Hydrology MSc

Vrije Universiteit Amsterdam - Fac. der Aard- en Levenswetenschappen - M Hydrology - 2013-2014

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 2013 - 2014 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 .

Inhoudsopgave

Expired programme components Hydrology

MSc Hydrology year 1

Opleidingsdelen:

- MSc Hydrology year 1 elective options
- MSc Hydrology general programme

MSc Hydrology year 1 elective options

Vakken:

Naam	Periode	Credits	Code
Applied Geographical Information Systems	Periode 2	3.0	AM_450227
Aquatic Ecology	Periode 1	6.0	AM_450137
Basics in Geographical Information Systems	Periode 5	3.0	AM_450226
Climate Modelling	Periode 3	6.0	AM_450004
Groundwater Microbiology and Geochemistry (Geomicrobiology)	Ac. Jaar (september)	6.0	AM_450132
Isotope Hydrology	Periode 5	3.0	AM_450148

MSc Hydrology general programme

Vakken:

Naam	Periode	Credits	Code
Catchment Response Analysis	Periode 1	6.0	AM_450003
Ecohydrology	Periode 2	6.0	AM_450014
Environmental Remote Sensing	Periode 3	6.0	AM_450145
Field Course Hydrology Portugal	Periode 5+6	15.0	AM_1013
Field Course Netherlands (Measurements Techniques)	Periode 5	3.0	AM_450126
Groundwater Hydraulics	Periode 2	6.0	AM_450009
Hydrochemistry	Periode 4	6.0	AM_450052
Hydrological Systems and Water Management	Periode 1	3.0	AM_1012

Unsaturated Zone and Near Surface Hydrological Processes	Periode 4	6.0	AM_450021

MSc Hydrology, year 2

Opleidingsdelen:

- MSc Hydrology year 2 elective options

Vakken:

Naam	Periode	Credits	Code
Groundwater Flow Modelling	Periode 1	6.0	AM_450008
Master Research Project Hydrology	Ac. Jaar (september)	27.0	AM_1104
Transport Processes in Groundwater	Periode 1	6.0	AM_450131

MSc Hydrology year 2 elective options

Vakken:

Naam	Periode	Credits	Code
Applied Geographical Information Systems	Periode 2	3.0	AM_450227
Aquatic Ecology	Periode 1	6.0	AM_450137
Basics in Geographical Information Systems	Periode 5	3.0	AM_450226
Contaminant Hydrogeology	Ac. Jaar (september)	3.0	AM_450133
Groundwater Microbiology and Geochemistry (Geomicrobiology)	Ac. Jaar (september)	6.0	AM_450132
Isotope Hydrology	Periode 5	3.0	AM_450148
Sustainable Land Management	Periode 3	6.0	AM_1015

Applied Geographical Information Systems

Vakcode	AM_450227 ()
Periode	Periode 2
Credits	3.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. R.A.M. de Jeu
Docent(en)	dr. R.A.M. de Jeu

Lesmethode(n)	Computerpracticum, Werkgroep
Niveau	400

Doel vak
Geographical Information systems were first developed in the early 1960s, were they were no more than a set of innovative computer based applications for map data processing that were used in a small number of government agencies and universities only. Today GIS has become an important field of academic study, one of the fastest growing sectors in the computer industry and, most important, an essential component of the information technology (IT) infrastructure of modern society.
This advanced course in GIS is developed to teach students how to use GIS in a research project. After completing this course, the student will be able to set up a GIS project individually. The student will learn how to make a reliable project plan, and how to present the results. Finally, the student will have familiarized his/herself with presenting research results in a compact and clear scientific poster and oral presentation, both in English.

Inhoud vak
This advanced course in GIS consists of a theoretical part and a specialization part, depending on the master profile. In the theoretical part the use of GIS in research is explained. The practical part focuses on the use of GIS in a chosen research project. The student will elaborate this small project into a scientific poster and a final oral presentation.

Onderwijsvorm
The course consists of 7 class meetings and 7 periods to work on your project in the computer lab. Each meeting starts with an introduction by the staff followed by group discussions, and feedback sessions. The project topics will be defined by the students and students will be working individually on their project. The staff has a list of proposed project, but the student is free to come up with their own project. The course is highly interactive and the students will be involved in the entire process from proposal to poster. In addition, they will be part of the review and evaluation process.

Toetsvorm
Scientific Poster (80 %), and oral presentation (20 %)

Literatuur
Scientific papers and handouts are provided during the course via Blackboard

Aanbevolen voorkennis
Successful completion of Basics in Geographical Information Systems (AM_450226) is strongly advised.

Doelgroep
Second-year MSc Hydrology students, MSc students from alternative Earth Sciences, Earth and Economy or Natural Sciences MSc programmes

Aquatic Ecology

Vakcode	AM_450137 ()
Periode	Periode 1

Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	prof. dr. J.E. Vermaat
Lesmethode(n)	Werkcollege, Practicum
Niveau	400

Doel vak
1. Acquire an understanding of the complexity and biotic richness of aquatic ecosystems and the importance of the medium, water, in shaping this.
2. Acquire an understanding of the links between aquatic ecology and water quality, and develop the capacity to interpret pattersn from the one into those of the other field
3. Be able to understand, summarise, and debate papers from the primary literature selected to deepen the subjects presented with help of the text book
4. Be able to design, carry out and report on a limited field study in the waters around Amsterdam and test a self-developed hypothesis

Inhoud vak
This is an introductory course to for earth scientists interested in water that want to enrich their expertise with ecology. It can also serve to add a view on aquatic habitats for ecologists that mainly have been exposed to terrestrial habitats so far. The subject is presented at a master's level with a focus on independent exploration in the field and primary literature. The course will be taught from a basic textbook, Dobson & Frid (2009), as starting point, with excursions to papers providing depth to the chapters.

Characterisation of the content: Commonalities versus specific features of aquatic ecosystems: lakes, rivers, estuaries, the sea. Interactions between water body and surrounding land (catchment). A systems perspective: important processes and the role of biota: marginal or crucial? Interactions among biota in the food-web (predation, competition) and otherwise (the role of engineers or keystone species, mutuality, mutualism). Aquatic biodiversity: what does it mean? Biota as indicators of water and sediment quality in rivers and lakes. Aquatic ecology for water quality and quantity management.

Onderwijsvorm
1. plenary lectures (5 x 4 = 20 hrs). Lecture format: Vermaat discusses chapter content, students give a brief presentation on deepening papers. Non-presenting students are expected to have prepared by reading these chapters and the two accompanying, deepening papers (see below) before the lecture. The lecture is concluded with debate on the accompanying paper.
2. comparative fieldwork in small groups of 2-4 students: spatial gradients among and within water bodies around Amsterdam (field 2 d, lab processing 2 d), concluded by student seminars on fieldwork (4 hrs); student groups write a report on their fieldwork subject (length 5-10 pp, 11 pt Times New Roman, Introduction, Method, Results, Discussion, References containing ~ 10 papers from the primary literature)
3. literature study for deepening presentations and field work report.

Toetsvorm
Written exam (60%), fieldwork report (30%), oral presentations (both on book and lab work, content and quality, 10%). The written exam is open book.

Literatuur
Book: Dobson M & Frid C., 2009. Ecology of Aquatic Systems, 2nd edition.Oxford University Press, 321 pp; ISBN: 9 780199 297542
Selected deepening papers (liable to change, will be communicated at start of course):

Rivers
Poole GC, 2002. Fluvial landscape ecology: addressing uniqueness within the river discontinuum. Freshwat Biol 47, 641-660.
Lamouroux N, Poff NL, Angermeier PL, 2002. Intercontinental convergence of stream fish community traits along geomorphic and hydraulic gradients. Ecology 83, 1792-1807

Estuaries
Bishop MJ, Kelaher BP, Smith MPL, York PH, Booth DJ, 2006. Ratio-dependent response of a temperate Australian estuarine system to sustained nitrogen loading. Oecologia 149, 701-708.
Soetaert K, Middelburg JJ, Heip C, 2006. Long-term change in dissolved inorganic nutrients in the heterotrophic Scheldt estuary (Belgium, The Netherlands) Limnol Oceanogr 51, 409-423.

Coastal Seas
Bianchi TS, Westman P, Andren T, Rolff C, Elmgren R, 2000. Cyanobacterial blooms in the Baltic Sea: natural or human-induced? Limnol Oceanogr 45, 715-726.
McQuatters-Gollop A, Raitsos DE, Attrill M, Edwards M, Lavender S, Mee L, 2007. A new long-term chlorophyll dataset reveals a regime shift in North Sea phytoplankton biomass unconnected to nutrient levels. Limnol. Oceanogr. 52, 635-648.

Open Ocean
Worm B, and many others, 2006. Impacts of biodiversity loss on ocean ecosystem services. Science 314, 787-790.
Beaugrand G, 2009 Decadal changes in climate and ecosystems in the North Atlantic Ocean and adjacent seas. Deep Sea Res II 56, 656-673.

Aanbevolen voorkennis
Basic statistics, introduction in hydrology

Doelgroep
MSc Earth Sciences (all tracks), MSc Hydrology, MSc Biology, MSc Ecology

Basics in Geographical Information Systems

Vakcode	AM_450226 ()
Periode	Periode 5
Credits	3.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	drs. A.J. Wagtendonk
Docent(en)	dr. R.A.M. de Jeu, drs. A.J. Wagtendonk

Lesmethode(n)	Computerpracticum
Niveau	400

Doel vak
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.

Inhoud vak
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. The student will be trained in the use of GIS and special attention will be paid to the use of mobile GIS systems.

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

Toetsvorm
Written exam (ca. 50%) and practical computer exam (ca. 50%).

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

Aanbevolen voorkennis
Advice regarding previous course taken: AB_!076: GIS and digital geographical data

Catchment Response Analysis

Vakcode	AM_450003 ()
Periode	Periode 1
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. M.J. Waterloo
Docent(en)	dr. M.J. Waterloo, dr. H.J. van Meerveld
Lesmethode(n)	Werkcollege, Computerpracticum
Niveau	400

Doel vak
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.

Inhoud vak
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.

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

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

Literatuur
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.

Vereiste voorkennis
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.

Aanbevolen voorkennis
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).

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

Overige informatie
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 Modelling

Vakcode	AM_450004 ()
Periode	Periode 3
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	prof. dr. H. Renssen
Docent(en)	prof. dr. H. Renssen, dr. M.J. Waterloo, prof. dr. A.J. Dolman, dr. D.M.V.A.P. Roche
Lesmethode(n)	Werkcollege, Computerpracticum
Niveau	400

Inhoud vak
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?

Onderwijsvorm
Lectures, discussion meetings and computer exercises.

Toetsvorm
Compulsory participation in discussion meetings, computer exercises, oral presentation and written exam.

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

Overige informatie
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.

Contaminant Hydrogeology

Vakcode	AM_450133 ()
Periode	Ac. Jaar (september)
Credits	3.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. B.M. van Breukelen
Docent(en)	dr. B.M. van Breukelen
Lesmethode(n)	Werkcollege

Doel vak
To understand which processes and factors determine the spreading behaviour of various groups of anthropogenic pollutants during subsurface transport; to obtain a coherent view of useful methods to investigate contaminated sites; to understand the physical/chemical/biological principles of several remediation techniques and to evaluate their effectiveness in restoring the groundwater/soil quality.

Inhoud vak
Overview of pollution sources; Properties of pollutants (sorption, volatilization, degradation); Overview of processes and factors which determine the spreading of major pollutants such as: petroleum and chlorinated hydrocarbons, pesticides, PAHs, heavy metals, radionuclides, landfill leachate, acid mine drainage, and nutrients; How to investigate contaminated sites? Approaches to reactive transport modelling; Remediation methods: pump & treat, monitored natural attenuation and active bioremediation; Environmental policy on soil and groundwater pollution.

Onderwijsvorm
Apart from one introductionary lecture, the students have to read and answer questions about a selection of research papers in preparation for each meeting. During the meetings, the questions and answers will be discussed in the group.

Toetsvorm
Written examination of lecture-subjEC and the discussed literature (70% of final mark); evaluation of assignments and participation in group discussions (30% of final mark).

Literatuur
A compilation of (scientific) literature will be provided on Blackboard. Parts of: P.A. Domenico & F.W. Schwartz, 1998. Physical and Chemical Hydrogeology. 2nd edition.

Aanbevolen voorkennis
Successful completion of Hydrochemistry (450052) and Transport Processes in Groundwater (450131) is recommended.

Ecohydrology

Vakcode	AM_450014 ()
Periode	Periode 2
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. M.J. Waterloo
Docent(en)	prof. dr. L.A. Bruijnzeel
Lesmethode(n)	Werkcollege, Computerpracticum
Niveau	400

Doel vak
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.

Inhoud vak
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.

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

Toetsvorm
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%).

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

Vereiste voorkennis
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.

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

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

Overige informatie
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.

Environmental Remote Sensing

Vakcode	AM_450145 ()
Periode	Periode 3
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. R.A.M. de Jeu
Docent(en)	dr. R.A.M. de Jeu
Lesmethode(n)	Werkcollege, Computerpracticum

Niveau	400

Doel vak
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.

Inhoud vak
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.

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

Toetsvorm
Written Exam

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

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

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

Field Course Hydrology Portugal

Vakcode	AM_1013 ()
Periode	Periode 5+6
Credits	15.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. M.J. Waterloo
Docent(en)	dr. B.M. van Breukelen, dr. H. Kooi, drs. M.M.A. Groen, dr. R.A.M. de Jeu
Lesmethode(n)	Veldwerk
Niveau	600

Doel vak
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.

Inhoud vak
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.

Onderwijsvorm
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.

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

Literatuur
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.

Vereiste voorkennis
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).

Aanbevolen voorkennis
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).

Doelgroep
First year MSc Hydrology Programme students

Overige informatie
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)

Vakcode	AM_450126 ()
Periode	Periode 5
Credits	3.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. J. Groen

Docent(en)	dr. B.M. van Breukelen, dr. J. Groen, drs. M.M.A. Groen, dr. M.J. Waterloo
Lesmethode(n)	Werkcollege, Veldwerk
Niveau	500

Doel vak
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.

Inhoud vak
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.

Onderwijsvorm
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).

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

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

Doelgroep
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

Overige informatie
Participants work in groups of three to four persons.

Groundwater Flow Modelling

Vakcode	AM_450008 ()
Periode	Periode 1
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. H. Kooi
Docent(en)	dr. H. Kooi
Lesmethode(n)	Werkcollege, Computerpracticum
Niveau	400

Doel vak
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.

Inhoud vak
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).

Onderwijsvorm
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.

Toetsvorm
Written exam (60%) + modelling assignments (40%).

Literatuur
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.

Vereiste voorkennis
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).

Doelgroep
2nd year students in the Hydrology Master

Groundwater Hydraulics

Vakcode	AM_450009 ()
Periode	Periode 2
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. H. Kooi
Docent(en)	dr. H. Kooi
Lesmethode(n)	Werkcollege
Niveau	400

Doel vak
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.

Onderwijsvorm
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.

Aanbevolen voorkennis
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.

Doelgroep
Students in the Hydrology Master

Groundwater Microbiology and Geochemistry (Geomicrobiology)

Vakcode	AM_450132 ()
Periode	Ac. Jaar (september)
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. W.F.M. Roling
Niveau	400

Doel vak
At the end of this interdisciplinary course, students will be able to describe and explain:
AspEC 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

Inhoud vak
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.

Onderwijsvorm
90 hours of guided self-study, 70 hours for essay writing. After each of the five modules, the student and lecture discuss the answers (~1 h per module).

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

Literatuur
Madigan, M.T.,Martinko, J.M., Stahl, D.A. & Clark, D.P. (2012), Brock biology of microorganisms, 13th edition. Pearson Higher Education. ISBN: 0-321-73551-5 (about 75 euro)

Lovley D.R. (2000). Fe(III) and Mn(IV) reduction, In: Environmental Microbe-Metal Interactions (pdf via lecturer).

Handout for guided self-study (via lecturer).

Overige informatie
This course is an elective option for master students in Hydrology and Geo-environmental Sciences. 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.

Hydrochemistry

Vakcode	AM_450052 ()

Periode	Periode 4
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. B.M. van Breukelen
Docent(en)	dr. B.M. van Breukelen
Lesmethode(n)	Werkcollege, Computerpracticum, Practicum
Niveau	400

Doel vak
Doel: 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.

Inhoud vak
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.

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

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

Literatuur
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.

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

Doelgroep
Hydrology Master students

Hydrological Systems and Water Management

Vakcode	AM_1012 ()
Periode	Periode 1
Credits	3.0

Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	prof. dr. P.J. Stuijfzand
Docent(en)	prof. dr. P.J. Stuijfzand
Lesmethode(n)	Werkgroep, Hoorcollege
Niveau	400

Doel vak
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.

Inhoud vak
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.

Onderwijsvorm
Lectures (~24 contact hours), practical exercises (8 hours), literature study (60 hours).

Toetsvorm
Written examination (100%)

Literatuur
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.

Vereiste voorkennis
450024 (Inleiding Hydrologie)

Aanbevolen voorkennis
Advice regarding previous courses taken: AB_450024: Inleiding Hydrologie.

Overige informatie
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

Isotope Hydrology

Vakcode	AM_450148 ()
Periode	Periode 5
Credits	3.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. H.J. van Meerveld
Docent(en)	dr. H.J. van Meerveld, dr. H.P. Broers
Lesmethode(n)	Werkcollege
Niveau	400

Doel vak
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

Inhoud vak
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.

Onderwijsvorm
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.

Toetsvorm
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.

Literatuur
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.

Doelgroep
M.Sc. Hydrology students

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

Master Research Project Hydrology

Vakcode	AM_1104 ()
Periode	Ac. Jaar (september)
Credits	27.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. M.J. Waterloo
Niveau	600

Sustainable Land Management

Vakcode	AM_1015 ()
Periode	Periode 3
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	drs. W.A.M. Tuijp
Docent(en)	dr. W.R.S. Critchley
Lesmethode(n)	Werkcollege
Niveau	400

Doel vak
What are the enabling and limiting factors to sustainable land management? How can smallholder farmers in the developing world adapt to climate change? What can farmers in developing countries – and especially Africa – do to improve their food security? Can organic agriculture help feeding the world? Are biofuels the solution for our

energy needs of tomorrow?
These and many other questions will be discussed during this interdisciplinary course. Its main focus is on what can be done about the problems of soil erosion and land degradation, and their relevance to climate change and poverty reduction. "Sustainable Land Management" is a new approach that involves both people and technical issues. The course spans a wide range of topics, including environmental problems, history of approaches, conservation technologies in the field, indigenous knowledge, working with local people, and skills in research and development in the tropics. There is a combination of theory and practice, with a strong emphasis on illustrated case studies from over 20 countries.

Inhoud vak
Environmental degradation and rural poverty: processes and impact. History of conservation: from failed approaches to new concepts in rural development; principles and practices of Sustainable Land Management (SLM). Agriculture in Development. SLM technologies: humid areas/dry areas. International environmental protocols and their impact on rural development programs. Socio-economic factors including population/land tenure/gender/incentives/marketing and labeling. Energy and biofuels; biodiversity, genetic modification and organic production. ICTs in rural development. Indigenous knowledge and local innovation, Participatory learning and action, including research methodology).

Onderwijsvorm
Interactive lectures (about 38 hours in total) with illustrated case studies supplemented by group work activities; conducted and examined in English.

Toetsvorm
One topic will be chosen by each student for a paper of 3.000 words based on further reading (50% mark). There will also be a final examination (50% mark).

Literatuur
"Where the land is greener" WOCAT, Eds Liniger and Critchley, plus additional supporting literature.
https://www.wocat.net/en/knowledge-base/documentation-analysis/global-overview-book.html

Doelgroep
Aimed at Master’s students with environmental and developmental interests: especially those with some geography/earth science/hydrological/biological/ecological/environmental background, but social scientists can also benefit from this course.

Overige informatie
Comments from former students:
"I think this course gives a good overview and helps students with a non environmental background to understand essential issues."
"Good job, keep on going! Continue to be part of the ERM programme."
"Whereas other courses focus on scientific dimension of environmental problems SLM is also about the human dimension of environmental solutions. It is one of the few courses that gives a positive perspective for practical solutions. Whereas other courses try to inject "knowledge" theoretical problems and solutions."
"The course was a great launch pad for my thesis research. "
"This should be a specialization track! Sustainable Land Management 2

would be very interesting and give students more time to learn about the topics."

For more information please contact Wendelien Tuyp (w.a.m.tuijp@vu.nl)

Transport Processes in Groundwater

Vakcode	AM_450131 ()
Periode	Periode 1
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. H. Kooi
Docent(en)	dr. B.M. van Breukelen, dr. H. Kooi
Lesmethode(n)	Hoorcollege, Computerpracticum
Niveau	500

Doel vak
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.

Inhoud vak
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.

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

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

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

Aanbevolen voorkennis
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

Vakcode	AM_450021 ()
Periode	Periode 4
Credits	6.0
Voertaal	Engels
Faculteit	Fac. der Aard- en Levenswetenschappen
Coördinator	dr. H.J. van Meerveld
Docent(en)	dr. H.J. van Meerveld
Lesmethode(n)	Computerpracticum, Werkcollege
Niveau	400

Doel vak
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.

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
• Present the results of a small hydrological modelling study in a clear and concise way
• Have obtained an awareness of how vegetation and land management affect soil erosion and water quality

The Unsaturated Zone and Near-Surface Hydrological Processes course contributes to the final attainment levels defined for the hydrology master's:
• 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 workshops provides the skills and understanding required to process and analyse hydrological data
• Critical judgment – the student is encouraged to critically judge

his/her work during the modelling workshops and the preparation of the report
• Communication – the presentation of the modelling results (structure, readability, etc.), as well as oral communication and discussion skills during the lectures

Inhoud vak
The course focuses on the following topics: hydraulic potential theory; soil water retention aspects; measurement techniques for soil water content and matric potential; stationary and non- stationary unsaturated flow (hydraulics); infiltration during conditions of ponding; determining saturated and unsaturated soil hydraulic conductivities; macropore vs. matrix flow; surface erosion processes (splash, wash and rill erosion) and governing factors.

Onderwijsvorm
The course consists of ten lectures and three computer practicals. The number of contact hours is in the order of 40.

Toetsvorm
Written examination.

Literatuur
Books:
• Koorevaar et al. (1983) Elements of Soil Physics. Elsevier, ISBN 0-444-42242-0 (selected chapters)
• Hillel D (1998) Environmental Soil Physics. Academic Press, ISBN 0-12-348525-8 (selected chapters)
• Morgan, R.P.C. (2005) Soil Erosion and Conservation, 3rd edition. Blackwell Publishing, Oxford, ISBN 978-1405117814 (selected chapters)

Articles:
• Anderson, A., Weiler, M., Alila, Y., and Hudson, R. O., 2009 Dye staining and excavation of a lateral preferential flow network, Hydrology and Earth Systems Science 13, 935-944.
• Bengtsson, L., R.K. Saxena, and Z. Dressie (1987) Soil water movement estimated from isotope tracers, Hydrological Sciences Journal 32:497-520.
• Horton, J.H. and R.H. Hawkins (1965) Flow Path of Rain From the Soil Surface to the Water Table, Soil Science. 100(6):377-383.
• Hoogmoed, W. B., and J. Bouma, (1980) A Simulation Model for Predicting Infiltration into Cracked Clay Soil, Soil Sci. Soc. Am. J. 44: 458–461
• Tricker, A.S. (1981), Spatial and temporal patterns of infiltration, Journal of Hydrology 49: 261-277.
• Western and Grayson. 2000. Soil Moisture and Runoff Processes at Tarrawarra, in: Grayson and Bloschl, Spatial Patterns in Catchment Hydrology: Observations and Modelling, Cambridge University Press.

Vereiste voorkennis
Participants are advised to follow the course on Groundwater Hydraulics (450009) first.

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