examinator	U. Nunes da Rocha
Level	400

Course objective
At the end of this interdisciplinary course, students will be able to describe and explain:
- Aspects of the growth and cellular functioning of microorganisms
- The role of microorganisms in nutrient cycli
- Important microbial processes in polluted and pristine groundwater ecosystems
- The dependency of microbial presence and activity on environmental conditions
- Modern methods in microbial ecology

Students can relate the obtained knowledge to hydrology.

Course content
Theory will consist of:

Introduction to environmental microbiology:

- Microbial growth, metabolism and kinetics in relation to environmental conditions.
- Types and diversity of micro-organisms in groundwater ecosystems.
- Interactions between micro-organisms.
- Basics of molecular microbiology; overview of modern techniques in microbial ecology and biogeochemistry.

Impact of microbiological processes on hydrochemistry:
- Microbial contribution to important biogeochemical processes and nutrient cycles.
- Microbial mediated mineral dissolution and precipitation.

Degradation of organic contaminants in groundwater:
- Biodegradation, bioremediation and "natural attenuation" of pollution.

Form of tuition

~90 hours of guided self-study (the student will study the book Brock Biology of Microbiology, on basis of 5 modules containing instructions and about 20 questions per module), 70 hours for essay writing. After each of
the five modules, the student and lecturer discuss the answers (~1 h per module).

Type of assessment

Written essay (70% of final mark) on a geo-microbiological subject, linked to the interests of the student and general course content. Oral discussion on the essay and studied text (30%).

Course reading

Michael T. Madigan, John M. Martinko, Kelly S. Bender, Daniel H. Buckley, David A. Stahl (2014), Brock biology of microorganisms, 14th edition. Pearson Higher Education. ISBN-3: 9781292018317 (about 85 euro)
[you may also use the 13th edition]

Weber K.A. et al.(2006), Microorganisms pumping iron: anaerobic microbial iron oxidation and reduction. Nature Reviews in Microbiology, 4, p. 752-764.

Handout for guided self-study (via lecturer).

Registration procedure

The course can be started at any time during the academic year, in consultation with the coordinator

Remarks

This course is an elective option for master students in Hydrology. The course is also open to students in the masters Biology and Earth Sciences. Part of the content can be adapted to fit the interest and educational background of the student. Students are advised to contact the coordinator before starting.

Groundwater Processes

Course code	AM_1164 ()
Period	Period 4
Credits	6.0
Language of tuition	English

Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. ir. Y. van der Velde
Examinator	dr. ir. Y. van der Velde
Teaching method(s)	Seminar
Level	400

Course objective
The objective of the course on Groundwater Processes is to gain knowledge and insight in the terminology and theory of groundwater hydraulics, including its mathematical notation and physical meaning.

Course content
The movement of groundwater through the subsurface is a fundamental part of the hydrological cycle. In this course, you will get acquainted with the fundamental hydraulics of groundwater flow. You will get profound insight into fundamental hydrological concepts related to groundwater flow and its mathematical notation and solutions. The application of this knowledge will be illustrated using some basic groundwater flow modelling exercises.

Form of tuition
The course consists of a set of lectures supplemented with practicals.

Type of assessment
Written examination

Target group
Hydrology MSc students and other earth sciences related MSc programs

Hydrochemistry

Course code	AM_450052 ()
Period	Ac. Year (September)
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Teaching method(s)	Seminar, Computer lab, Practical
Level	400

Course objective
This course module will no longer be offered. It has been replaced by Water Quality.

To acquire a qualitative and a quantitative insight in how biogeochemical processes and the geochemical composition of the subsurface determine and change the chemical composition of water during the hydrological cycle: from precipitation, via soil, and groundwater, to surface water. To be able to interpret hydrochemical data with various methods, and to apply the numerical geochemical model PHREEQC to hydrochemical problems and interpret the simulation results. To obtain basic skills in performing laboratory analyses.

Course content

Hydro(geo)chemistry is essential for solving problems related with (ground)water quality and ecohydrology. The following topics are included: sampling and analysis of (ground)water; thermodynamics and kinetics of hydrogeochemical processes; reactive properties of hydrogeological systems; dissolution and precipitation of minerals; carbonate chemistry; weathering of silicates; cation exchange; surface complexation; redox-processes; effects of evaporation and mixing of different water types; introduction to geochemical modelling; lab and field analysis of inorganic solutes in water.

Form of tuition
Working lectures (8x4 hours), Computer practical (4x4 hours), Lab practical (1x4 hours). Total contact hours is 52 hours.

Type of assessment
Written examination of lecture-subjects (100%); evaluation of computer and laboratory practical reports (pass/no pass).

Course reading
C.A.J. Appelo & D. Postma, 2005. Geochemistry, groundwater and pollution. 2nd edition; digital content distributed via blackboard: lecture slides, course manual, computer and lab practical manuals.

Entry requirements
inleiding in de anorganische geochemie (450022; BSc Earth Sciences) or course of similar level (to be decided by dr. B.M. van Breukelen).

Target group
Hydrology Master students

Hydrological Systems and Water Management

Course code	AM_1012 ()
Period	Ac. Year (September)
Credits	3.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	drs. W.J.A. Stuijfzand
Examinator	drs. W.J.A. Stuijfzand
Teaching staff	drs. W.J.A. Stuijfzand
Teaching method(s)	Study Group, Lecture
Level	400

Course objective
To provide insight into: groundwater occurrences on earth in various aquifer systems; actual and ancient recharge and discharge; methods of hydrological and hydrochemical systems analysis; groundwater monitoring and tracing; palaeogroundwater; the effects of groundwater pumping; fresh/salt relationships; and water management with emphasis on MARS (Managed Aquifer Recharge Systems), artificial recharge and river bank filtration in particular.

Course content
After introducing the concepts of porosity and permeability the hydrogeological characteristics of various regions in the world are

explored, in connection with their geomorphology, lithology / sedimentology and structural geology.
Groundwater mapping techniques based on both a hydrological and hydrochemical systems analysis are presented. The dynamics in flow and chemistry of groundwater are elucidated and explained in terms of natural and man-made variations in groundwater recharge and discharge, fresh and salt water intrusion / inundation, pollution and leaching of aquifers, and climate change.
The occurrences of and how to recognize palaeogroundwater are explained.
Environmental effects of groundwater pumping, like wetland degradation, land subsidence, salinization and acidification pass in review.
Methods are presented, to monitor groundwater pressure and quality, to determine the origin and age of groundwater, and to image groundwater flow using physical, chemical and isotope tracers. Various techniques are presented to manage groundwater in stressed environments. The focus is here on MARS (Managed Aquifer Recharge Systems, like artificial recharge and river bank filtration). Special attention is given to define suitable hydro(geo)logical settings for MARS and to optimize water quality improvements during aquifer passage.

Form of tuition
Lectures (~24 contact hours), practical exercises (8 hours), literature study (60 hours).

Type of assessment
Written examination (100%)

Course reading
a) Hydrochemistry and Hydrology of the coastal dune area of the Western Netherlands. Available via Stuyfzand (25 €).
b) Syllabus (from Blackboard).
c) Physical and Chemical Hydrogeology by Schwartz & Domenico (1998 or later): Available at Geo-VUsie (10% discount).

Additional reading (not obligatory)
• De Vries, J.J. 2002. Regional Hydrogeology. Course syllabus 2nd edition, ca. 167p. Available through Stuyfzand (10 €).
• Dufour, F.C. 2000. Groundwater in the Netherlands; facts and figures. NITG-TNO Delft, Ch.7-12.
• Davis & de Wiest 1966. Hydrogeology. Available in Library.

Entry requirements
450024 (Inleiding Hydrologie)

Recommended background knowledge
Advice regarding previous courses taken: AB_450024: Inleiding Hydrologie.

Remarks
For questions regarding the course, besides ‘contact hours’, you can contact:
Prof. dr. Pieter Stuijfzand, room E-237, phone 020-5987.968 (VU) or 06-10945021 (mobile), pieter.stuyfzand@falw.vu.nl or pieter.stuyfzand@kwrwater.nl

Integrated Modeling in Hydrology

Course code	AM_1165 ()

Period	Period 3
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. H. de Moel
Examinator	dr. H. de Moel
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective
The objectives of this course are for the students to:
- get acquainted with the wide range of modeling tools used in integrated hydrological studies
- understand the type of questions that can be answered using such tools
- acquire hands-on modelling skills and gain experience with some commonly used analytical programs (Matlab, GIS, Excel)

Course content
The course is set up with a limited amount of lectures and two large exercises. In these exercises the students will set up and apply their own models from start to finish. The first exercise concerns a spatial rainfall-runoff model using publicly available data sources. This model will be used to simulate river discharge under current and future climatic conditions, and results will be related to water resources availability and associated measures. The second exercise is a flood risk assessment where hazard, exposure and vulnerability will be combined to estimate flood risks. Using the model, measures will be evaluated on their risk reducing effect.

Form of tuition
There will be a limited amount of lectures (in mornings) as the focus is on the development of the two exercises. Practical sessions are scheduled throughout the period where staff will be available to help with technical questions and to help start up the model development. The rest of the time students will work on their models, analyses and reporting themselves.

Type of assessment
Assessment will be done in the form of a report and a presentation related to the assignments.

Course reading
Relevant course reading material (papers, reports) will be provided via blackboard

Target group
Hydrology MSc students and other earth sciences related MSc programs

Isotope Hydrology

Course code	AM_450148 ()
Period	Ac. Year (September)
Credits	3.0
Language of tuition	English

Faculty	Fac. der Aard- en Levenswetenschappen
Teaching method(s)	Seminar
Level	400

Course objective
The objective of this course is to provide students with a basic understanding of the isotopic variations in water and its solutes, and fractionation and mixing processes in order to i) know which isotope analyses could be useful for certain hydrological problems and ii) be able to read and understand literature on isotope hydrology.

At the end of this course students should be able to:
• Discuss the spatial and temporal variation in the isotopic composition of water and dissolved CO2
• Discuss the fractionation and mixing processes that determine the isotopic composition of water and solutes
• Solve simple fractionation and mixing problems
• Discuss how radioactive and stable isotopes can be used for age dating of young and old groundwater and streamflow
• Discuss how radioactive and stable isotopes can help to improve our understanding of physical processes (e.g. groundwater recharge and runoff generation mechanisms) and hydrogeochemical processes (e.g. sulphate reduction, carbonate dissolution) in the hydrological system
• Determine which isotope measurements may help solve a particular research question and have obtained a general awareness of how isotope data can be helpful in hydrological studies.

All courses in the MSc Hydrology programme contribute to certain educational Dublin Criteria that lead to the student reaching the final attainment levels defined for the Hydrology Master's. The Isotope Hydrology course contributes to:
• Knowledge and understanding – knowledge and insight into the subject is obtained through studying the theory as provided during the lectures, in the text books, and through self-study of scientific papers
• Application of knowledge and understanding – analysis of data during lectures and take-home assignments provides the skills and understanding required to process and analyse isotope data
• Critical judgment – the student is encouraged to critically judge published scientific work

Course content
After falling on the earth as precipitation, water is redistributed repeatedly in vegetation, soil, groundwater, rivers, and lakes, until it sooner or later returns to the atmosphere. During this course, water also continuously changes in solute content. The isotopes of water and its solutes are ideal tools for tracing the various hydrological processes. As such isotope hydrology is applied in scientific studies to obtain more insight in these processes, as well as for practical purposes like understanding the runoff behaviour of rivers, the effects of land-use and climate change on streamflow and recharge, groundwater exploration and management, and assessment and monitoring of water pollution.

Isotope hydrology deals mainly with the isotopes 18O, 2H and 3H in water and 3He, 4He, 13C, 14C, 15N, 34S, 37Cl, 87Sr, and 222Rn in solutes. These isotopes are diagnostic for water and solute transport and many hydrogeochemical processes. This course discusses the isotopic processes of mixing, fractionation, and decay, which lead to endless variations of isotopic ratios in nature. These patterns in space and time enable us to determine and quantify the origin and age of water, water and solute fluxes, and chemical reactions.

Form of tuition
There are six lectures: 2 introductory lectures, 2 lectures on isotopes in groundwater, and 2 lectures on isotopes in surface water. There is a short lab visit during one of the lectures. Students are expected to make the assignments before the lectures as these will be discussed during the lectures.

The number of contact hours is in the order of 25.

Type of assessment
The grade for this course is based on the written exam (100%). The written exam is a closed book exam and consists of open ended questions, simple calculations, and interpretation of graphs.

Course reading
Books:
• International Atomic Energy Agency and United Nations Educational, Scientific and Cultural Organization (2000) Environmental Isotopes in the Hydrological Cycle: Principles and Applications (selected chapters)
• Mook, W.G. (2005) Introduction to Isotope Hydrology. IAH series International Contributions to Hydrogeology. Taylor & Francis, London. ISBN 0415-39805-3 (selected chapters)
• Kendall C. and J.J. McDonnell (Eds.) (1998) Isotope Tracers in Catchment Hydrology, Elsevier Sci., ISBN 0-444-50155-X (selected chapters)
• Clark, I.D. & P. Fritz (1997) Environmental Isotopes in Hydrogeology. CRC Press, ISBN 1566702496. (selected chapters)

Articles:
• Broers, H.P. (2004) The spatial distribution of groundwater age for different geohydrological situations in The Netherlands: implications for groundwater quality monitoring at the regional scale. Journal of Hydrology 299: 84-106.
• Edmunds, W.M. et al. (2006) Groundwater recharge history and hydrogeochemical evolution in the Minqin Basin, North West China, Applied Geochemistry 21 (12): 2148-2170.
• McGuire and McDonnell (2006) A review and evaluation of catchment transit time modeling, Journal of Hydrology 330: 543-563.
• Vitvar et al. (2005) A Review of Isotope Applications in Catchment Hydrology, Isotopes in the Water Cycle, 151-169.

Target group
M.Sc. Hydrology students

Remarks
Advice regarding previous courses taken: Inleiding hydrologie (bachelor course) 450024, Geochemie voor aardwetenschappers 450068 (bachelor course), and Hydrochemistry 450052 (master course Hydrology).

Master Thesis Hydrology

Course code	AM_1170 ()

Period	Ac. Year (September)
Credits	36.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. H. de Moel
Level	600

Course objective
To conduct a research project in the scope of the MSc program Hydrology. The student will learn to develop his/her own research question, plan this research, collect data, perform analyses, draw proper findings and report on this.

Course content
The student will set up, execute and report on a research project on a hydrological topic. This research and report serves as the final activity of the student within the MSc program where knowledge and skills obtained during the program are integrated and demonstrated by the student.

Form of tuition
This is course consist of self-study by the student, under guidance of a supervisor from the staff related to the MSc hydrology.

Type of assessment
Written report/paper and oral presentation.

Entry requirements
A minimum of 36 ects is required before starting with this thesis project.

Target group
MSc Hydrology students

Measuring Techniques in Hydrology

Course code	AM_1168 ()
Period	Period 5
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. R. Lasage
Examinator	dr. R. Lasage
Teaching method(s)	Seminar, Computer lab
Level	400

Course objective
The objective of this course is to familiarize students with measurement methods and techniques from different disciplines, that are commonly used in hydrology and related environmental sciences. The course is divided into 3 modules, in four weeks. The three parts are focused on measuring hydrological processes: Module 1 focuses on measuring techniques to understand and quantify the basic processes in the water

balance and hydro chemistry, such as measuring discharge and rainfall. Module 2 focuses on using remote sensing to measure variables such as soil moisture and vegetation characteristics. Module 3 focuses on measuring the effects from hydrological processes (water availability and quality, and extremes such as floods) on people and the economy. For this, students will learn how to design, conduct, and statistically analyse a household survey to quantify economic impacts.
At the end of the course the student should be able:
1. to select the appropriate field measurement methods and techniques to measure hydrological processes and impacts on society;
2. to implement the methods and techniques, including equipment operation;
3. to analyse, evaluate and interpret the results, using computer models and statistical methods;
4. to carry out the final integrating fieldwork, which directly follows this course, and other research projects independently.

Course content
Module 1. Hydrological field tools
This part of the course deals with a broad range of field measurement aspects of hydrological studies. Practical research experience is gained through a study of the water balance and hydrochemistry of the field area. This includes instructions in geohydrological, meteorological, and hydrochemical measurement techniques that are commonly used in surface and groundwater movement studies and in water quality investigations. Spatial data collection and processing methods are practiced through the use of portable geographic information systems. Key course subjects are installation of hydro-meteorological equipment for measuring rainfall, temperature, water level and discharge, soil and aquifer permeability measurements, soil moisture and tension measurements, water sampling and chemical analysis, datalogger programming, data processing and analyses.
Module 2. Remote sensing
This module will make the student more familiar with remote sensing and the main objectives of this module are: (i) to understand the fundamental characteristics of electromagnetic radiation and how this interacts with vegetation, soil, rock and water; (ii) to understand and master the methodology behind a large variety of remote sensing applications related to land surface observations, including a clear understanding of the limitations of these observations; (iii) to develop practical computer skills to use remote sensing products in environmental studies. During the lectures the physical basics and mathematical principles of remote sensing will be discussed. During the practical exercises we will use a suite of remote sensing-derived environmental data from satellites to derive information on geology, soil, water, and vegetation. The focus is on the integration of several remote sensing techniques in hydrological analysis and modeling
Module 3. Measurement of economic values of water
The discipline of environmental economics has developed stated preference techniques whereby non-market values of water can be estimated, such as those related to water quality, amenities of water and the control of water risks. This module will make students familiar with these techniques, such as contingent valuation and choice experiment methods that elicit water related values using surveys of households. During the lectures these techniques as well as the design of surveys will be discussed. Moreover, students will get hands on experience with data collection by conducting a stated preference survey in the field. In a practicum class students will learn to analyse the data they collected using statistical methods.

Form of tuition
Lectures, practicals, field practicals.

Type of assessment
Written exam, assignment report, participation during field practical.

Course reading
Will be provided by the teachers

Modern Climate and Geo-ecosystems

Course code	AM_1124 ()
Period	Period 1
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. G.M. Ganssen
Examinator	dr. G.M. Ganssen
Teaching method(s)	Excursion, Seminar
Level	400

Course objective
In the first part the course gives an introduction of modern atmospheric and oceanic processes which form an important basics for the reconstruction of the climate of the past. Next to important basic parameters which trigger the modern circulation of both spheres, atmosphere and oceans, the main circulation paterns will be discussed together with the implications for the global climate.
In the second part the modern ocean changes and their implications for the geoecosystems will be discussed. Together, this will form the basic understanding of processes which govern changes in the geological past.

Course content
-the basic parameters and properties for atmospheric and ocean processes leading to the formation and circulation of air and water masses
- characterization of climatic regions of the world from the poles to the tropics
- special features of the climate systems like the monsoon, ENSO and NAO systems
- the effect of ocean changes on geoecosystems now and in the recent past

Form of tuition
Lectures and workshops, literature reading, oral and written presentations by the students and discussing the results and quality of the presentation

Type of assessment
Written exam after week 2 about the basics (50% of the grade)
oral and written presentation of a topic (second part of the course, 50% of the grade)

Course reading

Lecture notes (powerpoints of the presentations by the teacher), selected papers and Ruddiman, W.F., 2013. Earth's Climate: past and future.W.H. Freeman and Company New York.

Entry requirements
Some basic knowledge of the climate system, interest in climate change

Target group
Students from the geo and environmental study areas

Registration procedure
Subscription via BB

Reflection Seismic for Geologists

Course code	AM_450170 ()
Period	Period 4
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. J.J.G. Reijmer
Examinator	prof. dr. J.J.G. Reijmer
Teaching method(s)	Seminar, Computer lab
Level	500

Course objective
The participant is expected to collect sufficient understanding of the fundamentals and the limitations of the applications of reflection seismology as a tool to predict the structure and geology in the shallow to deeper (100's to 1000's of metres) subsurface. The aim is to derive the evolution of sedimentary basins and underlying crust by using seismostratigraphic and structural interpretation of seismic lines. In particular, the participant will learn:
 the application of technical and methodological principles of reflection seismology to real situations;
 the basic principles linking geology and reflection seismology, including an introduction to petrophysics;
 seismic workstation skills for seismic interpretation, and
 how to extract reliable information on sequence stratigraphy and structure from seismic reflection and well log data.

Course content
Assuming a basic knowledge of the principles of reflection seismology, this course provides a modular programme with hands-on experience on interpreting seismic lines and integrating data from well logs, principles and interpretation of reflection seismic data and geology. Special attention will be paid to pitfalls in data acquisition, processing and interpretation. The course will use in part similar methodologies used in hydrocarbon exploration and development.
The course is constructed in 5 parts:
 Part 1 Introduction to seismics. The introduction will cover the technical and methodological broadband principles of reflection seismology. Note that this section will build on already existing Applied Geophysics course knowledge;
 Part 2 Introduction to interpretation. Students will learn how to

interpret basic geological features, such as strata relationships, faults and folds as well as the reliability of seismic interpretation at various scales;

Part 3 Seismic sequence stratigraphy. Learning seismostratigraphy will mean in practice how to extract stratigraphic, sedimentological and basin evolution information from seismic data. This information is used as a tool in exploration and basin analysis to derive regional analysis of sedimentary basin-fills with a view towards constructing models for gross lithology prediction. It is recommended that students remind themselves the principles and methodology of sequence stratigraphy, already acquired during their BSc courses;

Part 4 Seismic structural interpretation. This section will provide students with the knowledge of interpreting deformation structures at various scales;

Part 5 Interpretation on workstation. This section gives the students the opportunity to work on case studies by using standard workstation methodologies for seismic interpretation. Students will learn how to handle, visualize and interpret 2D and 3D seismic data using a standard industrial software package;

Part 6 Integrating wells with seismics for seismostratigraphy, deriving basin evolution. The section will give students the chance to start from reflection seismic and correlative well interpretation to derive the evolution of sedimentary basins at local and regional scale.;

Part 7 Advanced seismic interpretation This section will give students the opportunity to work with advanced methodologies of seismic interpretation specific for petroleum exploration.

Form of tuition

The course uses two different methods:

Oral lessons, where the lecturer presents various topics. Students must be aware that the content of this course is difficult to find in one-two textbooks. Therefore, understanding the handouts is essential. Our advice is to attend the oral lessons during class hours.

Practical lesson; the bulk of this course is made up by a large number of practical exercises and a few case studies. You will have to hand in at the end of the course a part of these for evaluation purposes, as noted by the staff. Make sure you understand which are those exercises and case studies needed for evaluation. The thumb rule: this is individual work, unless otherwise specifically noted.

Type of assessment

The final mark is made up by 50% the practical exercises and case studies handed in at the end of the course and 50% the final examination. The practical exercises and case studies must be handed in no later than one day prior to the final examination. The exam will cover the topics presented during course. It is typically organized in blocks of questions from every part of the course AND 2 - 5 data sets (seismic lines) which you will be asked to interpret in terms of specific issues.

Course reading

All materials will be digitally provided through Blackboard.

Remarks

Teaching staff: John Verbeek

Scientific Writing in English

Course code	AM_471023 ()
Period	Period 2, Period 5
Credits	3.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	M. van den Hoorn
Examinator	M. van den Hoorn
Teaching method(s)	Study Group
Level	400

Course objective
The aim of this course is to provide Master's students with the essential linguistic know-how for writing a scientific article in English that is well organized idiomatically and stylistically appropriate and grammatically correct.
At the end of the course students
- know how to structure a scientific article;
- know what the information elements are in parts of their scientific article;
- know how to produce clear and well-structured texts on complex subjects;
- know how to cite sources effectively;
- know how to write well-structured and coherent paragraphs;
- know how to construct effective sentences;
- know what collocations are and how to use them appropriately;
- know how to adopt the right style (formal style, cohesive style, conciseness, hedging)
- know how to avoid the pitfalls of English grammar;
- know how to use punctuation marks correctly;
- know what their own strengths and weaknesses are in writing;
- know how to give effective peer feedback.

Final texts may contain occasional spelling, grammatical or word choice errors, but these will not distract from the general effectiveness of the text.

Course content
The course will start with a general introduction to scientific writing in English. Taking a top-down approach, we will then analyse the structure of a scientific article in more detail. As we examine each section of an article, we will peel back the layers and discover how paragraphs are structured, what tools are available to ensure coherence within and among paragraphs, how to write effective and grammatically correct sentences and how to choose words carefully and use them effectively.

Topics addressed during the course include the following:
- Structuring a scientific article
- Considering reading strategies: who is your readership? How do they read your text? What do they expect? How does that affect your writing?
- Writing well-structured and coherent paragraphs
- Composing effective sentences (sophisticated word order, information distribution).
- Arguing convincingly – avoiding logical fallacies
- Academic tone and style: hedging – why, how, where?

- Using the passive effectively
- Understanding grammar (tenses, word order, etc.)
- Understanding punctuation
- Referring to sources: summarising, paraphrasing, quoting (how and when?)
- Avoiding plagiarism
- Vocabulary development: using appropriate vocabulary and collocations

Form of tuition
Scientific Writing in English is an eight-week course and consists of 4 contact hours during the first week and 2 contact hours a week for the rest of the course. Students are required to spend at least 6 to 8 hours of homework per week. They will work through a phased series of exercises that conclude with the requirement to write several text parts (Introduction, Methods or Results section, Discussion and Abstract). Feedback on the writing assignments is given by the course teacher and by peers.

Type of assessment
Students will receive the three course credits when they meet the following requirements:
- Students hand in three writing assignments (Introduction, Methods or Results, Discussion) and get a pass mark for all writing assignments;
- Students provide elaborate peer feedback;
- Students attend all sessions;
- Students are well prepared for each session (i.e. do all homework assignments);
- Students actively participate in class;
- Students do not plagiarise or self-plagiarise.

Course reading
Effective Scientific Writing: An Advanced Learner's guide to Better English (A. Bolt & W. Bruins, ISBN 978 90 8659 6171). VU bookstore: €27.95.

Target group
This course is only open to students of the following Master's programmes of the Faculty of Earth and Life Sciences: MSc Biology, Health Sciences, Ecology, Biomolecular Sciences, Biomedical Sciences, Neurosciences, Global Health, Hydrology, and Management, Policy Analysis and Entrepreneurship in Health and Life Sciences.

This course is an alternative for students who are not able to attend Scientific Writing in English in their designated group (this is not applicable for students Hydrology).

Registration procedure
Students should register on time by sending an e-mail to onderwijsbureau.beta@vu.nl, selfregistration in VUnet is not possible. Please note that this
course will only go through with a minimum of 18 participants andmaximum of 24. Students are advised to consult their schedule carefully,since overlap may occur.

If you are registered for a group in VUnet, you are expected to attend all sessions (eight). If you decide to withdraw fromthe course, please do so in time. This all
will avoid a 'fail' on your grade list for not taking part in this

course and allows other students to fill in a possible very wanted group spot.

Remarks
- To do well, students are expected to attend all lessons. Group schedules are to be found at rooster.vu.nl and on Blackboard.
- If you (expect to) miss a session, please inform the group trainer as soon as possible. If you miss a session without notification, you may not be able to finish the course.
- For any questions concerning this course, please contact onderwijsbureau.beta@vu.nl.

Transport Processes in Groundwater

Course code	AM_450131 ()
Period	Ac. Year (September)
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Teaching method(s)	Lecture, Computer lab
Level	500

Course objective
This course module will no longer be offered. It has been replaced by Advanced Groundwater Processes.

The aim of this course is that participants: (1) develop basic understanding of theory of reactive transport in groundwater systems and its applications (2) are able to do transport calculations for simple problems (3) acquire some experience with modelling of (more complicated) transport problems using computer software.

Course content
Hydrogeology is to a large extent concerned with flow of water in the subsurface (courses Groundwater Hydraulics and Groundwater Flow Modelling). However, numerous practical and scientific applications of groundwater hydrology involve transport of solutes (dissolved chemical species) or heat in groundwater systems, rather than the flow of groundwater itself. Examples are contaminant hydrogeology, tracer hydrogeology, sea-water intrusion, subsurface energy applications and geothermal conditions. Knowledge of transport processes and conversion processes (reactions) is of paramount importance to hydrogeologists.
Topics that will be addressed in the course are:
Fundamental transport processes: advection, diffusion, dispersion and first-order reaction (sorption and retardation) in 1, 2 and 3 dimensions. Basic behaviour of the individual and combined processes. Numerical approaches, methods and codes. The role of uncertainty in process parameters. Implications of discrepancies in scale of measurement and process scale.

Form of tuition
Working lectures, desk exercises, exercises with computer codes and case studies, a modelling or literature assignment

Type of assessment

Written exam (70%) + assignments during the course (30%)

Course reading
Course notes; Domenico, P.A. & F.W. Schwartz, 1998, Physical and chemical hydrogeology, 2nd edition, Wiley.; paper(s) assigned via Blackboard

Recommended background knowledge
Some background in partial differential equations and related math such as taught in bachelor course Wis- en Natuurkunde voor Aardwetenschappers (AB_450073) is strongly recommended. Knowledge of Groundwater Hydraulics (AM_450009), Groundwater Flow Modelling (AM_450008) and Hydrochemistry (AM_450052) is useful, but not essential.

Unsaturated Zone and Near Surface Hydrological Processes

Course code	AM_450021 ()
Period	Period 2
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	S.F. Stofberg MSc
Examinator	S.F. Stofberg MSc
Teaching staff	S.F. Stofberg MSc
Teaching method(s)	Computer lab, Seminar
Level	400

Course objective
The main objective of this course is to provide basic insight into the hydrological processes operating within the unsaturated zone as a whole, and near the surface in particular. This hydrological knowledge forms the basis for determining recharge rates, plant available water, runoff ratios, etc. It requires fundamental theoretical and practical knowledge on soil properties and the physics of soil water movement.

Course content
At the end of this course students should be able to:
• Discuss soil characteristics in relation to soil water movement and storage
• Discuss the processes that determine the storage and movement of water in the unsaturated zone, and how this affects and is affected by other hydrological processes
• Describe the various measurement techniques to determine the storage and movement of water in and through the unsaturated zone
• Produce a simple hydrological model to analyse and describe the movement of water through the unsaturated zone and analyse how this is affected by soil properties
• Discuss the objectives, advantages and limitations of hydrological models for the unsaturated zone
• Have obtained an awareness of how vegetation and land management affect soil erosion and water quality

Form of tuition
The course consists of a set of lectures supplemented with practicals.

Type of assessment
Written examination.

Target group
Hydrology MSc students and other earth sciences related MSc programs

Water and Policy

Course code	AM_468023 ()
Period	Period 1
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. J.C.J.H. Aerts
Examinator	prof. dr. J.C.J.H. Aerts
Teaching staff	prof. dr. J.C.J.H. Aerts, dr. R. Lasage, prof. dr. D. Huitema, dr. H. de Moel
Teaching method(s)	Lecture, Computer lab
Level	400

Course objective
The objective of this course is to understand how water related processes such as floods and droughts influence our society and what role water management plays in addressing and tackling these issues. This course aims to provide students a multi-disciplinary understanding of water management, including the physical dimensions of the hydrological cycle and coastal proceses,
the policy, law and long term trends such as climate change and land use change. It puts emphasis on the uncertainty of future trends and how risk management methods can be helpful for water managers for dealing with these uncertainties.

Key goals for students to reach at the end of the course are:
• To understand the complexity of various water related issues (e.g. scarcity, floods, and droughts) and to assess the economic and social impacts
• To learn what kind of measures can be taken to alleviate water related problems and what kind of positive and negative effect these measures have on different users.
• To be able to systematically approach a complex and integrated water related issue and properly interpret data and information about this issue.

Course content
Water managers see themselves confronted with a continuous stream of increasingly credible scientific information on the potential magnitude of population growth, economic activities and climate change that increase the risk related to the earth hydrological system. It is expected that floods and droughts will increasingly affect societies and economies and new approaches in water management are needed to deal with these challenges. Furthermore, developing adequate water policies that can be used in practice is a difficult issue and is the result of a complex and long-lasting process from the national through to the local level. In this process, the science of the water- and socio-economic

systems can play an important role by supplying policy makers with answers on e.g. the socio-economic effects of floods and droughts. Uncertainty in future trends further puts new challenges to water management and risk based techniques can be helpful in dealing with these uncertainties. Finally, water management increasingly needs to cooperate with spatial planners, especially in large cities, to address increasing risk from storm surges and sea level rise.

Form of tuition
This course consists of several sessions going into different subjects related to water management. These sessions will consist of lectures by the professors with interactive discussion; two practical assignments, and student presentations. Apart from these sessions, you will team up in pairs of two students to write papers on water related issues and adaptation in cities, which will be peer-reviewed by other students.
Activity Hours
1 Attending and contributing to sessions (12 times 3 hrs) 36 hours
2 Readings associated with lectures 28 hours
4 Paper: literature review (32 hours), writing (24 hours), peer review (8 hours) 64 hours
5 Exam preparation 40 hours
TOTAL 168 hours

Type of assessment
Written exam (50%), essay (40%) and peer-review (10%)

Course reading
The literature for this course consists of various academic papers and chapters. These papers will be published 3 days before the lecture

Target group
MSc students Environment and Resource Management (ERM), MSc Hydrology; Earth Sciences and Economics(ESE).

Water Economics

Course code	AM_1167 ()
Period	Period 2
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	prof. dr. W.J.W. Botzen
Examinator	prof. dr. W.J.W. Botzen
Teaching method(s)	Seminar, Lecture, Practical
Level	400

Course objective
The overarching objective of this course is to familiarize students with the economic analysis of water related problems and solutions. After following this course, students should be able to judge how well certain policy instruments and institutional arrangements perform in terms of effectiveness, efficiency and the sustainability of water management. More specifically, after having participated in this module, students should be able to answer the following questions:
- What is the fundamental nature of water related problems from an

economic perspective, in relation to notions like externalities, public goods and free riding, and what does this imply for the feasibility of (easy) solutions?
- How are water resources and the economy and society interlinked, and what are the implications of such linkages for sustainable water use?
- What are the guiding principles of economic analyses of solutions for water related problems, such as hydro-economic modelling?
- How to characterize and measure economic values of water?
- Which economic policy instruments are available for water management, and what are their (dis)advantages?
- How to conduct cost-benefit analysis (CBA) to guide the design of water management strategies and what are the critical and debatable assumptions that underlie a CBA?

Course content
The course Water Economics aims to provide methodological skills for non-economic students to analyze the drivers behind and effects of water related problems and solutions around the world, in order to move towards a sustainable use of our valuable freshwater resources. Particular topics include evaluating the costs and benefits of alternative water policies to deal with water pollution, river and groundwater ecosystem restoration, water quantity and water-related hazards, such as floods, as well as integrated hydro-economic modelling and water markets and pricing.

The course has been designed to balance learning and training skills related to both theory and applied (quantitative) methodologies. Moreover, the students will apply their newly developed skills to relevant case study areas, such as Amsterdam. Each week will center around a main specific economic topic and/or method, allowing students to learn specific skills while practicing them on specific water topics.

Form of tuition
Lectures, Practicum, Computer lab.

Type of assessment
Written exam and assignment.

Course reading
Readings will be announced on blackboard.

Target group
Hydrologist, Water Science.

Water Quality

Course code	AM_1166 ()
Period	Period 4
Credits	6.0
Language of tuition	English
Faculty	Fac. der Aard- en Levenswetenschappen
Coordinator	dr. H. de Moel
Examinator	dr. H. de Moel
Teaching method(s)	Seminar
Level	400

Course objective
The objective of the Water Quality course is to acquire fundamental knowledge on different aspects, processes and impacts related to water quality, and the role of hydrochemistry herein. At the end of the course the student will:
- be familiar with different types of pollution affecting water quality;
- understand how pollutants enter and move through the hydrological system;
- understand how pollutants interact with their environment, affecting the chemical composition of the water throughout the hydrological cycle;
- be able to interpret hydro(geo)chemical data using various methods and interpret results of analyses.

Course content
Water of sufficient quality is required for, amongst others, agricultural and domestic uses as well as for healthy ecosystems. The role of hydro(geo)chemistry is of paramount importance to study the quality of ground and surface water. In this course students will study topics related to different types of pollutions, the processes (thermodynamic, kinetic) of how such substances travel through the hydrological cycle, how properties change (reactive properties, dissolution, weathering, evaporation, mixing), and how to sample and analyse water samples to elucidate these water quality properties and changes therein (in time and space).

Form of tuition
The course consists of a set of lectures supplemented with practicals.

Type of assessment
Written examination

Target group
Hydrology MSc students and other earth sciences related MSc programs