UNIVERSITY OF ZAMBIA
SCHOOL OF MINES
DEPARTMENT OF GEOLOGY

Proposed Master of Science Degree in Hydrogeology

1. **Title**

   The programme shall be **'Master of Science in Hydrogeology'**.

2. **Rationale**

   Groundwater forms the most important source of water supply in the urban, peri-urban and rural areas of Zambia, constituting a cardinal resource in driving the country's socio-economic development programmes. However, because it is *invisible*, groundwater has suffered from inefficient and uninformed development and management practices arising mainly from the users' and managers' inadequate understanding of the resource. In some instances, rapid expansion of urban areas has occurred and heightened human activities on recharge areas. Exacerbating this situation are (i) the adverse climatic conditions in the country in the last 15-20 years, which have resulted in rainfall becoming increasingly unpredictable, with extreme variations not just seasonally, but also between years, and (ii) the inadequate knowledge in the country of the available water resources, especially groundwater (which is *invisible*). This creates enormous challenges, and poses great scarcity and deterioration threats of groundwater, in terms of both quality and quantity – a situation that may, in turn, negatively affect continued provision of adequate and safe potable water to the to the country's population and impact on human health. Therefore, this programme intends to provide advanced training and build a cadre of professionals in hydrogeology, who will assist in making the *invisible* groundwater a *visible* resource and facilitate for its sustainable management to and promote socio-economic needs of today's Zambians, while also ensuring that those of future Zambians are secured.

3. **Aims of the programme**

   a) To create and improve awareness of how/where groundwater resources occur.
   b) To assess and determine parameters that govern the occurrence and flow of groundwater.
   c) To improve the level of integration between surface water and groundwater for its better development, utilisation and management.

4. **Target group**

   The programme is targeted at persons interested or working in river basin organizations and catchment management authorities, who manage both groundwater and surface water; water management authorities; water utility organisations; environmental and natural resources sectors; NGOs; etc.

5. **Admission criteria**

   Applicants should have a Bachelor's Degree (with Credit or better, or its equivalent) with a major in Geology, Geography, Natural Resources or any other related field from a recognised institution. In cases, where the applicant does not have the above qualifications, the publication of a research article in a peer reviewed journal on any topic in this field and/or relevant work experience, will be considered.

6. **Duration**

   The course will be offered on a **full time** basis for two academic years, which will be divided as follows:

   - Course work in the first year, and
   - An independent research project in the second year

7. **Mode of delivery**

   The mode of delivery will be through face-to-face contact for the taught component of the programme. The research part will independently be undertaken by each student under supervision from a member of the academic staff.

8. Structure

The taught component of the programme will comprise eight courses taken in the first year. All eight courses will be compulsory. The structure of the programme is given below.

8.1 Courses

8.1.1 Year 1

GHY 6501 Groundwater and its Occurrence
GHY 6615 Siting, Borehole Drilling and Well Completion
GHY 6721 Groundwater Flow in Aquifers
GHY 6625 Groundwater Contamination and Hydrogeochemistry
GHY 6712 Integrated Resource Management
GHY 6832 Groundwater Modelling
GHY 6885 Research Methodology
GHY 6895 Field School

8.1.2 Year 2

GHY 7900 Dissertation

9 Description of courses

9.1 GHY 6501: Groundwater and its Occurrence

9.1.1 Rationale

The student will learn the concepts of geology and the occurrence of groundwater – specifics of hydrogeology and the language of hydrogeologists.

9.1.2 Objectives

a) To identify terrain underlain by the different types of rocks
b) To learn about aquifer and aquitard characteristics, understand how to measure these characteristics, what influence they each have on groundwater flow, and what parameters restrict its flow
c) To identify environments that have groundwater, which is easy to access, and where it is not available.

9.1.3 Course Content

9.1.3.1 Geology and Geological Environments

9.1.3.1.1 Igneous rocks
9.1.3.1.2 Sedimentary rocks *(Alluvium; Consolidated deposits; Limestones and karst; effects of grainsize and mineral content)*
9.1.3.1.3 Metamorphic Rocks
9.1.3.1.4 Geological (Discontinuity) Structures *(Bedding/Foliation; degree of fracturation and faulting; fracture orientation and fracture frequency; fracture filling)*

9.1.3.2 Soils

9.1.3.2.1 Brief summary of rock weathering, soil formation processes and constituents (*mechanical breakdown of rock to form sands and silts; weathering of rock to form clay mineral)*
9.1.3.2.2 Mineralogy *(clay minerals surface charges adsorbed water flocculation, and its effect on sedimentation rate)*
9.1.3.2.3 Determination of particle size *(sieving for coarse sizes – sand sizes and larger; sedimentation tests for fine sizes – clay sizes ("fines"))*
9.1.3.2.4 Soil Classification by *Particle size (and shape); Mineralogy; Plasticity (Atterberg Limits)*
9.1.3.2.5 Atterberg limits *(a set of empirical tests that indicate mineralogy)*

9.1.3.3 Basic Hydrogeology

- 9.1.3.3.1 Groundwater in the hydrologic cycle
- 9.1.3.3.2 Use of Groundwater versus Surface Water
- 9.1.3.3.3 Regional versus local flow (Toth model)
- 9.1.3.3.4 Geothermal springs
- 9.1.3.3.5 Water budget

9.1.3.4 Groundwater Occurrence and Seepage

- 9.1.3.4.1 Aquifers
- 9.1.3.4.2 Aquitards
- 9.1.3.4.3 Total head, elevation head, pressure head
- 9.1.3.4.4 Flow driven by total head – D'Arcy's Law
- 9.1.3.4.5 Porosity, Permeability/hydraulic conductivity, and laboratory permeability tests
- 9.1.3.4.6 Groundwater flow towards a well
- 9.1.3.4.7 Estimation of hydraulic conductivity from particle size distribution
- 9.1.3.4.8 Field tests for permeability (pumping tests)

9.1.3.5 Rock fractures

- 9.1.3.5.1 Physical characteristics of fractures and fracture patterns
- 9.1.3.5.2 Definition and classification
- 9.1.3.5.3 Conditions of deformation
- 9.1.3.5.4 Stress and Strain
- 9.1.3.5.5 Brittle shear failure
- 9.1.3.5.6 Fracture mechanics
- 9.1.3.5.7 Mechanics of faulting
- 9.1.3.5.8 Fault rock types
- 9.1.3.5.9 Deformation mechanisms
- 9.1.3.5.10 Predicting fault rock distributions
- 9.1.3.5.11 Implications for fault seal and fluid flow
- 9.1.3.5.12 Fracture morphology and surface texture
- 9.1.3.5.13 Quantitative estimates of bulk permeability in fractured rock

9.1.3.6 Stresses

- 9.1.3.6.1 Total stress (σ) and pore-water pressure (u)
- 9.1.3.6.2 Definition of *effective* stress ($\sigma' = \sigma - u$)
- 9.1.3.6.3 Vertical stresses under level ground surface (total stress, effective stress and pore pressure)
- 9.1.3.6.4 State of effective stress where there is either upward or downward flow of water.

9.1.4 Teaching Methods

Lectures – 4 hours per week
Practicals – one three-hour session per week
Field trips – at least two per semester

9.1.5 Assessment

9.1.5.1 Continuous Assessment

- Assignments 10%
- Tests 20%
- Seminar / Field Report 10%

9.1.5.2 Final Examination

One three hour theory paper 60%

9.1.6 Readers

9.1.6.1 Prescribed

- Freeze, R.A and Cherry, J.A. (1979) **Groundwater.** Prentice-Hall
- Driscoll, F.G. (1986) **Groundwater and Wells**. Second Edition, Johnson Screens

9.1.6.2 Recommended / Supplementary

- Todd, D.K. and Mays, L.W. (2005) **Groundwater Hydrology.** International Edition, John Wiley & Sons Inc.
- Fetter, C.W. (2001) **Applied Hydrogeology**. Fourth Edition, Prentice-Hall
- Younger, P. (2006) **Groundwater in the Environment: An Introduction**. First Edition Wiley-Blackwell.

9.2 GHY 6615 Borehole Siting, Drilling and Well Completion

9.2.1 Rationale

Exploration for, and development of an *invisible* commodity is difficult. Therefore, it is important that siting, development of drilling programmes, development of water supply boreholes are appropriate, and that installation of well materials is done properly to ensure functional supply chains. Borehole geophysics will also be taught to provide tools on strata interpretation and screen placement. Well development and rehabilitation will provide tools for extending the life of a well.

9.2.2 Objectives

This course will teach the student how to:

a) To design an appropriate survey, carry it out, and interpret survey results
b) To Select sites for borehole drilling
c) To Develop a drilling program
d) To Select the appropriate equipment for and method of drilling
e) To Effectively supervise the drilling process and collect important data, and
f) To Select and direct the installation of proper well materials.

9.2.3 Course Content

9.2.3.1 **Groundwater Exploration Principles and Methods**

- 9.2.3.1.1 Geologic Methods
- 9.2.3.1.2 Remote Sensing
- 9.2.3.1.3 Surface Geophysics *(Electrical Resistivity; Seismic Refraction; Gravity Surveys; Magnetic Surveys)*
- 9.2.3.1.4 Other Techniques

9.2.3.2 **Methods of Borehole Drilling and Construction**

- 9.2.3.2.1 Hand drilling methods
- 9.2.3.2.2 Low cost mechanized methods
- 9.2.3.2.3 Mechanized drilling methods *(Rotary; Auger*; *Percussion*)

9.2.3.3 **Use of Test Holes *(water level and water quality measurements/determinations)***

9.2.3.4 **Well Completion**

- 9.2.3.4.1 Casing
- 9.2.3.4.2 Cementing
- 9.2.3.4.3 Screen Sizing
- 9.2.3.4.4 Gravel Pack
- 9.2.3.4.5 Wellhead Protection

9.2.3.5 **Well Development**

- 9.2.3.5.1 Purpose

9.2.3.5.2 Methods
9.2.3.5.3 Assessment of well loss and well loss Contributors
9.2.3.5.4 Rehabilitation of wells *(Symptoms*; *Physical Methods*; *Shock Chlorination)*

9.2.3.6 **Borehole Geophysics**
9.2.3.6.1 Calliper, temperature
9.2.3.6.2 Spontaneous Potential
9.2.3.6.3 Resistivity
9.2.3.6.4 Gamma-gamma
9.2.3.6.5 Neutron
9.2.3.6.6 CCTV

9.2.3.7 **Pumping Equipment**
9.2.3.7.1 Sizing of pump
9.2.3.7.2 Material selection of pump/risers
9.2.3.7.3 Storage of Water
9.2.3.7.4 Hand pump options
9.2.3.7.5 Maintenance
9.2.3.7.6 Electrical Considerations

9.2.4 Teaching Methods

Lectures – 4 hours per week
Practicals – one three-hour session per week
Field trips – at least two per semester

9.2.5 Assessment

9.2.5.1 **Continuous Assessment**

- Assignments 10%
- Tests 20%
- Seminar / Field Report 10%

9.2.5.2 **Final Examination**

One three hour theory paper 60%

9.2.6 Readers

9.2.6.1 **Prescribed**

Schneider, J. (2011) **Water Supply Well Construction Guidelines for Use in Developing Countries**. Second Edition

9.2.1.1 **Recommended / Supplementary**

- MacDonald, A., Davies, J., Calow, R. and Chilton, J. (2005) **Developing Groundwater: A Guide for Rural Water Supply**. Practical Action
- BRUSH, R. E. (1979) ***Wells Construction.*** **Hand Dug and Hand Drilled**. Information Collection and Exchange, Peace Corps, Washington D.C., USA

9.3 GHY 6721 Groundwater Flow in Aquifers

9.3.1 Rationale

This module intends to create an understanding of how water flows in the subsurface. It lays out the principles of conducting a pumping test to assess the potential for water supply, as well as assess the ability of the well(s) to deliver the volume of water desired in a given time.

9.3.2 Objectives

The student will learn how **to use pumping tests to create sustainable pumping practises** that not only provide the amount of water required but protect the aquifer as well.

9.3.3 Course Content

9.3.3.1 **Force potential and hydraulic head**

9.3.3.2 **Equations of groundwater flow**
- 9.3.3.2.1 Flow in Confined Aquifers
- 9.3.3.2.2 Flow in Unconfined Aquifers

9.3.3.3 **Planning a Pumping Test**
- 9.3.3.3.1 Pumping well in a confined aquifer
- 9.3.3.3.2 Pumping well in an unconfined aquifer
- 9.3.3.3.3 Packer test
- 9.3.3.3.4 Slug test
- 9.3.3.3.5 Large Diameter wells
- 9.3.3.3.6 Barometric, tidal effects, rainfall events during pumping test

9.3.3.4 **Steady radial flow to a well**
- 9.3.3.4.1 Confined aquifer
- 9.3.3.4.2 Unconfined aquifer
- 9.3.3.4.3 Leaky aquifer
- 9.3.3.4.4 Fractured aquifer

9.3.3.5 **Transient Flow**
- 9.3.3.5.1 Identification
- 9.3.3.5.2 Analysis of Data

9.3.3.6 **Hydraulic boundaries**
- 9.3.3.6.1 Surface water bodies
- 9.3.3.6.2 Impermeable boundaries *(Effects on pumping test data; Analysis of boundary conditions and locations)*

9.3.3.7 **Determination of Specific Capacity and well efficiency of a pumping well**

9.3.3.8 **Step draw-down test**

9.3.3.9 **Constant rate discharge tests**

9.3.3.10 **Recovery tests**

9.3.3.11 **Determination of aquifer parameters**
- 9.3.3.11.1 Specific capacity and influence of well losses
- 9.3.3.11.2 Transmissivity
- 9.3.3.11.3 Storativity

9.3.3.12 **Well Fields**

9.3.3.13 **Field Study of Domestic Well Installation**
- 9.3.3.13.1 Planning, drilling, well construction
- 9.3.3.13.2 Design of pumping tests
- 9.3.3.13.3 Analyses of data
- 9.3.3.13.4 Recommendations for remediation, pumping rate, completion to meet required yield

9.3.4 Teaching Methods

- Lectures – 4 hours per week
- Practicals – one three-hour session per week

- Field trips – at least two per semester

9.3.5 Assessment

9.3.5.1 Continuous Assessment

- Assignments 10%
- Tests 20%
- Seminar / Field Report 10%

9.3.5.2 Final Examination

One three hour theory paper 60%

9.3.6 Readers

9.3.6.1 Prescribed

Fetter, C.W. (2001) **Applied Hydrogeology**. Fourth Edition, Prentice-Hall

9.3.6.2 Recommended / Supplementary

- Kruseman, G.P., de Ridder, N.A. (1990) **Analysis and Evaluation of Pumping Test Data**. Second Edition, International Institute for Land Reclamation and Improvement.
- Brush, R. E. (1979) *Wells Construction.* Hand Dug and Hand Drilled. Information Collection and Exchange, Peace Corps, Washington D.C., USA

9.4 GHY 6625 Groundwater Contamination and Hydrogeochemistry

9.4.1 Rationale

Living in today's world means that there is the potential for groundwater contamination. By knowing these hazards groundwater can be protected from degradation. However, it is important to also understand how chemical interaction of water flowing within rocks in the subsurface may heighten certain chemical parameters in the water. Such chemical variations in groundwater can be used as a tool for understanding its flow paths in the subsurface.

9.4.2 Objectives

a) To characterise sources of both organic and inorganic contaminants in groundwater
b) To differentiate sources of contaminants between natural and anthropogenic
c) To assess their impacts on the potability of groundwater
d) To formulate methods to remediate contaminated groundwater sources

9.4.3 Course Content

9.4.3.1 Contamination

9.4.3.1.1 Transport processes

- 9.4.3.1.1.1 Movement/transport of contaminants *(Dispersion vs Diffusion; Use of Tracers)*
- 9.4.3.1.1.2 Effects of contaminants on Groundwater *(Metals; Organics)*

9.4.3.1.2 Sources of Pollution

- 9.4.3.1.2.1 Inorganic *(sources; behaviour in the subsurface; sampling protocols; sample handling)*
- 9.4.3.1.2.2 Organic *(sources; behaviour in the subsurface; sampling protocols; sample handling)*

9.4.3.2 Hydrogeochemistry

9.4.3.2.1 Chemical Signatures of Groundwater

- 9.4.3.2.1.1 Why different waters have different chemical compositions
- 9.4.3.2.1.2 Factors that control water compositions
- 9.4.3.2.1.3 How compositions vary with setting
- 9.4.3.2.1.4 How compositions vary with time

9.4.3.2.2 **Chemical Analyses**

9.4.3.2.2.1 Meq, TDS, EC, data quality, sample collection, analytical techniques

9.4.3.2.2.2 Drinking water/Irrigation standards

9.4.3.2.2.3 Biological analyses

9.4.3.2.3 **Carbonate system**

9.4.3.2.4 **Nitrate cycle**

9.4.3.2.5 **Redox reactions**

9.4.3.2.6 **Data presentation techniques, statistics**

9.4.3.2.7 **Assessing changes in laboratory data**

9.4.3.2.8 **Effect of dissolved vs particulate data**

9.4.3.2.9 **Naturally high concentrations of metals**

9.4.3.2.9.1 Fluoride

9.4.3.2.9.2 Arsenic

9.4.3.2.10 **Water Treatment**

9.4.3.2.11 **Isotope Hydrology**

9.4.3.2.11.1 Stable Isotopes

9.4.3.2.11.2 Unstable Isotopes for Age Dating *(Carbon 14; Tritium)*

9.4.3.2.11.3 Chlorofluorocarbons

9.4.3.2.12 **Groundwater protection zones from human activities**

9.4.3.2.12.1 Landfills

9.4.3.2.12.2 Sanitation / on-site excreta disposal

9.4.3.2.13 **Oil and Gas Industry Impacts**

9.4.3.2.13.1 Chemicals of Concern

9.4.3.2.13.2 Impacts to Potable Aquifers and Soil

9.4.3.2.14 **Remediation**

9.4.3.2.14.1 Attenuation Processes *(sorption; filtration; microbiological degradation; dilution)*

9.4.3.2.14.2 Pump and Treat Methods *(setting goals; system design; containment and capture techniques; pumping considerations; groundwater treatment methods)*

9.4.4 Teaching Methods

- Lectures – 4 hours per week
- Practicals – one three-hour session per week
- Field trips – at least two per semester

9.4.5 Assessment

9.4.5.1 **Continuous Assessment**

- Assignments 10%
- Tests 20%
- Seminar / Field Report 10%

9.4.5.2 **Final Examination**

One three hour theory paper 60%

9.4.6 Readers

9.4.6.1 **Prescribed**

- Domenico, P.A. and Schwartz, F.W. (1997) **Physical and Chemical Hydrogeology**. Second Edition John Wiley and Sons Inc.
- Fetter, C.W., (2008) **Contaminant Hydrogeology**. second Edition, Waveland Pr Inc.

9.4.6.2 **Recommended / Supplementary**

- Apello, C.A.J., and Postma, D. (2005) **Geochemistry, Groundwater and Pollutio**n. second Edition, Taylor & Francis.
- Clack, I.D., Fritz, P. (1997) **Environmental Isotopes in Hydrogeology.** Illustrated, reprint, Lewis
- Hem, J.D. (2005) ***Study and Interpretation of the Chemical Characteristics of Natural Water.*** USGS, Water Supply paper 2254

9.5 GHY 6712 Integrated Resource Management

9.5.1 Rationale

This course examines how groundwater as a resource nationally needs to be managed to ensure there is water for future generations. Other sources of water will also be included in this resource management. In addition, the effect of groundwater on manmade structures, and vice versa, will be examined in a bid to avoid detrimental interactions. Further, getting community buy-in to a project is critical to the latter's long-term sustainability. Therefore, a co-ordinated management scheme on a national scale is needed to ensure long-term sustainability of the resource.

9.5.2 Objectives

a) To teach students methods of data collection, storage and retrieval
b) To outline roles and responsibilities for successful data collection, storage and retrieval operations
c) To determine the relationship between surface and groundwater
d) To assess impacts of water pressures on excavations and water containment structures – *roads, dams, etc.*

9.5.3 Course Content

9.5.3.1 **Social Aspect of Water Projects**

9.5.3.2 **Collection of data**

- 9.5.3.2.1 Topographic Data
- 9.5.3.2.2 Geologic Data
- 9.5.3.2.3 Hydrologic and Climatic Data *(Bank storage*; *Influences of Rainfall Events)*
- 9.5.3.2.4 Hydrogeologic / Groundwater Data

9.5.3.3 **Use of Computers for Groundwater Management**

- 9.5.3.3.1 Data management
- 9.5.3.3.2 Groundwater flow analyses software *(steady state 1-D models for confined and unconfined aquifers)*
- 9.5.3.3.3 Groundwater flow analyses software *(steady state 2-D models for confined and unconfined aquifers)*
- 9.5.3.3.4 Transient 1-D Models for Confined Aquifers
- 9.5.3.3.5 Geochemical software

9.5.3.4 **Yield Studies**

- 9.5.3.4.1 Basin Analyses
- 9.5.3.4.2 Perennial Yield

9.5.3.5 **Groundwater allocation; interactions with surface water; monitoring and protection**

9.5.3.6 **Integrated use of resources**

- 9.5.3.6.1 Springs, rivers, furrows, pipelines and tanks
- 9.5.3.6.2 Water quality / quantity
- 9.5.3.6.3 Governing Legislation

9.5.3.6.4 Transboundary aquifer constellations
9.5.3.6.5 Protocols for managing and utilising transboundary aquifers

9.5.3.7 **Other sources of water (Rainfall Harvesting; Dew Collection; Storm-water Collection; Water** *Reuse)*

9.5.3.8 **Groundwater as a climate change measure**
9.5.3.8.1 Managing groundwater recharge
9.5.3.8.2 Managing its storage
9.5.3.8.3 Managing its quality
9.5.3.8.4 Managing its demand

9.5.3.9 **Geomechanics**
9.5.3.9.1 Ground excavations for engineering structures (roads, dams, tunnels, etc.) in soil and rock
9.5.3.9.2 Dewatering excavations
9.5.3.9.3 Excavations/constructions for Dams and tunnels
9.5.3.9.4 Lateral stresses in geologic materials – *lateral pile walls*
9.5.3.9.5 Deformation of geologic materials – *Ground compaction; settlement and subsidence*; *effects of rebounding water table/pressure*
9.5.3.9.6 Ground stabilization

9.5.3.10 **Teaching Methods**
- Lectures – 4 hours per week
- Practicals – one three-hour session per week
- Field trips – at least two per semester

9.5.3.11 **Assessment**

9.5.3.11.1 Continuous Assessment
- Assignments 10%
- Tests 20%
- Seminar / Field Report 10%

9.5.3.11.2 Final Examination
One three hour theory paper 60%

9.5.3.12 **Readers**

9.5.3.12.1 Prescribed

a) Lenton, R. and Muller M. (Eds., 2009) **Integrated Water Resources Management in Practice: Better Water Management for Development**. Earthscan Publishing, London.
b) Gooch, G.D. Rieu-Clarke, A. and Stalnacke, P. (Eds. 2010) **Integrating Water Resources Management: *Interdisciplinary Methodologies and Strategies in Practice*.** Illustrated Edition, IWA Publishing.

9.5.3.12.2 Recommended / Supplementary

- Heathcote, I.W. (2009) **Integrated Watershed Management – Principles and Practice.** Second Edition, John Wiley and Sons Inc.
- Grafton, Q.R. and Hussey, K (2011) **Water Resources Planning and Management.** Illustrated Edition, Cambridge University Press

9.6 GHY 6832 GROUNDWATER MODELLING

9.6.1 Rationale

Mathematical models in groundwater flow and contaminant transport are increasingly used to provide answers to hydrogeologic questions that arise at hazardous waste sites. While mathematical procedures in some models may be highly complex, and must be understood by the modeler to produce a useful simulation, the goal of modelling implied in this course is to provide an approximation of a site specific situation. Therefore, a qualified professional with a background in hydrogeology or groundwater hydrology and experience in groundwater modeling will be best suited to determine whether a simulation is reasonable, and to present recommendations based on a modeling study.

9.6.2 Objectives

a) To characterize groundwater regime at a site
b) To predict contaminant transport
c) To locate areas of potential environmental risk
d) To determine potential impacts of contaminated groundwater on nearby wells or surface water bodies, and
e) To aid in selecting and designing remedial actions

9.6.3 Course Content

9.6.3.1 **Introduction** – What is a model? Why model? Establishing the purpose; Modelling Protocol

9.6.3.2 **Equations and Numerical Methods** – Governing Equations *(Aquifer versus Flow System Viewpoints; Derivation of the Governing Equations)*; Numerical Methods

9.6.3.3 **The Conceptual Model and Grid Design** – Building the conceptual model *(Defining the hydrostatigraphic units; preparing the water budget; defining the flow system);* Types of Models *(Two-Dimensional Areal Models; Quasi Three-Dimensional Models; Profile and Full Three-Dimensional Models);* Laying out the Grid *(Types of Grids; Defining Model Layers; Orienting the Grid; Spatial scales)*; Assigning Parameter values – *Data needs; Transferring Field Data to the Grid; Kriging*.

9.6.3.4 **Boundaries** – Types of boundaries; Setting boundaries; simulating boundaries *(Specified head; Specified flow; Head-dependent flow);* internal boundaries.

9.6.3.5 **Sources and Sinks** – Injection and Pumping wells *(Finite Difference models; Finite Element models)*; flux across the water table *(Estimating water table fluxes; Finite Difference models; Finite Element models)*; leakage.

9.6.3.6 **Solute Transport** – Transport equations; Numerical techniques.

9.6.3.7 **Groundwater Models** – MODFLOW; MODPATH; MT3D; User Interfaces.

9.6.3.8 **Practical Guidelines for Groundwater Modelling** – General requirements; Components of a modelling project and Data requirements; Model set-up; Model calibration and Sensitivity analyses *(Calibration; Sensitivity analysis).*

9.6.4 Teaching Methods

- Lectures – 4 hours per week
- Practicals – one three-hour session per week
- Field trips – at least two per semester

9.6.5 Assessment

9.6.5.1 **Continuous assessment**

- Assignments 10%
- Tests 20%
- Seminar / Field Report 10%

9.6.5.2 **Final Examination**

One three hour theory paper 60%

9.6.6 Readers

9.6.6.1 **Prescribed**

- Anderson, M.P. and Woessner, W.W. (1992) **Applied groundwater modeling: simulation of flow and advective transport.** First Edition, Academic Press;
- Bear, J. and Verruijt, A., 1987. **Modeling Groundwater Flow and Pollution.** D. Reidel Publishing Company.

- Wang, H.F. and Anderson, M.P. (1982) **Introduction to Groundwater Modeling.** W.H. Freeman and Company, San Francisco, CA.
- McDonald, M.G. and Harbaugh, A.W., (1988) **A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model,** USGS TWRI Chapter 6-A1, 586 p.

9.6.6.2 **Recommended**

Bear, J. and Cheng, A., (2010) **Modeling Groundwater Flow and Contaminant Transport**. First Edition

9.7 GHY 6885 Research Methodology

9.7.1 Rationale

In order to conduct research that is justified and the results can be replicated or verified, research methods need to be consistent in technique.

9.7.2 Objectives

a) To provide candidates with necessary background knowledge on Research Methodology to enable them to:
   - Identify, evaluate and select an appropriate topic for their postgraduate research project
   - Find appropriate literature re/sources relevant to their chosen topic
   - Compile a concise, synthesized and critical literature review based on relevant literature sources with appropriate references
   - Formulate a problem statement, purpose statement and research objectives/research questions to guide their study
   - Develop an appropriate research design for their study
   - Compile a detailed research proposal of 30-50 pages to guide a study

b) To guide candidates in compiling a detailed research proposal for their postgraduate study based on a process of writing and peer evaluation.

9.7.3 Course Content

9.7.3.1 **Research:** Meaning; Purpose- Types of research-significance of research in social and business sciences

9.7.3.2 **Steps in Research:** Identification, selection and formulation of research problem; Research questions; Research design; Formulation of hypothesis; Review of literature

9.7.3.3 **Sampling Technique:** Sampling theory; Types of sampling; Steps in sampling; sampling and Non-sampling error; Sample size; Advantages and limitations of sampling

9.7.3.4 **Data for Research:** Primary data; Meaning; Collection methods; Observation; Interview; Questionnaire; Schedule; Pretest; Pilot study; Experimental and case studies; Secondary data; Meaning; Relevance, limitations and cautions

9.7.3.5 **Processing Data:** Checking; Editing; Coding; Transcriptions and Tabulation; Data analysis; Meaning and methods; Quantitative and Qualitative analysis

9.7.3.6 **Structuring the Proposal/Report:** Chapter format; Pagination; Identification; Using quotations; Presenting footnotes; Abbreviations; Presentation of tables and figures; Referencing; Documentation; Use and format of appendices; Indexing

9.7.4 Teaching Methods

- Lectures – 4 hours per week
- Practicals – one three-hour session of presentations per week
- Field trips – at least two per semester

9.7.5 Assessment

9.7.5.1 **Continuous Assessment**

- Assignments 10%
- Tests 20%

- Seminar / Field Report 10%

9.7.5.2 **Final Examination**

One three hour theory paper 60%

9.7.6 Readers

9.7.6.1 **Prescribed**

Kothari, C.R. (2009) **Research Methodology: Methods and Techniques**. Second edition, New Age International Publishers

9.7.6.2 **Recommended / Supplementary**

- Ranjit Kumar (2005); **Research Methodology: A Step-by-Step Guide for Beginners**. Second edition, SAGE Publishers Ltd
- Goddard, W. and Melville, S. (2004) **Research Methodology: An Introduction.** Second edition, Juta and Co. Ltd.

9.8 GHY 6895 Field School

9.8.1 Rationale

Hands-on learning is often the most practical. This week-long field school will take the academic lessons and put them into a real-life context of how they are conducted.

9.8.2 Objectives

To demonstrate practical aspects of conducting a groundwater investigations

9.8.3 Course Content

9.8.3.1 **Surveying and GPS**

9.8.3.2 **Assessment of potential drill sites**

9.8.3.3 **Contaminant assessment for domestic supplies**

9.8.3.4 **Contaminant investigations**

9.8.3.4.1 Integrating soil and groundwater investigations

9.8.3.4.2 Site Assessment

9.8.3.4.3 Logging of drill cuttings

9.8.3.4.4 Piezometer completion methods

9.8.3.4.5 Piezometer development

9.8.3.4.6 Groundwater sampling and handling

9.8.3.4.7 Results interpretation

9.8.4 Teaching Methods

Demonstrations	-	2 hours per week
Field Practicals	-	1 per topic
Field exercises	-	1 per topic
Reports	-	1 per topic

9.8.5 Assessment

9.8.5.1 **Continuous Assessment**

- Participation in field practicals 10%
- Field reports 20%
- Tests 20%
- Seminar 10%

9.8.5.2 **Final Examination**

One three hour theory paper 40%

9.8.6 Readers

9.8.6.1 **Prescribed**

- Willis Weight (2008). **Hydrogeology Field Manual.** Second Edition**,** McGraw-Hill Professional.
- Rick Brassington (2006). **Field Hydrogeology (Geological Field Guide).** Third Edition, Wiley-Interscience

9.8.6.2 **Recommended / Supplementary**

- McClay, K. R. **(1991). The Mapping of Geological Structures.** Wiley
- Milsom, J. J., Eriksen, A. (2011)**. Field Geophysics (Geological Field Guide)**. Second Edition, Wiley.
- Telford, W. M., Geldart, L. P., Sheriff, R. E. (1990). **Applied Geophysics.** Second Edition, Cambridge University Press.

9.9 GHY 7900 Dissertation

9.9.1 Rationale

Working in the real world will have challenges that aren't taught in a classroom. This project will include aspects of analyzing what the issue is and how to determine how to find a way to solve the problem.

9.9.2 Objectives

To learn how to problem-solve without the structured classroom activities.

9.9.3 Course Content

Each student will have an advisor for assistance, but the work will be conducted independently.

9.9.4 Assessment

9.9.4.1 Continuous Assessment

- Seminar Presentations 20%
- Contact with supervisor 10%

9.9.4.2 Final Examination

- Final Presentation 20%
- Thesis 50%