CIVIL ENGINEERING

Departmental Facilities

The laboratories at Ellis Hall and the West Campus are well equipped for research studies in structures and rehabilitation, concrete, soils, geotechnical and geoenvironmental engineering, groundwater and hydrology, environmental engineering, water distribution systems and rivers, lakes and coastal engineering. A state of the art server room facilitates software modeling in all areas. In addition, researchers and students have access to the University's High Performance Computing Virtual Laboratory and to facilities located in other University departments and at the Royal Military College of Canada. There are 2 workshops and an instrumentation shop to service all areas of research.

A 380m2 high bay structures laboratory with strong floor, a 380m2 low bay testing laboratory, a concrete laboratory and a state-of-the-art materials testing laboratory are equipped with various loading systems for testing structures, structural components and materials. Two closed-loop servo-hydraulic power supplies drive 7 dynamic actuators ranging from 100kN to 2000kN for static and dynamic load testing. In addition, a 2000kN concrete cylinder tester, a 100kN and a 1000kN universal testing machine and a 600kN universal testing machine equipped with a muffle furnace for high temperature materials testing are available. Five programmable environmental chambers ranging in size from 10m2 to 38m2 are equipped for freeze-thaw, wet-conditioning/curing and cold temperature testing.

Laboratory facilities totaling 1900m2 are available for research into rivers, lakes and coastal engineering and fluid mechanics. The water research laboratory is equipped with 3 wave flumes with programmable wave generators, sediment transfer flume, and a laser laboratory and a 20m internal wave flume and a 1m diameter rotating table, for research on environmental and geophysical fluid dynamics. Extensive use is made of state-of-the-art measuring equipment, including ADV's, LIF and PIV used in hydrodynamics studies. The laboratory is equipped with an 8-inch pump which supplies a constant head water distribution pipe network for experimental testing in a 175m2 model river basin (used in research on river morphology and river morphodynamics), a 10m-long tilting flume for open-channel flow studies, and a 2m-long recirculating sediment transport flume.

A 420m2 geoengineering laboratory and a 435m2 geotechnical/geoenvironmental laboratory complex are well equipped to carry out unique physical model testing. Facilities include a world class Geosynthetic Landfill Liner Simulator laboratory, an analytical laboratory, geosynthetic aging equipment and a geotechnical materials laboratory. The test pit located at West Campus is the only facility in North America capable of testing a range of buried infrastructure systems as well as conventional and trenchless construction processes at scale. A 20m3 landslide testing facility located in the water research laboratory is available and is capable of modeling tsunami/landslide interactions.

The environmental laboratory complex is equipped to carry out studies in water quality, water treatment, groundwater, hydrology of fractured rock, bioreactor systems, water distribution systems and human health studies. A 360m2 laboratory complex includes two Level-2 biosafety laboratories, a field staging laboratory, environmental chambers, pilot plant laboratory, analytical laboratory, a clean water testing laboratory and general wet lab facilities. There are 3 fully equipped field research trailers available for hydrology field testing and various field equipment for water treatment and biological systems field studies.A 70 m2 drinking water discolouration laboratory consisting of two 200m long, 4-inch diameter pipe loops and wet laboratory is a stand-alone facility housed at the West Campus water research laboratory.

Financial Assistance

Qualified first class students are recommended for university scholarships and bursaries, although the number of scholarships which can be awarded is limited. Research students are generally supported through Research Assistantships administered under the regulations of the awarding agency. Qualified students will also be considered for Teaching Assistantships. Specific details of funding arrangements are agreed upon by students and their supervisor(s).

Admission Requirements

Applicants are accepted into a Master's or Doctoral Program under the general regulations of the School of Graduate Studies providing they also satisfy the requirements of the Department. Normally, the minimum Departmental requirements are a four-year Bachelor's degree with a standing in the mid B range (70% graduating average or a ranking in the top third of the graduating class where number grades are not available).
Applicants with a Bachelors degree in a cognate science may be admitted, at the discretion of the department, to the Master's degree program.

Fields of Research

Research activity in the Department of Civil Engineering is generally classified under two fields: Civil Engineering Environment and Civil Engineering Infrastructure. Environment encompasses the areas of Environmental, Geotechnical, Geoenvironmental and Hydrotechnical Engineering, while Infrastructure comprises the areas of Structural Engineering and Geotechnical Infrastructure. These two fields reflect the growing inter-relationships and collaborations among the areas within the Department, and with other research programs both within and outside the University.

Civil Engineering Environment

Environment research is directed toward surface water quality, source water protection, groundwater quality, and subsurface remediation.

In the areas of surface water quality, source water protection and biotechnological processes, current topics of investigation include use of natural/engineered biological systems for water quality control in traditional and innovative on-site applications, and the use of integrated environmental management techniques for the control of surface water degradation resulting from urban storm runoff. Research projects are carried out in collaboration with faculty in Civil Engineering and other Queen's departments, and with local and regional consulting firms and government agencies. Many projects are conducted at regional field and demonstration facilities.

Geoenvironmental engineering research involves the development of design concepts, computer modelling, laboratory testing and field monitoring relating to the design of landfills. This includes the examination of clay and geomembrane liners, primary and secondary leachate collection system (both granular and geosynthetic) aging and contaminant migration through berm systems.

In the area of subsurface water quality, research is being directed at the development of numerical models to simulate multiphase/multi-component flow and transport in both porous and fractured media, as well as the investigation of remedial technologies for the clean-up of chemical spill sites contaminated by hazardous industrial liquids such as PCB oils, jet fuel, and chlorinated solvents. Research is also conducted on the development of new site characterization techniques including new hydraulic and tracer testing methods. Collaborative research is carried out within Queen's with the Biology, Chemistry and Chemical Engineering Departments, School of Urban and Regional Planning and outside of Queen's with International Consortiums.

Geotechnical research is involved in studies of the stress-strain behaviour of soils, the influence of repeated loadings on soils, the influence of frost heaving on natural and stabilized soils, the performance of railroad track ballasts and fills, slope stability and earth dams. State-of-the-art computer facilities are used in modelling the behaviour of geosynthetics, reinforced walls, slopes and embankments. Modelling also plays a key role in work on soft ground tunnelling. The existence of coastal engineering, mining engineering and engineering geology at Queen's provides opportunities for interdisciplinary research. Waste management and contaminant control are areas of growing research needs and are areas of current expansion of the geotechnical research carried out at Queen's.

Hydrotechnical research includes the areas of lake dynamics, fluvial hydraulics, river engineering and pipelinecoastal engineering. A common theme in many of these areas is sediment motion, which requires the application of fluid mechanics, physical modelling and mathematical modelling to both steady and oscillating conditions. Research is also underway into the evaluation and mitigation of short and long term anthropogenic impacts on rivers, lakes and estuaries, including physical impacts such as channel incision, increased bank erosion, etc., and environmental impacts such as hypoxia, harmful algae blooms and loss of quality of the aquatic environment for animal species. Further research topics include river and coastal hydrodynamics and power generation, and long term coastal erosion and protection. Both physical modeling and advanced numerical modeling are used, and often conducted in collaboration with faculty in other areas of civil engineering (environmental, geotechnical and structural), other departments at Queen's (Mechanical Engineering, Biology, Chemistry and Mathematics and Statistics) and other research institutes (National Water Research Institute and National Research Council).

Civil Engineering Infrastructure

The Structures Group currently undertakes research in the areas of (i) using novel and sustainable materials for new construction, (ii) retrofitting of existing structures, (iii) the performance of structures in extreme temperatures and (iv) structural health monitoring. Research projects in the area of novel materials include the use of FRPs for stay-in place formwork for reinforced concrete construction. The use of straw bales as both an energy efficient and environmentally friendly alternative to traditional construction techniques is also an on-going topic of interest. The group has conducted pioneering research into the use of FRPs for strengthening of structures, including the use of prestressed FRPs for efficient flexural strengthening. Current research projects in this area seek to investigate if FRP can enhance the buckling and flexural strength of steel members. The group also has

a long standing research collaboration with the National Research Council of Canada that seeks to better understand the performance of both reinforced and retrofitted concrete structures in fire. Research projects in the area of structural health monitoring aim to investigate the link between deterioration and structural capacity through the application of advanced measurement systems for both above ground and buried infrastructure. The structures group conducts a number of these research projects in co-operation with both industrial and government partners including the Ministry of Transportation Ontario and Transport Canada.

Faculty

Head
da Silva, A.M.F

Coordinator of Graduate Studies
Take, W.A.

Professor
Brachman, R.W.I., da Silva, A.M.F., Fam, A.Z.[1], Filion, Y., Green, M.F.[10], Hoult, N., MacDougall, C., Mulligan, R.[13], Moore, I.D.[2], Mumford, K., Novakowski, K.S.[11], Rowe, R.K.[3], Take, W.A.[8]

Associate Professor
Boegman, L., Genikomsou, K.

Assistant Professor
Abdelaal, F., Devoie, E., Eichhorn, G., Olsthoorn, J., Payne, S.J., Van Gulck, J., Woods, J.[9], Wright, S., Xin, X.

Professor Emeritus
Anderson, B.C., Kueper, B.H.

Adjuncts
Anderson, B., Bentz, E.[5], Braga, A.[6], Balomenos, G., Gales, J.[7], Jabarri, A., Law, B., Sarhat, S., Valipour, R., Zhao, Y.

Cross Appointed
Bathurst, R.J.[4], Beddoe, R.[4], Dagenais, M.[4], Dumas, S.[4], Heffernan, P.[4], Hulley, M.[4], Siemens, G.[4], Shan, D.[4], Taheri, A.[6], Wright, G.[4], Yaseri, A.[4], Weber, L.[4]

[1] Canada Research Chair in Infrastructure Innovative and Retrofitted Structures
[2] Canada Research Chair in Infrastructure Engineering
[3] Canada Research Chair in Geotechnical and Geoenvironmental Engineering
[4] Royal Military College (RMC)
[5] University of Toronto
[6] Queen's University
[7] Universite Laval
[8] Canada Research Chair in Geotechincal Engineering
[9] Mitchell Professor, Intelligent Infrastructure Monitoring
[10] Canada Research Chair in Infrastructure Innovative and Retrofitted Structures
[11] Special Advisor to the Vice-Principal (Research)
[12] Barrington Batchelor Distinguised University
[13] Director, Beaty Water Research Centre (BWRC)

Programs of Study

All M.A.Sc. and Ph.D. students must successfully complete CIVL 801, a non-credit course in laboratory safety, at the first opportunity after their initial registration. M.Eng. students who are not engaged in laboratory project work are not required to take CIVL 801. Admission to CIVL 801 is restricted to graduate students enrolled in Civil Engineering only.

- Civil Engineering - Doctor of Philosophy (https://queensu-ca-public.courseleaf.com/graduate-studies/programs-study/civil-engineering/civil-engineering-phd/)
- Civil Engineering - Master of Applied Science (https://queensu-ca-public.courseleaf.com/graduate-studies/programs-study/civil-engineering/civil-engineering-masc/)
- Civil Engineering - Master of Engineering (https://queensu-ca-public.courseleaf.com/graduate-studies/programs-study/civil-engineering/civil-engineering-meng/)

Courses

NOTE: Most courses offered in the Civil Engineering Department are of one term in length (3.0 credit units). Courses that are 1.5 credit units are as shown in the course descriptions below. Examinations are held at the end of each term.

All listed courses may not be offered each year.

APSC 801 Master of Engineering Foundations
An introduction to the Master of Engineering (MEng) graduate studies program at Queen's University. The course provides students with essential administrative information, an introduction to information literacy within Smith Engineering, as well as an overview of the various support services on campus. Additionally, the course contains several modules on professional and career skills. This non-credit course is comprised of a number of individual modules, and its completion is a requirement to graduate from the MEng program. Graded on a Pass/Fail basis.
Prerequisite: Enrolment in the MEng program.

APSC 810 Teaching and Learning in Engineering
This course is an introduction to learning principles and effective teaching in engineering, intended to prepare for roles like teaching assistant, university course instruction, or training in engineering industry. The course includes relevant theories of teaching and learning with practical elements

like classroom management, designing sessions and assessments, signature engineering teaching approaches, and using digital pedagogies.

APSC 812 AI Ethics and Society
This course investigates the ethical implications of Artificial Intelligence (AI) as a social, technological and cultural phenomenon. Given the increasing use of intelligent systems for decision-making and autonomous control, it is essential that designers and developers are aware of the ethical and social implications that AI can have. The course materials will examine fundamental ethical principles related to the application of AI and investigate its influence in a number of industries including self-driving vehicles, healthcare, law and defense. The course will also examine the delicate balance between innovations in AI versus regulation, privacy, and individual rights. This course is graded on a Pass/Fail basis.

APSC 877 Engineering Project Management
The course will examine the essential skills and knowledge required for effective engineering project management. The foundational principles of project management including integration, scope, cost, time, human resources, stakeholders and procurement are examined. The course will be delivered online.
Exclusions: MECH 896, APSC 223

APSC 888 Engineering Innovation and Entrepreneurship
This course will help learners from across engineering develop an entrepreneurial mindset capable of turning problems into opportunities. Learners will investigate the relationships between innovation and industrial dynamics, and seek to understand the fundamental forces that drive the science and technology industries' evolution and industry life cycles.
EXCLUSION: CHEE 410

APSC 896 Engineering Leadership
The course is designed to develop a range of leadership skills essential for engineering professional practice. Students will explore their own leadership abilities and develop their competencies in areas such as managing conflict, team dynamics and developing others. The course content will be presented through lectures, case studies, panel discussions and other active learning activities. Fall. P. Hungler

CIVL 801 Health and Safety in Civil Engineering Research

An introduction to safety procedures in civil engineering research. This non-credit course consists of a general introduction lecture and modules on: (i) specimen & experiment fabrication, (ii) chemical & biohazard safety and (iii) field research. ALL students must successfully complete CIVL 801 at the first opportunity. Fall, Winter and Summer.

CIVL 820 Engineering Design and Professional Practice
This course will develop foundational skills associated with the development and implication of geotechnical or environmental designs from a practitioner's perspective. Students will be introduced to environmental permitting and regulatory approval processes, effective methods to document and present an engineering design to various stakeholders, the components of a design package that a client and contractor use to inform construction/ implementation, construction costing, as well as, the roles and responsibilities of the engineer in construction/ implementation stage. (3.0 credits: term course delivered in one 12-week semester, 3 hours/week)
PREREQUISITE: Graduate students in science and engineering must have a strong background in civil engineering design to take this course.

CIVL 822 Structural design of buried pipes
Overview of soil-pipe interaction, design of rigid pipes for bending moments, design of flexible pipes for thrust and deformation, and design of profiled thermoplastic pipes considering local buckling and local bending. (1.5 credit units)

CIVL 823 Pipe repair using liners
Overview of pipe deterioration and lining methods available for repair, liner design of gravity flow pipes to withstand external fluid and soil loads, and liner design for pressure pipes. Introduces the design code for cured in place liners and the instructor's design procedures. (1.5 credit units)

CIVL 824 Pipe replacement using bursting
Overview of pipe replacement by pipe bursting, the causes of ground movement and their effects on other infrastructure, and the expected and allowable pulling forces needed to pull the new pipe into place. It introduces the instructor's simplified design tools and their limitations. (1.5 credit units)

CIVL 825 Horizontal directional drilling
Overview of directional drilling, use of drilling mud and causes for and prevention of mud loss, soil-pipe interaction and the expected and allowable pulling forces. It introduces the current ASTM design code and the instructor's simplified design tools and their limitations. (1.5 credit units)

CIVL 828 Serviceability of Concrete Structures
This course is intended to provide structural engineers with an in-depth understanding of the performance of reinforced, prestressed and composite concrete-steel structures under service conditions, including both the short and long term performances. The course deals with the effects of creep and shrinkage of concrete, relaxation of prestressing steel, temperature, and settlement of supports on deflections, cracking and internal forces. The displacement and force

methods of analysis are used to account for these affects in calculating the deformations and time dependent forces and moments. The course also covers the effects of construction and loading in different stages. The course deals only with service conditions and doesn't deal with concrete structures at the ultimate stage or at failure. Lecture based, 3 hrs/week.

CIVL 831 Assessment and Monitoring of Infrastructure
This course provides an introduction to commonly used numerical assessment techniques (e.g. plastic collapse and FEA) and discusses the pros and cons of these techniques. Monitoring technologies (e.g. fibre optic sensors, conventional transducers etc.) are then investigated and discussed with a focus on supporting experimental work and assessment.

CIVL 832 Finite Element Analysis
The objective of this course is to introduce the students to the finite element method and its applications in civil engineering using commercial finite element software. A course presenting the fundamental ideas involved in conventional finite element analysis in civil engineering. Domain discretization, interpolation and shape functions, element derivation and types, element stiffness or property equations, assembly procedure, boundary conditions, solution methods for the algebraic equation system, and stress analysis. Students will, throughout the course, write and test their own finite element code through individual subroutine construction as the course progresses. PREREQUISITE: Students must have a strong background in Numerical Methods, Structural Analysis and Applied Mathematics for Civil Engineers to take this course.

CIVL 834 Advanced Reinforced Concrete
This course aims at developing an in-depth understanding of the fundamental structural behavior of reinforced concrete members subjected to a variety of loading conditions. The topics include introduction of material properties and design approaches, flexural behavior using actual material constitutive relationships, bi-axial bending with or without axial loads, slender columns, serviceability, ductility, shear analysis using various advanced approaches such as truss model, strut and tie model and compression field theories, torsion, two-way slabs including yield line theory, and FRP reinforcement for concrete structures (Three lecture hours a week).

CIVL 835 Advanced Infrastructure Materials
Design of masonry, fibre reinforced polymer (FRP) and wood structures is covered. Topics include design of masonry beams and walls; seismic design of masonry structures; manufacturing techniques for FRPs; stiffness and strength design for FRPs; design of wood beams and columns; wood connections. A project is normally undertaken in the course. Three term-hours, fall (offered in alternating years).

CIVL 836 Advanced Steel Design
Applications of Linear Elastic Fracture Mechanics; Fatigue of Steel Structures; Stability and Design of Columns; Stability and Design of Beams; Stability and Design of Beam-Columns; Stability, Analysis, and Design of Frames. Three term-hours, Summer.

CIVL 837 Prestressed Concrete
Behaviour, analysis and design of pretensioned and post-tensioned concrete systems including simply supported and continuous beams. Considerations of prestress losses, cracking, deflection and anchorage zones. A design project is undertaken in the course. Three term-hours, winter.

CIVL 838 Design of Concrete Structures with Fibre Reinforced Polymers
This course considers the design of new concrete structures reinforced or prestressed with fibre reinforced polymer (FRP) reinforcement, and the design of FRP repairs for existing concrete structures. Topics will include properties of FRP reinforcement, flexural design with internal FRP, shear design of concrete reinforced with internal FRP, prestressing with FRP, flexural and shear strengthening of concrete beams and slabs with external FRP, and confinement of concrete columns with FRP. Three term hours, Winter.

CIVL 839 Approximate Structural Analysis
This course will present a number of advanced approximate methods for analyzing structures. Topics covered include: analysis of statically indeterminate trusses and frames; model analysis; energy principles; numerical integration for solving structural problems including Newmark's method and beams on elastic foundations; structural vibrations including Rayleigh's principle, Stodola's iteration technique, and distributed mass systems using Newmark's method; structural stability including the energy criterion for stability, lower-bound methods, the method of Vianello, columns with lateral loads, Perry's approximation, the conjugate beam method, stability of unbraced frames and multi-storey building frames; plastic collapse of plane frames, including the plastic moment of a cross-section, and limit theorems of plastic collapse; limit analysis of plates and slabs including the upper and lower bound methods, failure mechanisms, combined loading, and the strip method for slab design. Three term hours, spring.

CIVL 840 Advanced Soil Mechanics
Current theories on the yielding and failure of soils are presented and discussed in lectures. Topics include stress-dilatancy, critical state soil mechanics, and the interpretation of triaxial test data. Additional advanced topics are

investigated through a seminar project including fracture, anisotropy, time dependent behavior, and cyclic loading. Three term-hours, Fall (offered in alternating years).

CIVL 842 Foundation Engineering
Topics and seminars to be chosen from soil classification, compaction, swelling, frost, seepage, stress distribution, settlement, site investigation, shallow and deep foundations, site and soil improvements, excavations, retaining and support structures, and overall stability problems. Three term-hours, winter. Held at Queen's or RMC depending on enrolment. NOTE: This is a joint course with RMC Civil Engineering Department.

CIVL 843 Landslides
Mechanisms and methods of analysis of landslide triggering are presented and discussed in lectures along with various remedial and preventative measures. Topics include triggering processes, and remediation through earthworks, erosion control measures, dewatering, anchors, and retaining structures. A seminar project is usually undertaken in this course. Three term hours, Fall (offered in alternating years).

CIVL 844 Geotechnical analysis 1: Elasticity
Overview of equilibrium and classical elasticity; introduction to elastic finite element analysis; derivation of stiffness equations using the principle of virtual work; static and kinematic boundary conditions; error checking. (1.5 credit units)

CIVL 845 Geotechnical analysis 2 : Inelastic analysis
Overview of equilibrium and classical plasticity; failure criteria; flow rule and elastic plastic constitutive response; inelastic finite element analysis; modelling and solution of geotechnical engineering problems. (1.5 credit units)

CIVL 846 Human Factors and GeoEngineering Projects
Human factors affecting the success of geoengineering projects are examined predominantly through a series of Case Studies. A major focus will be on the human related causes of engineering failures (often ending in legal cases). Technical issues will be discussed as needed to understand the issues but a focus will be made on how many poor engineering and/or management decisions accumulated to result in the final problem in most cases.

CIVL 847 Geosynthetics in Geotechnical Engineering
Topics include: types of geosynthetics and manufacturing processes; properties and test methods; methods of analysis and design for geosynthetics used for separation, filtration, soil reinforcement, erosion control and liquid/hazardous waste containment. Held at Queen's or RMC depending on enrolment. Three term-hours, fall, lectures. NOTE: This is a joint course with RMC Civil Engineering Department.

CIVL 848 Sustainable Barrier System Design
Design of fluid containment systems considering hydrogeology, climate change, and contaminant transport for applications including landfills (e.g., containing PFAS), lagoons (containing leachate, mining, brine, and RO water), tailings storage facilities, heap leach mining, and dams for storage of clean energy. UN SDG 6, 7, 9 & 12. (3.0 credit units). Three term-hours, winter.

CIVL 849 Polymer Microstructure and Testing in Civil Engineering Applications
This course introduces the Microstructure and testing for polymeric materials used in civil engineering applications. This course will be focused on fundamental knowledge essential to civil engineers to understand the performance of polymeric materials used in different applications such as geotechnical engineering and structural engineering. (1.5 credit units).

CIVL 850 Advanced Fluid Mechanics
Fundamental equations of real fluid flows are developed and discussed using vector and tensor notations. Some exact and approximate solutions of these equations are introduced. The stability of laminar flows and the transition to turbulence are examined; the Reynolds equations are derived and some applications of these equations are investigated. The boundary layer concept is introduced. Recent developments in the theory of turbulence are outlined and discussed. Three term-hours, fall.

CIVL 851 Introduction to Hydrodynamic Modelling
This course will develop fundamental modelling tools that are used to model surface- and groundwater processes. Students will be introduced to the essential elements of dimensional analysis, scaling analysis, and model development, which provide the leading-order solution of a system. Emphasis will be placed on comparing model predictions with measured data. (3.0 credits: term course delivered in one 12-week semester, 3 hours/week)
Prerequisites:
-Permission of instructor;
-Graduate students in science and engineering must have a strong background in Applied Mathematics to take this course;
-Students should have previously taken courses in numerical methods and environmental hydraulics.

CIVL 852 Environmental Fluid Dynamics
Topics to include: conservation equations for turbulent flows; wall-bounded shear flows; spectral dynamics; measurement and modelling of mixing and dissipation in stratified flows; stability of stratified flows; linear, nonlinear and dispersive waves (e.g. seiches, Kelvin waves, Poincare waves and solitary waves); internal wave breaking; convection. Theory will be

discussed with reference to field observation, computational and laboratory modelling of lake and ocean flows. Three term-hours.

CIVL 853 Water Waves
Fundamentals of surface gravity wave physics including generation, propagation, dispersion, refraction, diffraction, reflection and dissipation are covered. Topics include wave theories, spectral analysis, wave momentum flux, wave-driven currents, wave-sediment interactions, wave forces and design of structures. Emphasis will be on theoretical analysis and practical engineering design, as well as on physical and numerical modelling (Three lecture hours per week).

CIVL 855 Hydrodynamics of Coasts and Estuaries
An advanced class in physical processes acting in coastal environments ranging across the continental shelf to estuaries, river deltas, beaches, barrier islands and tidal inlets. Topics include surface waves, long waves, storm surges, tides, mixing, coastal circulation, wind forcing, upwelling, salinity, morphology, sediment transport and contaminant dispersion. Observation and prediction methods will be covered and examples from major events such as hurricanes and tsunamis will be discussed. Emphasis will be on theoretical analysis, numerical model applications and engineering designs (Three lecture hours per week).

CIVL 856 River Morphodynamics
Aspects of the bed and bank deformation of alluvial rivers will be addressed. Topics covered include hydraulics of flow in river channels; mechanics and quantification of sediment transport; sediment transport continuity equation; bed forms and flow resistance; regime concept and determination of equilibrium (stable) alluvial channels; adjustments of equilibrium and river channel changes; geometry and mechanics of meandering and braiding streams; local scour and related problems. Computer-aided study of alluvial river processes will be discussed. Three term-hours, fall.

CIVL 857 River Engineering
A course in the basics of river engineering including the study of alluvial process, the prediction and consequences of sediment transport, the design of measures to control erosion and accretion, and the design of dams, spillways and diversions. Hydraulic modelling of fluvial processes and engineering structures is addressed. Water quality including transport and mixing of conservative and non-conservative substances is discussed. Techniques for water quality monitoring, and control and bioengineering in a riverine environment are also addressed. Three term-hours, winter.

CIVL 879 Groundwater Resources in Cold Regions
This course will review groundwater system behavior in cold regions, including the influence of seasonally frozen ground and permafrost occurrence on flow and contaminant transport. Fundamental processes will be discussed including surface energy balances, coupled heat and fluid transport, solute effects on freezing, and numerical implementation of freeze-thaw processes in hydro(geo)logical models. These processes will be applied to a range of topics including groundwater recharge, drinking water supply, surface water-groundwater interaction, and permafrost thaw, with an emphasis on evaluating system behavior under climate change. (3.0 credits: term course delivered in one 12-week semester, 3 hours/week).
PREREQUISITE: This course is designed for learners who have previously taken a course on hydrology or hydrogeology and have a basic understanding of partial differential equations.

CIVL 880 Subsurface Contamination
This course deals with subsurface contamination by hazardous industrial liquids such as PCB oils, gasoline, jet fuel, chlorinated solvents and coal tars. The fundamentals of multiphase/multicomponent flow and transport will be outlined followed by specific treatments of both dense and light non-aqueous phase liquids. The course will examine the subsurface distribution of these liquids, sampling and detection, clean-up technologies, regulatory aspects, and selected case histories. (CIVL-480 plus additional material.) Three term-hours, fall.

CIVL 881 Flow and Transport in Fractured Rock
The course will cover a review of structural geology relevant to hydrogeology, an introduction to the cubic law, transport in discrete fractures, flow and transport in fracture networks, methods for measurement of parameters (i.e. hydraulic testing), modelling of flow through fractures and fracture networks, groundwater flow in low permeability environments and a detailed case study.

CIVL 882 Analytical and Numerical Methods in Groundwater Modeling
This course will provide an advanced treatment of groundwater modeling techniques. The student will be introduced to analytical methods based on advanced calculus and to traditional and novel numerical methods. Topics in analytical methods will include the Laplace transform technique for PDEs and other integral transform methods, with applications to radial groundwater flow and linear solute transport problems. Topics in numerical methods will include a brief introduction to Finite Difference and Finite Element theory and the practical application of numerical methods to groundwater flow and transport problems. Three term hours, Fall.

CIVL 883 Gases in Groundwater
Advanced topics in multiphase flow relevant to gases in subsurface porous media, focused on contamination and remediation, with emphasis on fundamental theory and conceptual models. Lecture topics include interfacial properties, pore-scale conceptual models, phase partitioning, vapour transport, bubble flow, and mass transfer to trapped gases. Three term-hours, Winter (alternating years).

CIVL 884 Field Methods in the Hydrogeology of Fractured Rock
This course will provide students with hands-on experience in conducting the field techniques typically used for the characterization of fractured rock aquifers. The course will include a combination of lecture material and field testing. The course will be delivered at the Kennedy Field Station and will involve approximately six days of on-site testing.

CIVL 886 Advanced Water Treatment
This course will involve the principles and applications of advanced water treatment technologies. Students in this course will learn about gas transfer, advanced oxidation processes, reductive processes, photocatalysis, electrocatalysis, pressure-driven membrane processes, and forward osmosis. Students will learn about the applications of those advanced technologies, understanding their challenges and gaps. Emphasis will be placed on mechanism analyses and potential applications. Students will get training in mechanism exploration, novelty development, comprehensive review writing, and oral presentation. (3.0 credits: term course delivered in one 12-week semester, 3 hours/week)
PREREQUISITES: Graduate students in science and engineering must have a strong background in Applied Chemistry for Civil Engineers to take this course. In addition, students should have previously taken undergraduate courses in water treatment and environmental chemistry.

CIVL 887 Biomass Conversion
This course introduces the pertinent underlying concepts for the conversion of biomass to bioenergy, biofuels and higher value bio-based products considering the interface of biotechnology, microbiology, chemistry and material science and how processes can be successfully engineered to support/promote environmentally sound practices.

CIVL 888 Theory of Groundwater Flow and Transport
This advanced course examines the theoretical foundations of ground-water flow and contaminant transport. Topics covered include potential concepts, groundwater flow, aquifer-aquitard systems, unsaturated flow, reactive and non-reactive solute transport, stochastic flow and transport, fractured media, and density-dependent transport. Three term-hours, winter.

CIVL 889 Bioremediation Processes and Applications
Bioremediation as an option to treat contaminated soils, ground water, fresh water and the marine environments. Advantages and disadvantages of bioremediation compared to nonbiological processes. Factors affecting choice of in situ or ex situ processes. Assessment of biodegradability; biostimulation vs. bioaugmentation; mineralization vs. partial degradation; factors affecting microbial activity (choice of electron acceptor, toxicity of pollutant, C/N/P ratio, co-substrates, soil humidity, pH and temperature); bioavailability of pollutant. Biodegradation of specific contaminants (eg. Diesel fuel, polychlorinated biphenyls, dyestuffs, aromatic and polyaromatic hydrocarbons) will be studied in detail. This course is co-taught with CHEE-884.
EXCLUSION: CHEE-884

CIVL 890 Water Network Analysis/Design
Topics to include: review of basic fluid mechanics of closed-conduit flow; hydraulic characteristics of pumps, valves, tanks and reservoirs; network hydraulics (includes pipes in series and parallel, systems of equations for steady state network flow and solution algorithms, fire analysis, unsteady flow conditions, extended period simulation, hydraulic transients); water quality simulation (includes transport mechanisms, reaction kinetics, mixing in storage facilities, transport and mixing in pipe network, steady state and dynamic water quality modelling); water demand and design standards; master planning of water networks. The course will also cover advanced topics in: water network optimization, sensor placement, contaminant detection, sustainable water systems, dual water systems and water re-use. Three term hours, winter.

CIVL 891 Water Quality and Discolouration in Drinking Water Distribution Systems
This course presents approaches to analyze and model drinking water quality and discolouration in distribution systems. The course covers approaches in aquatic chemistry for the testing of drinking water. Transport processes and advanced topics in discolouration of drinking water are examined with emphasis on the measurement and modelling of the growth and mobilization of cohesive layers in pipes.

CIVL 892 Structural Dynamics
The objective of this course is to introduce students to structural dynamics and its practical application in earthquake engineering. Topics include single and multi-degree-of-freedom systems, formulation of equations of motion, methods of analytical mechanics, free and forced vibration, numerical methods and the use of computer

software for the response analysis of structural systems. Three term-hours, fall.

CIVL 893 Statistics for Environmental Applications
In this course, students will learn to use essential statistical concepts and tools to explore and compare data. The course will focus on environmental applications and discuss how to deal with issues such as frequent measures below detection limits as well as data that requires transformations. Students will learn how to identify the appropriate statistical tools to evaluate data sets to answer questions about environmental surveillance and regulatory compliance. Students will also learn about experimental design and strategies to determine the most appropriate design, size and power. The course material is designed to help students evaluate the strength of experimental design and interpretation when reviewing research in the literature and togive them the tools to develop strong experimental design for their own research projects. (3.0 credits: term course delivered in one 12-week semester, 3 hours/week)
PREREQUISITE: Graduate students in science and engineering must have a background in mathematics that would be covered in a science or engineering undergraduate degree.

CIVL 894 Drinking Water Management
In this course, students will examine frameworks for providing safe drinking water using a systems thinking approach. We will examine the impacts of unintended consequences of change and poor design on downstream water quality. Vitally, we will conduct in-depth analysis of case studies of waterborne outbreaks or toxic exposures, looking at failure elements and fault-tree analysis. We will also examine new threats to water quality through impacts of climate change and identify strategies for managing unquantifiable or unknown risks from contaminants of emerging concern. Students will gain hands on experience for evaluating unintended consequences of change through laboratory-based research. (3.0 credits: term course delivered in one 12-week semester, 4 hours/week)
PREREQUISITE: CIVL 372, CIVL 472 or equivalent course in water and/or wastewater treatment. Background in wastewater treatment may be acceptable, but student would need to commit to independent learning to have sufficient background on water treatment processes.

CIVL 895 Special Topics in Civil Engineering
Current topics of interest to civil engineering students, as well as other engineering and non-engineering students, will be presented.

CIVL 896 Engineering Sustainability and Reconciliation
This course recognizes that sustainability has many definitions and approaches, but its understanding by engineers in all fields is required. Through the lens of climate change and the 17 sustainable development goals (SDGs), northern and remote areas are identified as a key resource for the continued prosperity of humanity. Providing engineering services in these areas poses significant challenges and opportunities for Canada's future. As such, engineering companies require professionals who understand the physical challenges of working in remote areas as well as the societal and cultural impact of working in Indigenous communities. With this background in mind, CIVL 896 provides expertise in cultural sensitivity, best practices for working with Indigenous communities, reconciliation, the SDGs, and engineering sustainable solutions while building communication skills. Course material will be offered throughout the term in the form of seminars, workshops and online readings. (3.0 credit units)

CIVL 897 Water Policy and Governance
This course investigates waters governance from the science, engineering and policy aspects found around the world. This course is designed to engage graduate students in discussions on a wide range of governance issues relating to water in a way that is relevant to their current field of study. Specific policies and governance that are relevant world-wide will be covered and include climate change, water quality, water supply, water and the environment and water and human health. This course, although placed in the Department of Civil Engineering, is designed for inclusion in the course offerings from departments across Queen's University.

CIVL 898 Master's Project
The department requires three copies of a Master's Report. These will be retained by the department. (3.0 credit units)

CIVL 899 Master's Thesis
See School of Graduate Studies and Postdoctoral Affairs regulations concerning thesis requirements.

CIVL 999 Ph.D. Thesis
See School of Graduate Studies and Postdoctoral Affairs regulations concerning thesis requirements.