

Elements



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THE NEWSLETTER OF THE CANADIAN GEOPHYSICAL UNION

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LE BULLETIN DE L'UNION GÉOPHYSIQUE CANADIENNE

President's Column

While writing this, my first president's message, I think back to when I first joined the CGU at the time of the formation of the CGU-Hydrology Section and forward to next year when we meet jointly with the American Geophysical Union in Montreal. The link between these events is the meaning of the word "Union" in both our names, and the ways in which the CGU encourages "union" to occur within our society.

As noted in the President's message in the last issue of *Elements*, one of the primary functions of the CGU is to act as a Union of various geophysical sections. The CGU encourages 'union' activities through a number of mechanisms, including: development of sections within the CGU (currently we have two sections – Hydrology and Geodesy); encouraging other groups to meet at CGU Annual Meetings (the Climate Systems History and Dynamics (CSHD) is one, very successful example); and through joint meetings with other societies (the 2002 meeting with the Canadian Society of Soil Science is the most recent example). In addition, we have an ad hoc committee with the Canadian Meteorological and Oceanographic Society (CMOS) in order to develop further collaboration between the two societies. All of these activities have brought added diversity to the CGU.

Although the CGU has attempted to enhance our union activities, I do not think that we have been completely successful to date. One example of our lack of success is shown by both the limited number of sections within CGU (2 compared to eleven within the AGU for example), and by the poor performance of the earth

science community in Canada during past NSERC reallocation exercises. In spite of these problems, there is a growing consensus that many scientific questions can only be answered through the combination of what have previously been considered separate scientific disciplines. As a result, there is a growing need to further encourage the interactions between the wide range of geophysical disciplines. A major task of the CGU is to provide the means for furthering these interactions within the Canadian geophysical community.

As you know, the CGU is meeting jointly with the American Geophysical Union in Montreal between May 17 and May 21, 2004. I expect that this will be an outstanding meeting, covering a wide array of geophysical disciplines covering the full range of subjects included in the sections and focus groups of our two Unions.

This is a great opportunity for Canadian geophysics. It will allow us to demonstrate the breadth and depth of our sciences, and it will give us an opportunity to consider how we should advance the Union aspects of the CGU. In order to meet these goals, I would strongly encourage you to participate in next year's meeting by proposing sessions to be held in Montreal, by presenting papers at the meeting, and by considering how we can utilize these activities to further the union of geophysical sciences in Canada through stronger interactions between currently separate societies, and by strengthening the CGU through the development of new sections within CGU.

--- Philip Marsh

CGU 2004 Annual Scientific Meeting, Montreal, May 17-21
A Joint Meeting with the AGU (American Geophysical Union)
Venue: Palais des congrès de Montréal (www.congresmtl.com/en/index.php)
CGU Program Chair: W.R. Peltier (peltier@atmos.physics.utoronto.ca).

See also CGU website: <http://www.cgu-ugc.ca>

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Canadian National Committee for the International Union of Geodesy and Geophysics (CNC/IUGG)

Ronald Stewart, McGill University

The Canadian National Committee for the International Union of Geodesy and Geophysics (CNC/IUGG) has continued to be active supporting and representing the geosciences in Canada. Some of its recent activities are briefly described in this report and more information is available through the CGU web site.

CNC/IUGG has been promoting greater collaboration between the two Societies representing our fields. That is, it has supported more interactions between the Canadian Geophysical Union and the Canadian Meteorological and Oceanographic Society. This interaction currently involves joint sessions at each others conferences and in the future it is expected that this will also include joint workshops and conferences.

CNC/IUGG has been making major contributions to the upcoming IUGG Joint Assembly in Sapporo, Japan. Canadians are leading several symposia at this Assembly, giving several invited presentations, and participating within Association and IUGG official meetings that chart IUGG's course for the future.

For this Assembly, CNC/IUGG is also producing a Quadrennial Report (1999-2003) summarizing recent

scientific activities in the geosciences in Canada. A tremendous amount of research continues to be carried out in our fields in Canada, university funding is on the upswing, but in general government funding is eroding. This report also contains several recommendations for IUGG's consideration; these include increasing IUGG's profile within its member countries and making its Joint Assemblies more effective. This report is available through the CGU web site and copies of it are also given to the IUGG Secretariat, IUGG member countries, and numerous Canadian agencies.

The end of the IUGG Assembly also marks a major turn-over in the membership of CNC/IUGG. Several of our members are stepping down after long service to the Committee. Thank you for all your efforts.

And, I am stepping down as well. Thank you for the opportunity to lead CNC/IUGG for the last several years and I wish the geosciences great success in the future!

Further CNC-IUGG information is available at:
<http://www.cgu-ugc.ca/cnc-iugg/index.html>

CGU and CMOS (Canadian Meteorological and Oceanographic Society)

Charles Lin, McGill University

A number of activities took place to promote interaction between the CGU and the CMOS:

1. The 2003 CMOS Congress (Ottawa) and CGU Meeting (Banff) were open to members of the other society at their own members' registration rates.
 2. A jointly sponsored session on MAGS (Mackenzie GEWEX Study) was held at CMOS, with Hok Woo as an invited plenary speaker.
 3. The CMOS Executive has taken steps to designate CGU members as CMOS Associate Members. The details are being worked out now.
 4. Discussion is ongoing for joint workshops between the two societies.
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CGU 2003 ANNUAL SCIENTIFIC MEETING, 10-14 MAY, Banff, Alberta

HIGHLIGHTS AND SESSION SUMMARIES

The 29th annual scientific meeting of the Canadian Geophysical Union took place at the Banff Centre, in Banff, Alberta, in the period 10-14 May 2003. There were 258 registered participants. All enjoyed an excellent technical program consisting of 218 oral and poster presentations, as well as a number of social activities (e.g.,

the icebreaker, barbeque, and the annual awards banquet). A notable event was the awarding of the J. Tuzo Wilson Medal to Garry Clarke of the University of British Columbia. The citation and acceptance speeches for the Wilson Medal, as well as some of the session summaries, follow.

The CGU 2003 J. Tuzo Wilson Medallist: Garry K.C. Clarke

Citation by Dan Moore

Terry Prowse and I take great pleasure in citing Garry Clarke, of the University of British Columbia, for the 2003 J. Tuzo Wilson Medal, on the basis of his manifold contributions to teaching, research, and service to the geophysical community. In the comments that follow, we have incorporated quotes from several of the letters of support for the nomination.

Garry is a consummate teacher at all levels. I had the great pleasure to be an undergraduate student in Garry's course Geophysics 221 (Physics of the Earth) in the 1970's. His teaching combined a high level of mathematical and physical rigour with an irresistible enthusiasm for teaching and a passion for the subject matter. His effervescence and obvious sense of joy in his work was contagious, and inspired me to consider pursuing graduate work and a career as an academic.

He has also made notable contributions in graduate teaching. Professor Ed Waddington of the University of Washington was one of Garry's graduate students in the 1970's. In his letter of support for Garry's nomination, Professor Waddington compared the sense of excitement he experienced from Garry's classes, seminars and informal discussions to that which he encountered during his undergraduate days at University of Toronto, when he heard Tuzo Wilson speaking on new ideas such as plate tectonics. Another of Garry's former graduate students, Professor Shawn Marshall, wrote that "I had the good fortune to enjoy both Ph.D. and Postdoctoral work with Garry The quality of Garry's research group and the research environment at UBC were outstanding and I could not have picked a better mentor or place in the country to gain my training. Work with Garry has always been on a two-way, collegial basis, and there is no question in my mind that he brings out the best in people."

Garry's research accomplishments are outstanding in both quantity and quality. A citation search on Web of Science

turned up 88 references, all of which were in international peer-reviewed journals of high standing, including *Nature*, *Science*, *Journal of Geophysical Research*, *Climate Dynamics* and *Journal of Glaciology*. Although Garry is best known for his work in glaciology, he has published in a broad range of fields, including structural geology, signal processing and potential-field theory.

Garry is truly a scientific "renaissance man." On the one hand, he and his group have been at the forefront of field measurement of glacier processes. All glaciological studies that involve investigations of the subglacial environment have their basis in the methods and instrumentation developed by Garry and his research group. His commitment to field work is in line with Tuzo Wilson's statement "I preferred a life in the woods to one in the laboratory." However, in addition to his standard-setting field work, Garry has been at the forefront of theoretical and numerical modelling research on topics such as ice flow and subglacial hydrology. As Professor Andrew Fowler wrote in his letter of support for the nomination: "[Garry's] science is comprehensive. He designs new field instruments, he builds new theories. He does all this *himself*."

Garry has made significant, fundamental contributions in a range of glaciological areas, including outburst flooding, strain heating, ice creep, and the effects of wind pumping on ice-core records. Some of his main contributions have focused on glacier-bed processes. Such research has implications for natural hazard mitigation and for understanding past changes in large ice sheets and predicting future ice-flow and sea-level changes. Much of this work has drawn from his field program at Trapridge Glacier, likely the longest-running observational program on a surge-type glacier. The International Glaciological Society has honoured Garry's productive and high-impact research career by awarding him its Seligman Crystal.

The heart of Garry's research success is his intellectual depth and breadth. Professor Fowler wrote that "[Garry's] science really is innovative. Time and again he brings concepts from different fields across to glaciology. This is the hallmark of the truly original scientist [Garry's] theoretical analyses of the problems which his field work raises are full of invention and novelty. He is truly curious and unflawed by the kinds of preconceptions which can blunt the endeavours of lesser scientists."

Garry's intellectual strengths are combined with a strong sense of elegance and aesthetics that infuse his research. As Professor Richard Alley emphasized, "Garry does not simply solve problems, he solves them correctly. His papers are easy to read, compelling in their logic, clear in exhibiting any (rare) weaknesses and in pointing other workers to the next problems. The solutions are never brute force or ugly, but show an economy of thought and process Garry's research also shows a monetary economy ... he has repeatedly achieved major results for minor expenditures by doing things properly and elegantly."

Garry's service to the geophysical community has been exemplary. In 1986, he organized a Chapman Conference on "Fast Glacier Flow," which turned out to be, as Professor Waddington put it, "one of those seminal events that energizes its field by stimulating new interactions, new research ideas, and a new consensus." He served as Vice-President and President of the International Glaciological Society, and is widely credited with bringing its flagship publication, *Journal of Glaciology*, into the modern era of computer-based publishing. The International Glaciological Society has recognized Garry's contributions to the IGS and glaciology in general by awarding him its Richardson Medal.

Garry spearheaded the creation of the Snow, Ice and Permafrost Committee within the American Geophysical Union, which has gone on to become the Cryospheric

Sciences Focus Group. He has also been active in Canadian Geophysical Union. He served as President, and was a strong supporter of the creation of the Hydrology Section, one of the most active components within CGU. Garry served as a Natural Sciences and Engineering Research Council Grant Selection Committee Chair and as an IPCC Co-ordinating Author. He has also served as Editor or Associate Editor or member of the Editorial Board for a range of journals, including *Journal of Geophysical Research* and *Quaternary Science Reviews*.

In summary, Garry has had and continues to have a stunningly rich and productive career, with significant contributions to teaching, research and service to the geophysical community. In addition to his receipt of the Richardson Medal and Seligman Crystal from the International Glaciological Society, he has been made a Fellow of the Royal Society of Canada, Fellow of the American Geophysical Union, and Fellow of the Arctic Institute of North America. He has also been awarded two Killam Fellowships and a Killam Research Prize.

I would like to close with a quote from one of the supporting letters:

All of this misses Garry's main contribution, to research, to teaching and to service. Quite simply, Garry is the standard of elegance in the community. In "Dreams of a Final Theory," S. Weinberg struggled to describe the aesthetic sense in physics and concluded "You do not define these things; you know them when you feel them." Garry has this aesthetic sense, and he spreads it widely, lifting not only his own research, but his students', his colleagues', and the rest of the field to a higher level.

It is a great pleasure to see Garry's contributions recognized by the award of the J. Tuzo Wilson Medal.

Acceptance by Garry Clarke

Thank you, Dan, for your extremely generous words. I know that awards such as this do not come from out of the blue and that my nomination must have received strong support from fellow members of the Hydrology Section. I would therefore like to thank these anonymous friends, both for this honour and for generously viewing my work as a form of hydrology. It is humbling to look over the list of previous Wilson medallists, many of whom I have known and some of whom I have worked with. For me the most influential individual was the fourth medallist, George Garland, who by a stroke of luck was my professor in first-year physics at the University of Alberta. Garland so impressed me by his intelligence and wry wit that, as

soon as possible, I converted from physics to geophysics. Following my third year in that program, Garland suggested that I might enjoy working as a field assistant on a glaciological project in the Yukon and, in retrospect, this proved to be a pivotal event in my professional life. Subsequently, at the University of Toronto, Garland supervised my M.A. and Ph.D. thesis research.

While at Toronto, I had the great pleasure of knowing Tuzo Wilson and treasure my own memories of this marvellous man. One of the things I remember best about him was that he always seemed to be having fun. Something that gave him special pleasure was to goad

geologists and it must have been sweet indeed for him to see his heretical ideas become enshrined as the new orthodoxy. Like many great scientists he is best remembered for his major scientific contributions, but I would like to take this opportunity to mention some of his lesser known achievements that have a special resonance for me. Among many things, Wilson was a northern scientist and a glacial geologist. While working at the Geological Survey of Canada, he published several papers on glacial features in northern Canada and also proposed some clarifications of the map sketched by the arctic explorer Samuel Hearne around 1771. Immediately after the War, as Colonel Wilson, he led a major military/scientific expedition known as Exercise Musk-ox which involved winter travel using tracked vehicles in the Canadian North. The expedition followed a 3700 km circuit that started at Churchill, looped past Baker Lake, Cambridge Bay, Coppermine and Norman Wells, and terminated in Edmonton. Perhaps Wilson's most significant contribution to northern science and to glacial geology was the leading role he played in compiling the first Glacial Map of Canada (1958).

One reads a lot about how rapidly glaciers are changing in response to global warming, but from my perspective the greatest changes in glaciers have been conceptual ones. When I started in glaciology, it was the era of the Geophysical Glacier. In essence, glaciers were viewed as homogeneous slabs and their beds were geophysical targets to be probed using standard methods of applied geophysics. The Geophysical Glacier was a simple one, admired for its mathematical amenability and minimalism. Thickness was its main attribute but, at its most complex, the Geophysical Glacier also had length, width, slope, thermal stratification and rheology. With this limited alphabet I attempted to solve a challenging problem of glacier behaviour—surging—an episodic flow instability intrinsic to a small class of glaciers. This is a genuinely interesting question and I've spent much of my professional life approaching the problem from a variety of perspectives. As a start, by manipulating the small number of characters of the Geophysical alphabet, I proposed a plausible, though in hindsight incorrect, theory of surging that involved an interaction between the temperature and rheology of ice.

With time, the possibilities of the Geophysical Glacier seemed nearly exhausted and I was experiencing my own misgivings concerning the geophysical mindset. It struck me that if a team of geophysicists was charged with the task of determining whether the moon was indeed constituted of green cheese, they would dutifully examine the acoustic and dielectric properties of cheese, but it would never occur to them to taste it. Before these doubts became combustible, a significant change in perception

occurred and the Hydrological Glacier took centre stage. An important feature of the scientific study of the Hydrological Glacier is its focus on processes occurring at the ice-bed contact, rather than processes at the glacier surface which, though more readily studied, have a secondary influence on ice flow. To properly explore the ice-bed contact one must place instruments there, so our initial emphasis was on drilling technology and the design of cheap hydrological sensors that could monitor the state and function of the subglacial water system. The world that was revealed was a surprising one. The water system changed from point-to-point, hour-to-hour, day-to-day, season-to-season and year-to-year in a complex manner. On rare occasions, switching events transformed the system from one drainage morphology to another, accompanied by macroscopic changes in glacier motion. The elusive problem of surging might possibly be explained by morphological switching in the subglacial water system.

While the intricacies of the Hydrological Glacier were slowly being unravelled, a new glacier, the Soil Mechanical Glacier, presented itself. Actually, glacial geologists knew about this glacier decades before glaciologists recognized it. For glaciologists the turning point was the discovery that the seismic S-wave velocity of material beneath fast flowing West Antarctic ice streams was 160 m/s, astoundingly low. Only weak unconsolidated sediments have such low shear strength, so an association between fast glacier flow and a soft sediment substrate was established. Eager to learn more about this, we designed instruments that could be inserted into the material *beneath* the glacier that we were studying and found that, indeed, the subglacial material was deforming and had a complicated interaction with the subglacial water system. More processes and more possible surge mechanisms were to result.

The best change of all, however, has been the emergence of the Earth System Glacier. Unlike their less robust predecessors, these glaciers are full citizens of the Earth System. They not only respond to climate but, by controlling the delivery of freshwater to the oceans, can trigger abrupt climate changes. In doing so, they have led us back to the geophysical heartland—to the unity that connects the solid Earth, its surface, its ocean and its atmosphere—and remind us of all the reasons we love our planet and our science.

In closing I wish to offer my most heartfelt thanks to NSERC and my co-investigators in the Climate System History and Dynamics collaboration, to my excellent scientific colleagues, in particular my graduate and postdoctoral students, and to my wonderful family. Thanks everyone for this great honour.



Garry Clarke (left) receiving the J. Tuzo Wilson Medal from Phil Marsh (CGU President), during the CGU Awards Luncheon, May 14, 2003, held at the Banff Centre (photo by Ted Glenn).

CGU 2003 Annual Scientific Meeting, May 10-14, Banff, Alberta : Session Summaries

Planetary Physics

Ed Krebs and Patrick Wu (conveners)

Summary prepared by Patrick Wu

This session consisted of 2 oral presentations about Mars, 1 oral paper on the search for fireball debris via seismic arrays and 2 poster presentations about impact craters.

J. Arkani-Hamed studied the origin of the long and thick magnetic anomalies observed in the southern hemisphere of Mars. One possibility that is investigated involves thermo-remanent magnetization of the upper Martian lithosphere in the early history of the planet when the core existed ~ 4 G. yr ago, while the lower lithosphere has been gradually magnetized as it cooled below the Curie temperature in the presence of the strong magnetic field of the upper lithosphere. Another possibility is that there is an ilmenite-rich layer beneath the crust that acquired magnetization in the presence of the magnetic field of the crust.

J.B. Merriam, J. Arkani-Hamed, W. Cannon & M. Daly investigated the feasibility of detecting the size and mechanical state of the Martian core through Very Long Baseline Interferometry observations of its rotation. It is found that the Martian Chandler wobble is relatively insensitive to core constitution, while the magnitude of the wobble and Free Core nutation are too small to be of use.

W. Edwards & A. Hildebrand described the SUPRACENTER program which uses arrival times recorded by seismographs to locate the terminal burst of fireballs. This program was tested successfully for the El Paso superbolide event of October 9, 1997 and the two bursts of the Mount Adams fireball of January 25th 1989.

E. L'Heureux, H. Ugalde, B. Milkereit, N. Eyles, W. Morris & J. Boyce used gravity, magnetics, detailed bathymetry and high frequency seismic data over Wanapitei Lake to determine the exact size and extent of the Wanapitei impact crater. Their findings indicate that the crater has a much smaller diameter than anticipated (3 to 4 km), and is located in the central, deepest section of the lake.

H. Ugalde studied magnetization on the Chicxulub impact craters and quantified the contributions due to shock remanent magnetization, recrystallation of non-magnetic biotite & amphibole to assemblage of phases containing magnetite and hydrothermal alteration resulting in chemical remanent magnetization.

Electromagnetics, Integrated and Environmental Geophysics

Ed Krebs and Patrick Wu (conveners)

Summary prepared by Ed Krebs

There were 3 oral presentations and 1 poster in the area of Electromagnetics.

Jim Merriam (U. of Saskatchewan) talked about a new model for describing activation overvoltage, a particular type of induced polarization. His model differs from the standard Cole-Cole model in that the time constant is time-varying. The model produces decay curves which accurately fit the observed decays. He also presented a poster on the origin of electrode impedance (the impedance in a thin sheath surrounding the electrode), and showed that it is strongly dependent on the polarity of the electrode, the potential and current density at the electrode, the nature of the dominant ions in the pore water, and the material of which the electrode is constructed.

C. Malo-Lalande (École Polytechnique de Montréal – EPM), spoke about her mathematical, numerical and scale modelling studies, done in collaboration with M.C. Chouteau (EPM), D. Marcotte (EPM), and M. Boivin (SOQUEM Inc.), for establishing relationships between the time-domain electromagnetic response of a single loop configuration and the geometrical characteristics of a nickel ore body, for the purposes of providing the mining industry with a practical, direct interpretative tool.

Colin Farquharson (U. of British Columbia – UBC), talked about a new implementation of the integral equation method for modelling electromagnetic survey data that he developed together with Doug Oldenburg (UBC), which gives accurate responses even for large conductivity contrasts between the anomalous zone and the background. The theoretical results compared very well with physical scale modelling results provided by Ken Duckworth (U. of Calgary) for a graphite cube 15 cm to a side, in which the conductivity contrast was about 10^4 S/m.

There were 2 oral presentations and 1 poster in the area of Integrated and Environmental Geophysics.

J.M. Maillol (U. of Calgary), described the results of an archaeo-geophysical investigation, done in collaboration with D.L. Ciobotaru (Culte si Patrimoniul Cultural National Timis, Romania), and I. Moravetz (U. of Calgary), in which electrical, magnetic, and electromagnetic techniques were used to explore the features of an early settlement area in Romania. The results were very consistent with excavations that had

already been done, and will prove valuable in the planning of future excavations.

Hugh Miller (Memorial U. of Newfoundland – MUN), discussed his results, obtained together with B.J. Morrissey (MUN), on using available gravity data and 3D gravity modelling to determine Moho topography beneath the Avalone Zone, Newfoundland, and how it fits within the framework of the regional tectonic history. The results were also compared with earlier seismic interpretations of the region.

Kirsten Hannam (U. of Alberta - UA) presented a poster, together with S.A. Quideau (UA), S.W. Oh (UA), B.E. Kishchuk (Canadian Forest Service), and R.E. Wasylishen (UA), on the results they obtained from using CPMAS ^{13}C -NMR to examine forest floor composition in northern Alberta. They found that levels of aromatic carbon in forest floor were higher in conifer-dominated stands than in deciduous-dominated stands, and that these two types of stands respond differently, in terms of forest floor composition, to clear-cutting.

Melting Under Pressure

Hans J. Mueller (Convener)

This session consisted of 6 oral presentations. Unfortunately two further presenters had to cancel their contributions during the last week before the conference because of unexpected problems.

Hans J. Mueller (speaker), Frank R. Schilling and J. Lauterjung opened the session by an overview about state of the art high pressure techniques for experimental simulation of interior of the Earth conditions from lower crust up to the core. All techniques for high pressure generation were selected, which, already published or possible in principle, allow the measurement of the physical properties of the sample under in situ conditions. The emphasis of the presentation was on the measurement of elastic properties under those conditions. Results of elastic wave velocity measurements at elevated pressures and temperatures up to partial melting conditions, the comparison of experimental data and theory using digital image processing of post-experimental microscopic examination of the quenched samples, and their use for the material interpretation of seismic data from great depth were shown and discussed.

Baosheng Li (speaker) and Jennifer Kung demonstrated the tremendous progress in acoustic velocity measurements at high pressure and high temperature up to ~ 22 GPa and > 1600 K during the last decades using multi-anvil high pressure apparatus. All important techniques as ultrasonic interferometry, X-radiography and X-ray diffraction, necessary for the study of elastic properties of materials undergone phase transitions, melting, and plastic deformation, or multi-phase aggregate (mantle rocks), were described in detail. Recently these methods were applied to study melting processes and the properties of melts. Sound velocity measurements of Bi

had been monitored across phase transitions at room temperature and above melting temperature at 3 to 5 GPa. These results demonstrated the feasibility of current techniques to the study of melts at high pressure and high temperature.

In a student talk, Youcef Bouzidi (speaker) and Douglas R. Schmitt discussed the potentialities of the increasingly used amplitude versus offset (AVO) methods for inferring the existence of fluids in subsurface layers from seismic data. However, this technique, based on the Zoeppritz equations, assumes that the fluid saturated sedimentary formations may be characterized as completely elastic, which may not be adequate in certain fluid saturated porous formations in which wave propagation is complicated by the existence of the two phases of fluid and solid. In such a medium a second p-wave, never observed in nature due to its large attenuation, exists. To further understand this problem the authors developed the new technique of acoustic gonimetry and carried out a series of unique laboratory experiments on elastic and saturated porous materials. The demonstrated curves of reflectivity versus angle of incidence for a variety of cases highlighted the influence of porous media effects on AVO analyses.

Hans J. Mueller (speaker), B. Wunder, C. Lathe, and Frank R. Schilling discussed recent studies of the unquenchable high-p (HCEn) - Low-P (LCEn) clinoenstatite transition. The knowledge of the exact phase boundary positions for the MgSiO_3 -transitions is essential as pyroxene is an important component of the Earth's mantle and will significantly influence the elastic properties, e.g. v_p , v_s , of the mantle. However, the HCEn - LCEn-transition had still not been determined experimentally at temperatures other than room temperature at given pressure. The authors determined this phase transition by in-situ X-ray diffraction experiments under high pressures and temperatures using synchrotron radiation at HASYLAB, Hamburg. The experiments started from pure HCEn, which was formed by rising the temperature in steps of 50 K at given pressure. Then p and T of the first appearance of LCEn was determined by rising the temperature in steps of 50 K at four different pressures. The minimum pressure conditions of the the HCEn - LCEn phase boundary could be approximated by the empirical equation $p \text{ (GPa)} = 0.00211T \text{ (}^\circ\text{C)} + 5.97811$. The extremely low-porosity samples for the ultrasonic interferometry experiments were prepared by hot-isostatic pressing at 0.4 GPa and 1400°C for 2 h at MAX80. For the ultrasonic measurements one of the six anvils was exchanged by an anvil equipped with lithium niobate p- and s-wave transducers of 33.3 MHz natural frequency. The velocities of elastic compressional and shear waves of the sample were measured under in situ conditions in the HCEn and LCEn stability field, i.e. before and after the phase transition, using the classical digital sweep technique. The newly developed transfer function (TF) technique, first described by Li *et al.* (2002),

enabling much faster measurements under transient conditions, was used to measure both the elastic wave velocities of LCEn in dependence on pressure at 700°C. The comparison of the results at 6.7 GPa and 7.5 GPa for both interferometric techniques showed a correspondence in the limits of less than 1 %.

C.A. Hurich discussed the presence and distribution of melts and partial melts in collisional orogens characterized by significant crustal thickening and late orogenic extensional collapse as a major control on both the rheology and large-scale architecture by focussing or enhancing middle to lower crust channel flow. The widely used first order estimates of the degree of melting in the middle and lower crust of these orogens basing on the distribution and volume of plutons exposed at the surface are limited and possibly biased by the depth and extent of exposure. The author discussed statistical approaches to the interpretation of deep seismic reflection data as a possibility of estimating the volume and distribution of crustal melts and migmatites throughout the crust and the opportunity of studying the link between orogen architecture and melting. The effectiveness and resolution of statistical approaches for mapping melts and migmatites as well as exploration results for the role of partial melts in the growth and collapse of the Grenville Orogen were demonstrated.

In a student talk, Pavlo Y. Chlach, Joseph B. Molyneux, and Douglas R. Schmitt (speaker) presented laboratory measurements of compressional and shear wave velocities at elevated pressures of 3000 MPa on a set of metasediments of upper greenschist - lower amphibolite facies of metamorphism from two ductile shear zones of Flin Flon Belt (FFB) of Trans-Hudson Orogen (THO). The samples varied in composition from felsic to mafic. The determination of lithological and physical properties of highly deformed metasediments is essential for proper interpretation of the nature of observed seismic reflectors. To investigate anisotropic properties v_p was measured at 300 MPa in three mutually orthogonal directions with respect to the visible texture. In addition, to determine shear wave splitting, v_s was measured at two orthogonal polarizations on nine selected samples. Observed v_p anisotropy varied from quasi-isotropic to highly anisotropic ($A_p = 24\%$). Maximum shear wave splitting reaches the value of 0.77 km/sec at 300 MPa. The presented results indicate that the main reason for v_p anisotropy and shear wave splitting is lattice preferred orientation (LPO) of highly anisotropic minerals such as mica and hornblende.

On behalf of all speakers and the audience the convener wishes to thank David Eaton and Ed Krebs for the support and flexible management, which made this CGU special session possible. We are also grateful to the student audio-visual assistants for their kind technical support of the presentations.

Integrated Geoscience Studies within the Framework of the ICDP

B. Milkreit and D.R. Schmitt (conveners)

A standing committee of the Canadian Geoscience Council is currently examining broadly issues related to scientific drilling on the continents with specific focus on the role that Canada could play as a member in the International Continental Drilling Program (ICDP). A number of workshops have been held (Toronto-April 2002, Sudbury-September 2002, Edmonton-March 2003) on various topics that may be of interest to Canadian earth scientists. This special session is one further activity to spread information about scientific opportunities and to engage a broader spectrum of Canadian scientists.

Jeremy Hall, chair of the CGC standing committee, gave an overview of the ICDP program with a listing of some of the current projects supported by the ICDP around the world. As well, he mentioned the history of Canada and the ICDP and how we may go about continuing support of this program. There were three special speakers invited to give presentations on various ICDP research projects.

Stephen Hickman (USGS Menlo Park) gave an overview talk on the San Andreas Fault Observatory Project (SAFOD). This project is drilling near and into the San Andreas fault in the vicinity of Parkfield, California - a well studied area due to the 'regular' earthquake swarms that had demonstrated some remarkable periodicity. A 2-km deep pilot hole was drilled in 2002 and this served as a good place to test a variety of differing logging and surface geophysical methods. Studies are continuing this summer in high resolution seismic profiling. Drilling in the main hole is expected to proceed soon -- this hole has great interest as it will attempt to drill into the fault zone by deviating the well.

In the second talk, Wolfgang Rabbel from the Geophysikalisches Institut, Uni-Kiel, Germany provided a review of the past and current research at the KTB wellbore, Windischeschenbach, Germany. This well was drilled to a 9-km depth and some of the more surprising discoveries were the presence of substantial amounts of fluids in fracture zones at great depth and the much higher than anticipated temperatures. One further caution to geophysical interpretations are that surface seismic observations did not seem to have correctly predicted the folded, near vertical structures actually encountered in the well.

Canada's Scott Dallimore (GSC-Sydney) gave the final invited talk. He highlighted the technical requirements necessary to get the Mallik Gas-Hydrate well drilled, the international scientific efforts that went on there, and the model of co-operation between different industrial and scientific participants. The Mallik well was Canada's first ICDP participant project.

A. Calvert (SFU) and D. White (GSC-Ottawa) gave an overview of possible targets observed from surface

geophysical studies of the LITHOPROBE project. The authors questioned the assumption that the seismic images could always be used as a proxy measurement of strain at depth. A number of differing targets were presented beginning with the high grade metamorphic exposures of the Kapuskasing structural zone through to the Trans-Hudson orogen near Flin-Flon, Manitoba.

B. Milkreit (U of Toronto) discussed the proposed project to carry out scientific drilling in the Sudbury basin. There are a number of unresolved issues with respect to the structure of this basin despite a century of mining and geological studies. A number of factors - economic, impact, stress, etc. - motivate studies of this unique feature of the earth's crust. An ICDP sponsored workshop on the Sudbury structure was announced and will be held in September, 2003.

D.R. Schmitt (U of Alberta) provided a technical talk on drilling induced core disk fractures and discussed how these might be used as semi-quantitative indicators of crustal stress regimes.

H.M. Kern (Uni-Kiel, Germany) gave a talk on rock physics measurements on core ultrahigh metamorphic rock collected from the Sulu area and Dabie Mountains. These results were used to model anticipated observations at the currently drilling Chinese Continental Scientific Drilling Program at Donghai (China), an ICDP partner project. The experimental results led to a chemical model of the crust on the basis of comparison of laboratory and field refraction measurements.

The session concluded later in the evening with a reception attended by most of the participants. Discussions at this evening reception focussed on how to attract funding for scientific drilling in Canada, on what projects might be viable in terms of the best scientific value returned, and on other issues related to the potential for Canada's continued involvement in the ICDP.

Sediment Transport Processes

Peter Ashmore (Convenor)

The session featured a keynote speaker (Chris Paola, University of Minnesota), 8 invited oral papers and 11 posters. The session was designed to cover the range of research on sediment transport and landform development in Canada and to relate it to recent developments in the field. Talks covered surface dynamics over the complete range of spatial and temporal scales, by the major agents of water, wind and ice and illustrated the array of methods including laboratory and field measurements, historical / geological interpretation, theory and numerical simulation.

The invited oral papers began with Chris Paola (with Vaughn Voller and Efi Foufala-Georgiou) drawing a compelling analogy between fluid turbulence and landscape dynamics, speculating on how existing theory for turbulence might be adopted and adapted to describe and understand landscape morpho-dynamics, using

examples that included river morphology and the long-term erosional development of fluvial landscapes.

Small scale processes in rivers, wind and nearshore were covered by presentations by Marwan Hassan, Cheryl McKenna-Neuman and Alex Hay.

Marwan reviewed recent developments in the understanding of grain-scale entrainment and structure of gravel-bed rivers showing how the physics are affected by the particle size distribution, sediment supply, and hydrological regime and the way in which particle-scale structures enhance the stability of the river bed.

Cheryl gave an impressive review of the physics of entrainment by wind and then summarized wind tunnel results showing the effect of temperature and humidity on entrainment by wind in cold environments, including the interaction between moving grains and the flow close to the surface. The effect is to substantially increase the erosivity of wind at cold temperatures and the increase is greater than predicted due to air density alone.

Alex Hay described some of the mysteries of the morphology of bedforms developed in sand in near-shore environments and then showed how new experimental observations are providing more sophisticated descriptions of the morpho-dynamics and of the relation between wave dynamics and bedform response. Analysis and visualization has been significantly enhanced by recent technical developments in instrumentation.

Brett Eaton (with Mike Church) followed with a discussion of the analysis of river dynamics using 1-D numerical simulations of flow and sediment transport, pointing out the types of problems amenable to this type of analysis (e.g. downstream trends in sediment budget and development of longitudinal profiles) and then ways in which the utility of 1D simulations may be enhanced.

Moving up in scale, Dirk DeBoer provided a review of the analysis of sediment budgets in fluvial landscapes at various scales up to that of the entire drainage basin, showing examples of human impacts on sediment budgets and the way in which these impacts have been used to provide important concepts in the morpho-dynamics of drainage basins, especially the importance and persistence of the storage of eroded sediment in the landscape.

Moving up again in scale, and changing erosional agents, Tracy Brennand (with John Shaw) showed that stored glacial sediment and the associated landforms are vital evidence in reconstructing the processes of glacial erosion, sediment transport and deposition and diagnosing the patterns of sediment movement at the scale of the Laurentide Ice Sheet. A parallel theme was the way in which physical theory and geological evidence, used well, can provide considerable insight into the processes and the history of landscape development from which a major role for glacial melt-water can be argued.

The final two speakers took us into issues of long-term landscape development and numerical simulation.

Yvonne Martin discussed recent developments in erosion models for fluvial landscapes and then raised the

issue of the treatment of mass movement processes in such models and the problem of the realistic representation of these processes based on field observation along with the need for modellers to guide field studies to provide the critical information needed for modelling.

James Syvitski rounded things off with a wide ranging talk illustrating the potential for numerical modelling of sedimentary processes and ‘pitching’ the development of the Community Sediment (Surface Dynamics) Model as the earth surface dynamics equivalent to global circulation models. He discussed the essential character of such a model as well as the structure necessary for its development, dissemination and application and entertained us with several animations illustrating the potential contributions for the model.

The 11 posters covered a wide range of topics, scales and approaches within the themes of the invited talks: measurement of bed load in rivers using aDcp (Rennie and Villard); numerical simulation of gravel bedform development (MacVicar et al.); experimental studies of bed form development in sand (Venditti et al.); particle movement in gravel bed streams and the relation to fluvial morphology (Gaeuman); using morpho-dynamics to estimate bed load transport rates in braided rivers (Ashmore and Varkaris); the relation of suspended sediment load to climate in Boothia Peninsula (Forbes and Lamoureux); identification of sources of fine-grained sediment using stable isotopes (Petticrew and McConnachie); assessment of the effect of forest harvesting on sediment yield (Hudson); patterns of sediment storage in a high energy catchment in New Zealand (Kasai); nested sediment yield estimates in BC Coast Mountains (Menounos et al.) and the response of Prairie sand dunes to historical climate change (Hugenholtz and Wolfe).

The session was our first introduction of this general theme of earth surface dynamics and sediment transport at CGU. The session was well-attended and there is clearly enthusiasm for future sessions at CGU and the potential to expand the interest group. We expect that the first follow-up will be at the CGU-AGU meeting in spring 2004.

Study of the Earth's Deep Interior / Surface Mass Balance and Isostasy

Sam Butler (convener)

The CGU session on Study of the Earth's Deep Interior and Surface Mass Balance and Isostasy contained nine exciting oral presentations. The level of interest was evidenced by the many interesting questions following each of the talks. Topics ranged from computer simulations of the geodynamo in the Earth's core to seismic anisotropy in the Earth's mantle to analog models of crustal deformation.

The first presentation, “Numerical Models of Earth's Thermal History” by S. Butler and W.R. Peltier

was presented by Sam Butler of the University of Saskatchewan. Most work on the thermal history problem have used simplified parameterized convection equations while this work, using more complete numerical models, allows the researcher to examine the effects of spatial variations, short-time scale phenomena and the effects of mantle phase transitions. The main conclusions that arose were that models with high internal heating (as proposed by parameterized modelers) require the mantle to be in a more layered state while models with low internal heating (as proposed by geochemists) require the mantle to be in an actively overturning state.

“Intraplate Deformation Driven by Mantle Downwelling and the Effect of Crustal Radioactive Heating” by R.N. Pysklywec and C. Beaumont was presented by Russ Pysklywec of the University of Toronto. Using numerical modeling they investigated the affects on topography due to a mantle downwelling and focused, in particular, on the effects of a high radioactivity anomaly in the crust. They found that the results with a radioactive anomaly are significantly different from those without the anomaly and that substantial positive topography could be produced in this way. The results were compared to a Proterozoic intraplate orogeny in Australia.

“Mantle Downwellings and Surface Topography: A Comparison of Simple Laboratory and Numerical Model Experiments” by A.R. Cruden, R.N. Pysklywec, M.H. Shana and L. Thompson was also presented by Russ Pysklywec. The authors compared the results of analog experiments and numerical models scaled to be as similar as possible with special interest in the measurements of surface topography caused by a downwelling beneath a model continental lithospheric plate. They found broad agreement with some discrepancies that may have been due to the effects of the boundary conditions.

The fourth talk was “Deep Mantle Anisotropy Observed from Shear Waves” by Y.J. Gu, A.M. Dziewonski and G. Ekstrom and was presented by Jeffrey Gu of the University of Alberta. He presented analyses of seismic shear waves that indicate the presence of anisotropy in the mantle. The patterns show fast horizontal axes in the near surface beneath the oceanic lithosphere and fast vertical axes deeper in the mantle that may be associated with mantle up and down-wellings.

“Unconstrained Mantle Convection in a Complete Cylindrical Shell” by M. Hosein Shanas and G.T. Jarvis was presented by Gary Jarvis of York University. In this talk, convection constrained to a section of a cylindrical shell was compared to that in a whole shell. It was found that mean quantities such as the Nusselt number (heat flow) and the average temperature were in agreement making the constrained, numerically less expensive, model appropriate for thermal history studies. However, the plan-form of convection was different for the two types of models.

“Effects of Core Geometry on Convection and Dynamo Action in Planetary Interiors” by F. Al-Shamali,

M. Heimpel and J. Aurnou was presented by F. Al-Shamali of the University of Alberta. The researchers used a numerical model of magnetohydrodynamic convection in a spherical shell to calculate the critical Rayleigh number for the creation of a magnetic field for a number of different core geometries. They found that there is a preferred value for the inner-core to outer-core ratio for the creation of a magnetic field, a result that has implications for the evolution of the magnetic fields of the various terrestrial planets.

“Calculation of Crustal Loading Responses in the Presence of Strongly Heterogeneous Viscosity” by R. Bailey was presented by Dick Bailey of the University of Toronto. A significant problem in modeling tectonic deformation arises due to the large variations in the Maxwell relaxation time-scales due to the large variations in crustal viscosity. A novel numerical method was demonstrated that allows for large time-steps even in the presence of very soft crustal regions.

“Postglacial Induced Surface Mass Redistribution on a 3D Spherical, Self-Gravitating Viscoelastic Earth: Effects of Lateral Viscosity Variations” by Patrick Wu and Hansheng Wang was presented by Patrick Wu of the University of Calgary. A coupled Laplace-Finite Element model of the post-glacial rebound process was presented that allows the researchers to investigate the effects of laterally varying viscosity. The effects of laterally varying asthenospheric viscosity were shown to be important for predicting sea-level when they were close to the ice-sheet margin and for predicting up-lift rate when they were close to the centre of the ice sheet.

Seismic Imaging

Larry Lines and Ed Krebs (conveners)

Summary prepared by Ed Krebs

This session consisted of 8 oral presentations.

S. Chen, L. Lines, J. Embleton (speaker), and P. Daley from the University of Calgary, and L. Mayo from EnCana Corp., showed the results of their numerical modeling of the seismic response of a medium containing wormholes (high porosity channels generated by the simultaneous extraction of oil and sands). Although ultra-high frequencies would be needed to detect individual wormholes because of their small size, distributions of wormholes produce noticeable seismic anomalies in the conventional seismic exploration frequency bands.

L. Yan, L. Lines (speaker) and D. Lawton, all from the University of Calgary, presented recent advances in seismic depth imaging in the Western Canadian Foothills. The new methods involve coupling velocity analysis with the estimation of anisotropy parameters.

S. Richardson (student speaker), together with co-authors D.C. Lawton and G.F. Margrave, all from the University of Calgary, showed that exploration seismic methods can be effective tools in the prospecting and development of coalbed method reservoirs. Numerical

modeling methods assist in survey design and time-lapse differencing methods show reflectivity changes due to dewatering and gas injection. This talk won the Chevron Canada Award for the Outstanding Student Paper in Seismology.

D.A. Angus (student speaker), together with C.J. Thomson, both of Queen's University, presented the results of their numerical modeling of seismic waveform variations using a narrow angle one-way wave equation for 3D anisotropic heterogeneous media. Examples showing merging and splitting pulses, wavefront tearing, polarity reversals, and other effects were presented.

C.J. Thomson of Queen's University discussed the application of the coherent-state transform to the classic problem of the reflection of seismic waves at a plane boundary and its implications for the ray approximation. He also discussed the potential application of Poincaré invariants in seismic wave propagation and the implications they might have for familiar quantities such as reflection coefficients and geometrical spreading functions.

G. Spence (speaker) from the University of Victoria (UVic), W. Wood, J. Pohlmann and R. Coffin from the Naval Research Lab, U.S.A., and R. Hyndman from the Geological Survey of Canada (GSC-PGC), presented results of a multichannel seismic survey using a deep-towed acoustics geophysics system conducted in a region where gas hydrates are found. The processed data shows clear images of seismic blanking (reduced reflection amplitudes), probably due to gas-charged sediments, and of possible faults related to fluid venting.

M. Zykov (student speaker), together with R. Chapman, both of the University of Victoria, presented the results of a 2D travel time tomographic inversion of ocean bottom seismographic data acquired to study a gas hydrate field off shore Vancouver Island. More specifically, they discussed the results for profiles near a zone of seismic blanking.

K. Vasudevan (speaker) from the University of Calgary, together with Dave Eaton from the University of Western Ontario, discussed the application of the seismic skeletonization method (a pattern recognition method designed to assist seismic interpretation) to seismic and also aeromagnetic data. They presented some results using a new version of the method involving a two-pass approach and found that it can be used effectively for the filtering of aeromagnetic data on the basis of strike direction, and event linearity, amplitude and polarity.

Hydrology I: Wetlands

Convener: S. Beltaos

Summary prepared by B. A. Branfireun (chair)

This oral session consisted of five oral presentations (three by student presenters) concerned with the hydrology of wetlands and wetland-catchment hydrological interaction.

M. Shantz (student presenter) & J.S. Price discussed the hydrologic changes after restoration for a peatland near Riviere de Loup, Quebec. No differences in water table position or soil moisture were found between the restoration and un-restored comparison peatland sites prior to the restoration experiment. After the restoration which consisted of ditch blockage and bund creation, the mean water table and soil moisture increased significantly in the restored site, and vegetation re-colonization was evident. The authors suggest that the lack of evidence of increasing peat water storage indicates that more research on the changes in peat hydraulic properties with fluctuations in storage needs to be incorporated in restoration studies.

L. Halsey (presenter) and K. Devito reported on the role of landscape and geology on the occurrence and form of patterned fens on the western Boreal Plain. Although they occurred at all locations along a topographic gradient, all patterned fens exhibited groundwater discharge, with discharge from deeper strata occurring in fens in regional lows. Patterned fens located near regional highs tended to be more nutrient poor and acidic, while those near the regional lows were more basic and nutrient rich.

S. Berthold (student presenter), L. R. Bentley and M. Hayashi showed how electrical resistivity imaging (ERI) could be used to identify zones of salt leaching and evaporitic concentration around prairie depressions, both wetland and non-wetland. These zones of leaching and concentration were coincident with areas dominated by infiltration in the middle of the depressions and evaporative losses at depression margins, respectively. The ERI method revealed complex patterns of flow between adjacent wetland depressions.

B. D. Smerdon (student oral presenter), K. J. Devito and C. A. Mendoza presented research that focused on assessing the response of an outwash lake in northwestern Alberta to climate and precipitation variability using hydrometric techniques and numerical modeling. In this groundwater-dominated system, spatial and temporal variability of lake-wetland-groundwater exchange was documented hydrometrically and isotopically. Hypothesized reasons for a shift in the isotopic signatures of lake water toward the meteoric water line included freezing depletion.

The final paper of the first morning session was by Eric Kellner (presenter), J. S. Price and J. M. Waddington. Measurements of water table position, soil water pressure, volumetric water content and peat volume changes were made in undisturbed, newly drained and previously drained peatland sites. Hydraulic head measurements made in conventional piezometers showed little variation over the season, however pressure transducers that were not vented to atmospheric pressure showed much higher water pressures than the piezometers on average, and these pressure excesses were sometimes highly transient. A hypothesis was put forward that these pressure increases

are the result of the build-up of methane bubbles trapped in pores in confined layers in the peat.

Hydrology I: Wetlands was very well represented in the poster session with eight poster presentations, including four by student presenters.

The poster presented by R.A. Bourbonniere, K. Edmondson, F. Dunnet, K. Livingston, S. Kaufman and J.M. Waddington focused on the character of dissolved organic matter (DOM) in surface waters of a forested temperate wetland in Southern Ontario. Using measures of DOM quality inferred from UV-Visible spectroscopy and a modified fractionation method, it was found that the refractory humic acid fraction is least affected by discharge, while the more labile hydrophilic and hydrophobic concentrations tended to increase as discharge decreased and vary as a result of changing hydrologic stream-wetland interactions.

S. M. Day (student presenter) and J.M. Waddington reported on the impact of cutover peatland restoration on methane dynamics, and found that, methane emissions increased ten-fold after the restoration due to the increase in water table elevation and changes in peat carbon quality. The largest increases were observed in the permanently wetted former drainage ditches, constructed ponds and areas dominated by vascular vegetation.

J.M. Hogan (student presenter), G. Van der Kamp, S.L. Barbour and R. Schmidt presented research intended to further the understanding of the thermal and hydrological dynamics of a seasonally frozen patterned fen in Saskatchewan suggesting that freezing and subsequent energy loss is concentrated on exposed ridges in these systems.

P. Lafleur, T. Moore and N. Roulet declared that the water table does not influence ecosystem respiration (ER) in an Ontario ombrotrophic bog. Soil temperature was found to be the strongest determinant of (ER) with water table position only having an influence in the wettest year.

R.M. Petrone, M.M. Squires, K.J. Devito and M.L. Macrae examined the variability of carbon dioxide fluxes among three different wetland-pond complexes in Alberta, and found that the maximum emissions were from a moraine location. As the ponds within each complex dried, measured carbon dioxide emissions increased along a gradient from bare and vegetated wet exposed sediments, providing important information for a region subject to drought and changing hydrological regimes.

Noting the importance of soil properties in governing hydrological processes, T.E. Redding (student presenter) and K.J. Devito surveyed a range of soils across the western Boreal Forest landscape in Alberta. They found that soil properties such as porosity and particle density were surprisingly uniform across a large geographical area and a range of ecosystem types. The amount of organic carbon varied more widely, with the highest proportion among the wetland landforms found in bogs.

M. Richardson (student presenter), B. Branfireun and V.B. Robinson presented the first incarnation of the Wetland Object Model (WOM) for simulating intra-wetland ecohydrological processes. The use of object-orientation and a new conceptualization of fundamental data structures permit the examination of fine-scale wetland processes using an extensible modeling structure. Proof-of-concept testing that included flood-wave propagation, water table equilibration and transmissivity feedback indicate promising model behaviour consistent with physical principles. This poster was awarded the Campbell Scientific Award for Best Student Poster in Hydrology.

Finally, G. Tondeleir and K.J. Devito examined the groundwater-surface water interactions of twenty-four pond-wetland complexes in contrasting landscapes to evaluate the potential impacts of anthropogenic disturbance in northern Alberta. Hydrogeochemical analyses revealed that water exchanges with the atmosphere dominated the water balance in all of the wetlands. The response to recent drought conditions were highly variable, with outwash ponds not nearly so affected by drying as in moraine and clay plain areas. Changes in groundwater flows in response to drying conditions were found to be more subdued in the clay plain and outwash regions, while were more variable in the moraine landscape.

Hydrology II: Surface-Subsurface Interactions/Nutrients

Convener: S. Beltaos

Summary prepared by Peter Lafleur (chair)

On Monday May 12 the session on Surface-Subsurface Interactions/Nutrients was chaired by Peter Lafleur (Trent U). The first two of five presentations dealt with hyporheic exchange in streams (i.e., the downstream transport of water through the bed material).

Dan Moore (with P. Sutherland) discussed an experiment intended to measure all terms of the heat budget of a small mountain stream. Despite large uncertainties in some terms, they showed that hyporheic exchange could be very significant in explaining down stream changes in water temperature.

Next, Takashi Gomi (with D. Moore) presented a thorough discussion of the nature of hyporheic exchange in mountain streams and its controls, such as bed material, channel morphology, hydrogeomorphology of the hillslope-riparian-forest continuum. The importance of channel steps in initiating hyporheic exchange was highlighted.

The next three papers in this session discussed nutrient interactions in hydrologic systems.

Zabrina Gibbons (with K. Devito) discussed geochemical controls on phosphorus mobility in a riparian wetland located on a boreal outwash plain. Preliminary results showed that for the most part soil water nutrient

concentrations are associated with groundwater behaviour, however, some anomalies were found.

Merin Macrae (with M. English, S. Schiff, & M. Stone) presented a study of nutrient export from a first-order agricultural basin in southern Ontario. Data from an annual time series of hydrology and nutrient export was presented. The results suggest that only a few events produced the majority of export from this system; the implications for the monitoring of nutrient export were discussed.

Finally, Ian Halket (with K. Snelgrove) presented an overview of phosphorus in Manitoba's waters. Phosphorus budgets for Lake Winnipeg and its tributaries were presented. It was shown that a substantial amount of the phosphorus reaching L. Winnipeg arrives from outside of the province. In addition, the City of Winnipeg may be an important source of phosphorus. Again, it was shown that most of the phosphorus is discharged during the spring season events, which has important implications for monitoring strategies.

Hydrology III: Erosion and Sedimentation

Convener: S. Beltaos

Summary prepared by Ellen Petticrew (chair)

The four talks in this session dealt with fluvial sediment transfers using two distinct approaches. These included the modeling and testing of channel processes (Muzik and Haltigin) and field measurements of suspended sediment in small watersheds (Hudson and Irvine-Flynn).

The first presentation was given by Ivan Muzik (University of Calgary) who provided an historical perspective on the Athabasca River diversion channel. He outlined the rationale and the engineering design for a channel that in 1972 was used to pilot water from a problem meander bend which threatened to erode into another river system. A long term assessment of the success of the project (1999) indicated that the pilot channel design functioned as was expected, ensuring the Athabasca water and sediment load was maintained.

Tim Haltigin (McGill University) presented the award winning paper (CGU Best Student Paper Award: all fields of geophysics) on 3-D modeling of flow dynamics around stream deflectors. Preliminary data from flume measurements and modeling of flow near barriers identified the regions of scour and deposition. The results of his larger project will be used to evaluate the usefulness of generating and maintaining stream habitats with stream restoration structures.

The emphasis on field measurements to statistically assess catchment sediment dynamics was the other focus of this session.

Robert Hudson (B.C. Ministry of Forests) developed a sediment budget model for predicting sediment yields in a coastal B.C. watershed. Road crossings, gullying and landslides represented major

sediment sources in this 30 km² watershed. Field sampling of the nested watersheds provided data for predictive equations that were used to represent other unmonitored parts of the basin. The predicted yields were within 10% of the yields measured at the main stream gauge.

Tristan Irvine-Fynn (University of Calgary) gave the final talk in the session, and addressed the role of geocryological processes in contributing to suspended sediment loads in a pro-glacial stream. Climatologic data combined with discharge and suspended sediment records were analysed for an alpine and a high-arctic system using principal component analysis to determine if ground thaw processes were associated with observed increased suspended sediment loads. The linkage between periglacial and glacial systems was observed, indicating the sediment supply is modified by geocryological processes.

Hydrology IV: Hydrological Modelling

Convener: S. Beltaos

Summary prepared by C. Valeo (chair)

The Hydrological Modelling session included five oral presentations with three of these given by students.

Ken Snelgrove of the University of Manitoba presented a method for improving CLASS soil related runoff generating mechanisms that would also lead to a better integration between CLASS and the WATFLOOD model. He highlighted the importance of scale effects when verifying models and how IAHS initiatives like PUB (Prediction in Ungauged Basins) can benefit from such research.

Frank Seglenieks from the University of Waterloo presented research in support of MAGS that involved monthly water balance calculations using both WATFLOOD and WATCLASS for simulations of 5 to 8 year periods. By comparing water balance calculations using observed data to those produced by the models, he was able to demonstrate a very good water balance closure by the WATFLOOD model and a respectable closure by the WATCLASS model. He emphasized the importance of verifying watershed processes with internal state variables and not just streamflow measurements. His presentation was followed by three very notable student presentations that continued to highlight the importance of using process verification tools in addition to observed streamflow.

University of Waterloo MSc student John Bastien evaluated the WATCLASS model on the Wolf Creek Basin near Whitehorse, Yukon, and the Grand River Basin in Southern Ontario. Using both remotely sensed and insitu data, he demonstrated a good correlation between observed volumetric soil moisture estimates and averaged WATCLASS estimates of the upper soil layers.

MSc student Bruce Davison, also from the University of Waterloo, focused on improving the snow accumulation and depletion algorithms within the

WATCLASS model. The improvement results in a model of snow-hysteresis that incorporates horizontal advection and other important snow pack processes that are often ignored. The model is designed to more accurately predict the life of a snow pack.

Stephan Pohl, a PhD student at the University of Saskatchewan, demonstrated the importance of accurately capturing the patchiness of end of winter snow cover in arctic environments. This high spatial variability, which is due primarily to blowing snow, impacts land-surface energy exchanges and of course, meltwater release during springmelt. A candidate for the D.M. Gray award for best student paper in Hydrology, Pohl, combined spatially distributed snow cover with simulations of snowmelt energy balance on a small arctic catchment in order to demonstrate the importance of very fine grid resolution modelling of this end of winter phenomenon.

Hydrology IV: Subsurface Hydrology

Convener: S. Beltaos

Summary prepared by R.M. Petrone (chair)

This session consisted of 4 oral and 2 poster presentations.

M. Hayashi (speaker), W.L. Quinton and A. Pietroniro examined the importance of organic soils and upland hydrologic contributions to runoff predictions. They emphasize that since slight changes in the ground thermal regime due to climatic warming in cold regions can produce significant changes in water storage and runoff pathways. Because of this sensitivity it is imperative that regional climatic modelling is coupled with hydrological modelling such that land-surface schemes are capable of accurately representing the lateral drainage of subsurface water, which controls the water-table depths and moisture conditions and the potential feedbacks with the ground thermal regime. Hayashi et al. illustrated the need for testing of temperate subsurface runoff schemes in subarctic regions. Data was presented using a peat-covered permafrost slope near Fort Simpson, NWT examining moisture retention curves and saturated hydraulic conductivities obtained using field observations and lab testing. These data showed that the degree of spatial variability in these variables and their representation by commonly used empirical formulae were used to assess the potential errors inherent in current land surface schemes. Furthermore, in analyzing the field, lab and model data Kh showed strong heterogeneity and scale effects suggesting that there will be significant inherent errors in the representation of this variable in subsurface runoff.

B. Moorman presented an excellent account of the necessity to treat the hydrologic processes associated with glaciers and permafrost as one integrated system. He showed that in permafrost areas with polythermal glaciers there are direct linkages between the routing of subsurface water within the glaciers and the underlying permafrost. Using GPR data of two glaciers and associated icings on

Bylot Island. Moorman demonstrated that the significant factors such as ice dammed lake sources and seasonal glacial melting influence the routing of water in these systems.

G. Thorne provided a synopsis of surface-groundwater interaction research conducted at Canada's Underground Research Laboratory (URL). At the URL an extensive groundwater monitoring network and the installation of a 440 m deep shaft and other underground excavations was installed in the early 1980's and hydrogeologic characterization has been ongoing ever since, with the goals of evaluating the potential for granitic rock as a medium for the disposal of nuclear waste. However, Thorne illustrates that the construction of the underground research facility has dewatered bedrock fractures and created a drawdown cone around the main shaft of approximately 80-90m. Hydraulic head measurements in the main fracture zones in the bedrock illustrate that pressure responses in this zone can occur rapidly in response to excavation and drilling suggesting a low storage and higher permeability for this zone. However, groundwater within the low-permeability overburden with the drawdown cone area is de-coupled from the major perturbations in the bedrock and is largely controlled by evaporation and surface water inputs or runoff. Thorne also gave an excellent example of the importance of characterizing groundwater flow in operational mining areas because of infiltration from mine settling pond contaminating the main shaft hole. Thus, in these types of settings it is important to be capable of identifying the boundaries of the recharge area and possible locations to pipe pond water out to avoid such contaminations.

G. van der Kamp outlined the progress in recent years in the quantification of groundwater interactions with surface water using a variety of techniques. Nowhere is this more obvious than in peatlands and wetlands, which are areas where surface and groundwater continually interact. However, van der Kamp went on to outline conceptual, theoretical and technical challenges that still remain such as the scaling of point measurements of groundwater discharge or recharge up to the dimensions of a whole lake, wetland or stream reach. He went on to stress that more process studies are needed that treat surface and groundwater in one fully integrated experimental design. van der Kamp emphasized this point eloquently by ending his talk by saying that there are lots of interactions between surface and groundwater hydrology but not between surface and groundwater hydrologists.

The subsurface hydrology session was also complimented by two excellent poster presentations. Steven Quiring and Tim Papakryiakou presented the use of Palmer's Moisture Anomaly Index in the characterization of drought seasons in the Canadian prairies. 1961 was shown to be the most severe drought season in the prairies, covering more than 86 % of the region and with a mean

PMAI of approximately -5.67. Their spatial analysis showed that more severe droughts tended to affect larger areas, and that there exists three preferred spatial patterns of drought in the prairies, each of which responds to a unique set of larger scale climatic forcings.

Tim Van Dijk and Masaki Hayashi presented a poster describing the use of $\delta^{18}\text{O}$ in the analysis of groundwater recharge. They described an ongoing study to verify and apply a recently developed method for determining $\delta^{18}\text{O}$ in soil moisture developed by Koehler et al (2000) that does not involve the extraction of water from the soil matrix. Thus far, their results suggest that the accuracy of the measured $\delta^{18}\text{O}$ is dependent on the water standard used, and that there will tend to be better results if the samples are more saturated.

Hydrology V: Forest hydrology

Convener: S. Beltaos

Summary prepared by Younes Alila (chair)

The Wednesday morning session of Forest Hydrology consisted of five presentations.

The first talk by A. Wei (presenter), X. Zhou, and G. Zhou was entitled "Influence of Forest Management on Hydrological Processes in China". In this paper, Dr. Wei discussed the impact of the over exploitation of forest resources on water resources, biodiversity, soil erosion, wildlife habitat, and community stability in China. However, the main focus of the paper was on review of forest hydrology research conducted in China over the last 20 years. Dr. Wei shared with the audience the results of many studies on the impact of forest management on rainfall interception, stream flows, and evapo-transpiration on many forest ecosystems in China.

The second presentation was given by D. Scott of the Okanagan University College (BC) and was entitled "Designing Experiments to Measure the Effects of Forest Harvesting on Low-Flows". Dr. Scott asked in his talk the most provocative wake-up call question: Have paired watershed experiments in the past designed to not produce results? This is the result of his dissatisfaction with the state of science in forest hydrology which has been exclusively based on the paired watershed experiment approach. Dr. Scott gave an overview of the common flaws associated with paired watershed studies and cites examples of successful and not so successful case studies from the literature. The presenter provided the audience with a list of conditions to ensure useful and successful paired watershed studies, particularly those which are designed to quantify the impact of forest management on low-flows.

The third talk, by J.M. Buttle (presenter), S.S. Monteith, P.W. Hazlett, F.D. Beall, R.G. Semkin, and D.S. Jeffries, was entitled "Streamflow Generation During Snowmelt in Clear-cut and Forested Basins, Turkey Lakes Watershed, Central Ontario". Dr Buttle contended that the interpretation of results in traditional paired watershed

studies is often limited by an incomplete understanding of how intra-basin variability in such factors as hydrologic pathways and water residence times may confound the comparison between the control and treatment watersheds. Dr. Buttle shared with the audience comparison of water input, groundwater dynamics and streamflow generation during the 2001 snowmelt in paired clear-cut and forested basins studied as part of the Turkey Lakes Forest Harvesting Impacts Projects, conducted in old-growth tolerant hardwood forest in central Ontario. The study highlighted the need to consider internal basin properties and to employ a range of hydrometric and tracer techniques when studying forest harvesting impacts on basin hydrology.

The fourth presentation, given by Natasha Neumann, was entitled "Canopy Shading of the Snow Surface in a Mature Aspen-Hazelnut Stand". Ms Neumann shared the results of an experiment during the spring of 2002 that was designed to study the spatial variability of incident shortwave radiation under forest canopies. The experiment consisted of a grid of nine PAR quantum sensors placed near the snow surface under a mature aspen and hazelnut canopy and the spatial variability of incident radiation was compared with single PAR sensors installed above the hazelnut understory and above the aspen canopy. Results showed spatially uniform radiation levels at both the snow surface and above the hazelnut understory on cloudy days, and a uniform transmittance of 40% of the radiation incident above the canopy at all sun angles. However, on clear days when the sun angle exceeded 15 degrees above the horizon and tree trunks shaded the sensors, there was a high degree of variability in incident PAR radiation at the snow surface.

The fifth paper, by R. Winkler (presenter), D.L. Spittlehouse, and D. Golding, was entitled "A Comparison of Snow Accumulation and Melt in Clear-cut, Juvenile, and Mature Forests in South-Central British Columbia". Dr. Winkler investigated the relationships between snow accumulation and melt and forest canopy over three year period in a mature Engelmann spruce and subalpine fir stand, a juvenile and a juvenile-thinned lodgepole pine stand, and a clear-cut. Dr. Winkler experimental results showed that not only does snow accumulation and melt differ significantly between clear-cut, juvenile, and mature stands, but also that snowmelt patterns vary among juvenile stands with distinct structural differences.

Hydrology V: Climate Impacts on Hydrology

Convener: S. Beltaos

Summary prepared by Kathy L. Young (chair)

There were four papers in this session.

The first paper titled *Changes in Lena River Streamflow Hydrology: Human Impacts vs. Natural Variations* was presented by Daqing Yang. His co-authors were Douglas Kane and Baisheng Ye. Dr. Yang analyzed monthly streamflow records from the Lena River

watershed from 1936 to 1999. His results indicated that the northern streams of the watershed, without much human impact, show a stream regime shift to earlier snowmelt, and higher summer streamflow perhaps due to regional climate warming and permafrost degradation in southern parts of Siberia. He also indicated that reservoir regulations have significantly altered monthly discharge in lower stream sections. Basin outlet discharge records thus do not always reflect natural changes and variations because of this human intervention. Daqing's talk clearly illustrated the importance of human activities in regional and global environmental changes.

The second paper titled *Development of Future GCM Scenarios for Hydro-Climatic Studies over Northern Canada* was presented by B.R. Bonsal. Co-authors were D.L. Peters, T.D. Prowse and M.P. Lacroix. Dr. Bonsal described the development of a suite of future climate scenarios for 40 stations over northern Canada based on GCM projections. Four climate models (Canadian, British, German and Australian) were chosen for scenario development, and in total 84 future scenarios were examined. Future changes indicate cooler temperatures for Eastern Canada and more precipitation for northern regions by 2080.

The third paper in the session was titled *Climate Induced Changes of Ice Regimes in Northern Aquatic Systems* and was presented by M.P. Lacroix. The co-authors of this paper were B.R. Bonsal, D.L. Peters and T.D. Prowse. Presently, his ice model utilizes a simple

temperature index to determine ice growth and decay but plans are underway to refine it further and implement an energy-balance. Mr. Lacroix also utilized the four climate model scenarios introduced by Dr. B. Bonsal using climatic data from 40 stations spanning the Canadian North. Again, he also looked at future changes in ice growth/decay.

The final speaker in the session was Dr. Daniel Peters. His paper was titled *Potential Change to the Precipitation minus Evaporation Index in Northern Canada during the 21st Century* and his co-authors were B.R. Bonsal, M.P. Lacroix and T.D. Prowse. Dr. Peters examined the present and future P-E index for 40 northern weather stations and similarly to Bonsal and Lacroix utilized the four climate models, previously mentioned to determine future changes. Dr. Peters' talk emphasized how shallow lakes and wetlands would be affected in different areas of Canada with the west showing drying and the eastern regions showing wetter conditions. There was some concern raised by the audience that results should be shown with levels of confidence attached, since government officials might be quick to react to suggested changes without fully understanding the errors involved. Authors of the last three papers indicated that this work was initially done to select sensitive ecological sites across Northern Canada for future studies. To date, the results of these three authors pertain to only northern areas of mainland Canada. The Arctic Islands are still imperfectly modelled.



HYDROLOGY SECTION NEWS

Canadian Geophysical Union Hydrology Section 2002-2003 Committee Report

Forest Hydrology Committee

The forest hydrology committee convened its first meeting during the CGU Conference in Banff in May 2003. Twenty five scientists representing the various provinces and territories of Canada attended the meeting and signed on for Membership. During this meeting, the members brainstormed and discussed various ways of improving the visibility of Canadian forest hydrologists in national and international programs; fostering communication, professional development, and

collaboration amongst scientists; receiving and disseminating information from international forestry organizations and related disciplines; and bridging the gap between science and professional practice in watershed management.

A full report of the Forest Hydrology committee of CGU will be published in the winter issue of *ELEMENTS*. If you want to be a member of this committee or if you simply would like to be on our e-mail list server please contact:

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Glaciers and Environment Committee

Chair:

Prof. D. Scott Munro,
Department of Geography, Univ. of Toronto at
Mississauga, Mississauga, ON, L5L 1C6 CANADA,
smunro@eratos.erin.utoronto.ca

Vice-Chair:

Michael N. Demuth, Geological Survey of Canada

Advisory Members:

Prof. Martin J. Sharp, University of Alberta
Dr. Roy M. Koerner, Geological Survey of Canada
Jeffrey Schmok, Golder Associates Ltd.

Mandate and Objectives:

- a. Assist the CGU and its executive in promoting glaciological research which is relevant to hydrological and environmental problems.
- b. Provide CGU members with information about glaciological research activity, with emphasis upon identifying opportunities for collaboration among individuals and groups.
- c. Provide CGU members with information about the scope and extent of glaciological data, and promote efforts to improve accessibility to such data.
- d. Influence research development by establishing lines of communication with other working groups in snow and ice, such as the Cryospheric System (CRYSYS) to monitor global change in Canada and identify opportunities for the training of personnel.
- e. Identify and promote opportunities for educating other members of the scientific community and the general public about glaciers and their role in the environment.

Meetings and Activities:

1. Michael Demuth and Roy Koerner continue to consolidate Canadian glacier research activity under the Geological Survey of Canada (GSC), supported by Natural Resources Canada, Environment Canada and University partners, in order to amalgamate research in Arctic and Western Canada within the National Glaciology Programme (NGP).

2. A book entitled *Peyto Glacier: One Century of Science*, M.N. Demuth, D.S. Munro and G.J. Young (eds.), establishes a context for future research development at Peyto Glacier and other glacier sites in Western Canada. We expect that it will be released this year.
3. Michael Demuth, continues as Canadian Correspondent to the International Glaciological Society, and Canadian National Representative to the International Commission on Snow and Ice.
4. Scott Munro is currently working on a sequel to *Progress in glacier hydrology: a Canadian Perspective* (Hydrological Processes 14: 1627-1640), which will be sent for review this summer.

Progress on Issues and Objectives:

The NGP work in the context of hydrological and environmental problems is central to the first objective of this committee. A recent achievement here, completed December 2002, is automatic weather station and stream gauge support for the Peyto and Place Glaciers mass balance monitoring programmes. Toward the second objective, *Peyto Glacier: One Century of Science* places this research in full view of the CGU, while the sequel to *Progress in glacier hydrology: a Canadian Perspective* reports Canadian research achievements to the world glaciological community. Improvements to Canadian glacier monitoring will see new sites established and existing sites improved, in Alberta, Yukon and British Columbia, a key point in addressing our third objective. The NGP consolidation effort is essential to our fourth objective: linking research among universities and agencies. Success at Peyto and Place reflects collaboration among Mike Demuth(NGP), Scott Munro(University of Toronto) and Dan Moore(University of British Columbia). Our fifth objective, of public education on glaciology, previously addressed in the Canadian Geographic feature, *Mysteries in the Ice*, and the Canadian Broadcasting Corporation (CBC) program, *Quirks and Quarks*, continues to be met with the appearance of Mike Demuth on the CBC program, *Country Canada*, which aired in January 2003.

Future Meetings and Activities:

As committee chair, I note progress in expanding an effective, collaborative Canadian glacier network, a need identified in the Ottawa 2000 GSC Workshop. I have also addressed a need to better relate us to the Cryospheric System (CRYSYS) to monitor global change in Canada, reporting the progress made at Peyto and Place Glaciers to the annual CRYSYS meeting in Montreal, March 2003.

Other Business

The glacier inventory is a continuing matter of concern, particularly as it relates to water resources in Western Canada. Training new personnel, finding new research positions and ensuring continuity of research into

glaciers and glacier hydrology, is urgent due to aging of current personnel and the need to replace rather than to terminate ice science positions.

Erosion and Sedimentation Committee

Chair:

Peter Ashmore, Department of Geography, University of Western Ontario, London, ON, N6A 5C2

Email: pashmore@uwo.ca

Members:

Dr. Dirk DeBoer, University of Saskatchewan

M. Conly, Environment Canada (CWS), Saskatoon

Dr. M. Church, University of British Columbia

Dr. A. Roy, Université de Montréal

Dirk DeBoer is IAHS-International Commission on Continental Erosion Secretary and ICCE Canadian Delegate

Objectives:

The scientific advancement and practical application of knowledge of erosion, transport and deposition of sediment in fresh water systems - topic coverage similar to that of the IAHS Commissions on Continental Erosion some aspects of Water Quality.

- i) communication of current research via discussion, meetings, conferences and publications;
- ii) identification and promotion of high priority research topics in the Canadian context;
- iii) promotion and encouragement of the transfer of knowledge and technology in the field of interest.

Meetings & Activities:

- Continued representation at CGU-HS meetings. 2002 meeting included 8 papers with erosion-sedimentation topics.
- 2003 CGU meeting features Workshop on Sediment Transport featuring 9 invited speaker and 10 poster presentations.
- Web page nearing completion for HS site.
- Review paper on recent (1998-2002) Canadian contributions to erosion and sedimentation research for CNC-IUGG report (and publication in HP) is being written by Dirk DeBoer with assistance from Marwan Hassan and Mike Stone.

Commentary:

The erosion and sedimentation community is scattered and diverse, and often drawn to conferences other than CGU. The Committee was formed to bring together a multi-disciplinary group within Canada specifically interested in, in the broadest sense, 'landscape physics' related to river systems and fluvial landscapes, together with its applications and consequences. The 2003

CGU session will be our first attempt to do this and is set up to be of interest to the whole CGU (including, but not limited to, HS). Invited speakers and poster presenters are from across Canada and include several from U.S.

This addresses a general issue of integrating HS activities into CGU in general and encouraging CGU to broaden its scope.



Committee on River Ice Processes and the Environment (CRIPE)

Chair: Dr. Spyros Beltaos, National Water Research Institute, Burlington. Telephone: 905-336-4898; fax: 905-336-4420; email: spyros.beltaos@cciw.ca

Vice-Chair: Mr. R. (Rick) W. Carson, P.Eng., P.E., KGS Group, Winnipeg

Secretary: Dr. Brian Morse, Université Laval, Quebec

Treasurer: Dr. Kersi Davar (retired), Univ. of N.B.

Mandate and Objectives:

- (1) Identify specific high-priority topics for research and development and promote the undertaking of relevant research programs;
- (2) Facilitate information dissemination and exchange of ideas among practitioners, researchers, and resource managers; and
- (3) Encourage the incorporation of pertinent lectures or courses in undergraduate and graduate studies at Canadian Colleges and Universities.

Meeting and Activities:

2002 Annual Committee meeting

The annual meeting was held in Winnipeg, on September 20, 2002, and the next is planned for Edmonton (June 21) in conjunction with the 12th River Ice Workshop.

12th Workshop

The 12th Workshop on River Ice will be held in Edmonton, June 18-20. For further information, visit http://www.riverice.ualberta.ca/CRIPE_12_Workshop.htm or contact Program Chair Dr. Faye E. Hicks, Dept. of Civil and Environmental Engineering, University of Alberta, Edmonton; Phone: 780-492-7170, Fax: 780-492-0249, email: fehicks@civil.ualberta.ca.

Monograph on River Ice Breakup

The Canadian Society for Civil Engineering has sponsored the production of a Monograph on the breakup

of river ice, under the leadership of CRIPE Chair, Spyros Beltaos, who is also a member of the CSCE Hydrotechnical Division Executive Committee. CRIPE has endorsed this initiative and several members and non-members are contributing to the preparation of the monograph. A first draft of the Monograph has been circulated to chapter authors for comments.

Progress on Issues and Objectives: Task Forces

One task force is presently active: the TF on the numerical modelling of ice jams (Rick Carson and others). The numerical modelling effort aims at producing consistent and comparable tests of the several models that have been developed to simulate ice-jam profiles in rivers. A number of modelers have expressed an interest in this task, and a paper was presented at the 11th River Ice Workshop (Ottawa, 2001), summarizing the findings of Phase 1. In that phase, the models were applied to the idealized case of a rectangular, prismatic channel that terminates in a headpond. Phase 2, comprising model applications to a well-documented case study from Thames River (SW Ontario), is now in progress.

CGU-HS: Northern Research Basins Committee

Philip Marsh, NWRI, Saskatoon
Canadian Chief Delegate, NRB

The main activities of the CGU-HS Northern Research Basins Committee during the last year was the organization of Canadian participation in the upcoming 14th NRB Symposium and Workshop to be held in Kangerlussuaq, Greenland from August 25 to 29, 2003. The general theme of the 14th meeting is "the role of high latitudes in global water balance and element budgets". As outlined in the NRB Mandate and the Canadian NRB Terms of Reference, the Canadian participation in the NRB is limited to 10 delegates appointed by the Canadian Chief Delegate (and approved by the CGU-HS Executive) to represent Canadian interest in the hydrology of northern areas. The Canadian Chief Delegate for the 14th and 15th meetings is Philip Marsh and David Milburn is the Canadian Deputy Chief Delegate.

Canadian delegates to the 14th meeting were invited based on past experience and in order to represent various aspects of Canadian northern hydrology. Attendees and area of expertise include: Hok Woo (permafrost hydrology), Murray Mackay (regional climate modelling and large scale water fluxes), Kathy Young (high arctic), Terry Prowse (river ice), Wayne Rouse (surface fluxes and as a member of an NRB Task Force), Bill Quinton (northern peatlands), Sean Carey (slope processes), and Ric Janowicz (operational water resources and the Wolf Creek research watershed). Although only 10 Canadian delegates may attend, other Canadians were notified that they could apply to attend. However, attendance was

dependent on available space at the discretion of the local organizers.

Other attendees of the 14th NRB are expected to include representatives of the eight member countries which include Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden and the USA. In addition to science presentations, there will be reports from three NRB Task Forces. These include: (1) comparison of basin water balance from a range of circumpolar environments (Doug Kane, USA), (2) new field methods in northern hydrology (Bent Hasholt, Denmark), and (3) climate change and lake thermal regime in northern environments (Nikolai Filatov, Russia). As in past years, the meeting will result in a published proceedings of the meeting, and papers can also be submitted for consideration for publication in a special issue of the journal, *Nordic Hydrology*.

The Canadian National Committee for the International Association of Hydrological Sciences (CNC-IAHS).

(Report By G. Jones)

CNC-IAHS is a committee of the Hydrological Section of the Canadian Geophysical Union (CGU-HS). The main roles of CNC-IAHS are to encourage and promote the participation of Canadian scientists in IAHS, to further the collaboration between IAHS and Canadian scientific organizations and institutions, and to respond, on behalf of Canada, to scientific requests of IAHS. CNC-IAHS also has an administrative role in seeking and supporting the nominations of Canadian hydrologists to executive positions of IAHS and arranging the selection and nomination of National Representatives and National Correspondents to IAHS Commissions and Committees. IAHS is one of the seven associations of the International Union of Geodesy and Geophysics (IUGG).

The CNC-IAHS Executive

The Executive of CNC/IAHS consists of the Senior and Junior Canadian National Representatives (NR) for IAHS plus the President and Vice-President of CGU-HS, the Presidents of the Canadian Meteorological and Oceanographic Society (CMOS), the Canadian Water Resources Association (CWRA) and the Canadian Chapter of the International Association of Hydrogeologists (CCIAH), and one Member-at-Large elected from the general membership of CGU-HS. The Senior NR serves as the Chair of the Committee and the Junior NR as Secretary. The current Chair of CNC-IAHS is Professor Taha Ouarda, Institut national de la recherche scientifique (INRS-ETE), Université du Québec; his term of Office will terminate in April 2005. The Secretary is Professor John Pomeroy, Geography Dept., University of Saskatchewan (Aug/03); he will act as Junior NR until 2005 when he will replace Professor Ouarda as Senior NR.

Major CNC-IAHS activities

Presently, the main activities of CNC-IAHS concern the XXIII General Assembly of IUGG at Sapporo, Japan, in July 2003. These activities are the contribution of CNC-IAHS to the quadrennial report of the Canadian National Committee for IUGG (CNC-IUGG) to be tabled at Sapporo, and the Elections of IAHS Officers and those of the IAHS Commissions to be held during the Plenary Administrative Session of IAHS.

The *CNC-IAHS contribution to the CNC-IUGG report* consists of a series of review papers on the progress of Canadian hydrology for the period 1999-2003. Certain members of the Canadian hydrological community were solicited by CNC-IAHS to prepare the works and nine papers are currently being written. The papers and principal authors are: Forest Hydrology (J. Buttle), Wetland Hydrology and Biochemistry (J. Price), Snow, Frozen Soils and Permafrost Hydrology (Hok Woo and P. Marsh), River Ice Hydrology (B. Morse and F. Hicks), Glacier Hydrology (S. Munro), Remote Sensing Applications in Hydrology (A. Pietroniro), Processes of River Erosion and Sedimentation (D. de Boer), Statistical Hydrology (T. Ouarda), and Isotope Hydrology (J. Gibson). These same nine papers will also be submitted for peer review and publication as an insert in the CGU-HS Special Issue of Hydrological Processes to be published in late 2003 or early 2004. The Guest Editorial Board for this issue will be S. Beltaos, L. Martz, D. Moore, and T. Ouarda.

The *IAHS election* procedure was initiated in the fall of 2002 when CGU-HS and CNC-IAHS circulated a call for the nomination of candidates to stand for office in the IAHS Bureau and that of the IAHS Commissions. All terms of office are for the period 2003-2007 except for position of President, which involves serving two years as

President-Elect (2003-2005) and four years as President (2005-2009). The result of the call for nomination resulted in no candidates for the IAHS Bureau elections but two candidates were nominated for office in two IAHS Commissions. D. de Boer was nominated for the position of Secretary of the International Commission on Continental Erosion (ICCE) and A. Pietroniro for the position of President of the International Commission on Remote Sensing (ICRS). In addition two other Canadian candidates were nominated through a separate IAHS procedure. These are: J. Barker for the position of Vice-President of the International Commission on Groundwater (ICGW) and J. Gibson for the position of President of the International Commission on Tracers (ICT). As all these four Canadian candidates are unopposed for Office they will be elected by default.

Other current activities

A Canadian Journal of Hydrology: CNC-IAHS has opened discussions with CGU-HS and CWRA on the opportunity of publishing a Canadian journal devoted to the hydrological sciences. Publication of research in Canadian hydrology is presently fragmented between many journals of varying scientific quality. However, the excellent quality of papers by Canadian hydrologists is generally accepted internationally and would guarantee a high scientific credibility and widespread circulation of such a publication.

The Montreal AGU-CGU Meeting, 2004: CNC-IAHS and CGU-HS are looking closely at the need of attracting good Canadian convenors and proposals for special sessions on both Canadian hydrology and the more universal scientific problems of water resources.

H.G. Jones (for the CNC-IAHS)

June 14, 2003

GEODESY SECTION NEWS

Reported by Marcelo Santos (UNB) and Spiros Pagiatakis (York U.)

Marking the first anniversary of the Geodesy Section of the Canadian Geophysical Union, a series of events took place last May. Most of them, during the CGU Annual Scientific Meeting, in Banff, May 10-14, 2003: Meeting of the Executive, Annual General Meeting, Student Paper Competition and the First Sea Surface Topography (SST) Workshop.

There were five *student papers* competing for the \$500 prize awarded by the Geodesy Section sponsored by the Geodetic Survey Division of NRCan. The winner was Ms. Georgia Fotopoulos, a PhD student from the Department of Geomatics Engineering, University of Calgary. The competing papers were:

- “On the estimation of variance components using GPS, Geoid and levelling data, by G. Fotopoulos.
- “The new IAU recommended transformation between the Celestial and Terrestrial Reference Frame and its implementation in Matlab”, by M. Weigelt
- “Mean geoid-generated gravity disturbance along plumb line”, By B-A. Martin.
- “The development of a high-degree spherical harmonic model based on satellite, airborne and terrestrial gravity data”, by M. Kern
- “Orbit design for future gravity field satellite missions”, by C. Xu.

The First SST Workshop took place on the 14th of May. It was an excellent opportunity for a meeting involving members of the geodetic and oceanographic communities

dealing with a subject of interest to both: Sea Surface Topography. Various presentations set the stage for establishing a “common language” and identifying common areas of interest for possible collaboration. As a start, the participants representing the Universities of New Brunswick, Calgary, York and Dalhousie and the Federal Agencies of Geodetic Survey Division (NRCan) and the Institute of Ocean Sciences (DFO) agreed to prepare a research proposal for phase III of the GEOIDE/NCE. The Workshop participants are shown in the picture below.

The Seventh Geoid Workshop was an activity that took place after the CGU Meeting. It was held on 15-16 May 2003, at the University of Calgary. Besides the traditional open discussions on geoid modelling, the workshop was a venue for networking and discussions on two GEOIDE/NCE projects, namely “Seamless Vertical Reference System for Geomatics Applications,” and “Precise Geoid Determination.” It was very encouraging to see many geodesy students from all over Canada participate, give presentations and contribute to the discussions. Various topics in the field of geodesy and

geophysics were discussed, including absolute gravity measurements and temporal variations of gravity, glacial isostasy and time-dependent geoid height over the North American continent, vertical datum transformation issues, assessment of CHAMP models and downward continuation methods for gravimetric geoid modeling. Future collaboration was also on the agenda: The team is now preparing for Phase III GEOIDE/NCE funding aiming at international collaborations and contributions. Those who have not yet been caught by the ...Canadian Geodetic Web are particularly welcome to join in! (http://gge.unb.ca/CGU/GEODESY_SECTION.htm).

Future Meetings related to Geodesy:

Besides the Joint CGU/AGU Meeting, to take place in Montreal 2004, the following meetings will be held in Canada: The *3rd International VLBI Service General Meeting*, Ottawa, 9-11 February, 2004 (<http://ivscc.gsfc.nasa.gov/meetings/gm2004>), and the *XV International Symposium on Earth Tides*, Ottawa, 2-6 August 2004 (<http://www.eas.yorku.ca/ETS-2004/ets.html>)



First SST Workshop Participants

CGU 2003 Best Student Paper Award Winners

A number of awards were presented in recognition of outstanding performance in scientific research and presentation by students. Each of the awards comes with a \$500 monetary prize. The awards were announced and presented at the CGU Awards Luncheon on Wednesday, May 14, 2003. To be considered for an award, the student must be the first author and presenter of the paper. The winners are listed below, and their abstracts or extended abstracts are printed below.

The Organizing Committee of the CGU 2003 Annual Meeting and the CGU Executive Committee would like to sincerely thank all the judges of the student papers for their careful evaluations of the student presentations.

Student Oral Presentation Winners :

CGU Best Student Paper Award (all fields of geophysics): Tim Haltigin, McGill University

Chevron Canada Outstanding Student Paper in Seismology: Sarah E. Richardson, University of Calgary

D.M. Gray Award for Best Student Paper in Hydrology: Merrin Macrae, Wilfrid Laurier University

Geodesy Award for Best Student Paper in Geodetic Research & Education: Georgia Fotopoulos, University of Calgary

Student Poster Presentation Winners :

Shell Canada Best Student Poster Award (other than hydrology): Hernan A. Ugalde, University of Toronto

Campbell Scientific Award for Best Student Poster in Hydrology: Murray Richardson, University of Toronto

Some of the CGU 2003 Student Presentation Award Winners

(Photos by Ted Glenn)



**Tim Haltigin and Merrin Macrae (above).
Murray Richardson (right).**





Sarah Richardson (above left) and Hernan Ugalde (above right)

Three-dimensional numerical modeling of flow dynamics around stream deflectors

T.W. Haltigin¹, P.M. Biron² and M.F. Lapointe¹

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Stream deflectors are one of several instream restoration structures used to rehabilitate degraded fish habitats. However, the success of these projects has been limited due to the trial-and-error approach with which they are often designed and implemented, as well as the lack of understanding of the detailed flow dynamics around deflectors. This project uses a three-dimensional numerical model to examine the flow fields around these structures and to establish the relationship between flow behaviour, predicted bed shear stress, and known changes in bed topography. The model solves the fully three-dimensional form of the Reynolds-Averaged Navier-Stokes equations in conjunction with the Renormalized Group Theory k- ϵ turbulence model. Flow around paired deflectors of various angles and contraction ratios are simulated for both stationary and mobile beds. Results are compared against detailed flume measurements of three-dimensional velocity and shear stress. In general, velocity

predictions match well with the laboratory measurements. Extensive flow separation and recirculation characterize the velocity field; flow reattachment distance is greatest along the banks downstream of the deflectors, and strong vertical recirculation pockets are present both upstream of and in the lee of the structures. Predicted shear stress is greatest between the deflectors, but does not fully explain the scour viewed in the laboratory. Scour depths are greatest where the combination of shear stress and downwelling (negative vertical velocity) is maximized, while varying the deflector angle results in a shift in locations of highest shear stress and scour. This model will be adapted for application to a natural river in which deflectors have previously been installed. The success of this research may result in an increased reliance on numerical simulations prior to structure installation in future restoration projects.

Seismic investigations of coalbed methane reservoirs

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Exploration seismic techniques may be applied to the development of coalbed methane reservoirs, a potentially important new energy source in Alberta. A review of existing and newly developed technologies demonstrates that seismic methods are an invaluable tool in CBM prospecting and development.

Dewatering is a necessary step in CBM production, resulting in changes in the acoustic impedance and seismic reflectivity within the coal zone. Decreased velocities result in delayed arrival times for reflectors underlying the coal zone. Gas injection is used in enhanced coalbed methane production (ECBM) and will result in further changes in acoustic impedance of the coal. Numerical modelling demonstrates “proof of concept”,

and provides parameters to be considered in survey design prior to a field CBM trial. Time-lapse differencing is effective in imaging changes in reflectivity resulting from changes in density and velocity of coal after dewatering and gas injection (see Fig. 1).

Vertical seismic profiles of a CBM test well drilled in the Ardley coal zone yield clear seismic reflections from the coal using both compressional and shear wave sources. Surface seismic data at the site also recorded a high amplitude reflection from the coal zone. Attribute analysis of these events is anticipated to provide useful information regarding the physical properties of the coal and thus, its suitability for CBM development.

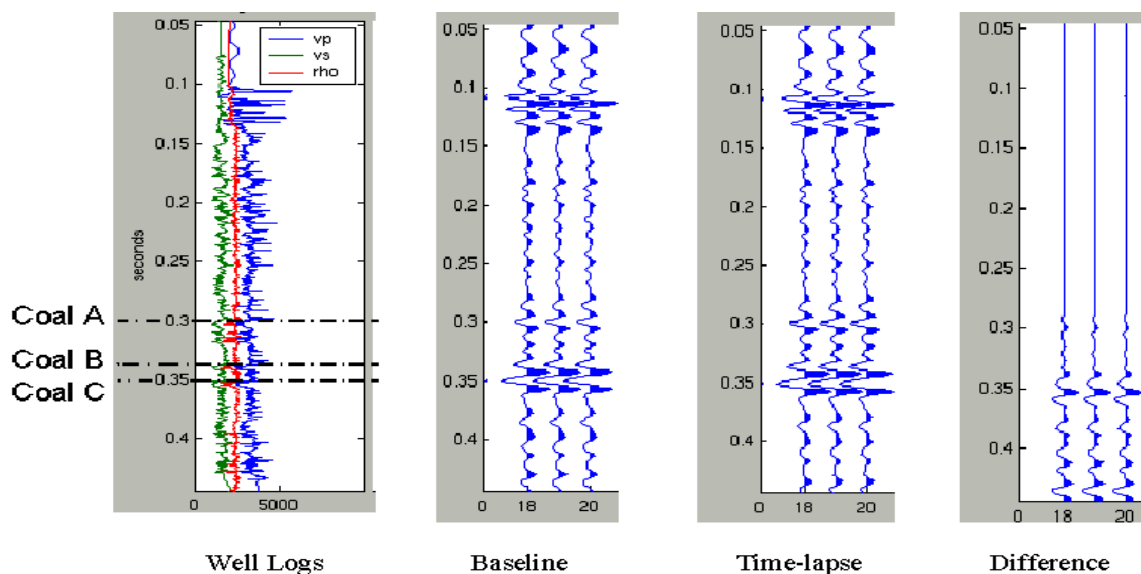


Figure 1: A synthetic seismogram created using the original well logs (“Baseline”) shows a clear coal response for each of three zones. Reducing the velocity and density values by 5% each results in the “time-lapse” image. The differenced seismogram illustrates the increased reflectivity within the coal zones as well as delayed arrivals for all events underlying the coal.

Temporal Patterns of Nutrient Export from a First-order Agricultural Basin in Southern Ontario

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Abstract

Due to the rising costs of environmental monitoring programmes, estimates of annual nutrient export are often based on data from a small number of representative storm events. Such estimates may be prone to significant error because of extreme events which may occur but be missed by sampling regimes. This study examines the importance of extreme events in annual estimates of nutrient mass export from a small headwater agricultural watershed in Southern Ontario. The importance of winter thaw events on annual nutrient losses in Southern Ontario is described.

Annual losses of total phosphorus (TP), soluble reactive phosphorus (SRP) and nitrate (NO_3^-) for 2000 and 2001 were 0.40 and 0.27 kg TP $\text{ha}^{-1} \text{yr}^{-1}$, 0.12 and 0.06 kg SRP $\text{ha}^{-1} \text{yr}^{-1}$, 39.06 and 29.50 kg $\text{NO}_3^- \text{N} \text{ha}^{-1} \text{yr}^{-1}$. Higher nutrient losses from the basin occurred during periods of elevated flow (70-80% of annual TP, 83% of annual SRP and 67-73% of annual NO_3^- losses occurred during 27-28 events per year). Winter losses were particularly important, accounting for 34 - 60% of annual TP losses, 54-63% of annual SRP losses and 23-73% of annual NO_3^- losses. One or two extreme events per year accounted for 18-43% of annual TP losses, 0-58% of annual SRP losses and 13-32% of annual NO_3^- losses. Export coefficients of 0.04 kg TP ha^{-1} , 0.01 kg SRP ha^{-1} and 3.39 kg $\text{NO}_3^- \text{ha}^{-1}$ per event are classified as *extreme* based on the data collected in the current study. In general, events that were extreme in their export of nutrients were also extreme in their hydrologic export.

Introduction

Nutrient loading to natural waters has been an area of concern over many decades due to the eutrophication of aquatic systems. Agricultural areas are a non-point source of nutrients and consequently are difficult to monitor and control (Carpenter *et al.*, 1998). The scientific community and policy-makers require accurate data sets and functional nutrient models for management purposes. Due to cost cutting, scientists and monitoring programmes are limited in the frequency with which storm events can be sampled. Annual estimates of nutrient export are often extrapolated from small data sets that have been collected from a small number of events and may exclude certain times of the year (C. Attema, Pers. Comm., 2003). These estimates may seriously under- or overestimate annual estimates of nutrient export.

The objectives of this study are (1) to report annual SRP, TP and NO_3^- export (2 years) from a first order agricultural basin in Southern Ontario; (2) to demonstrate temporal variability in nutrient export, emphasizing the significance of winter thaw events and extreme events in annual nutrient export, and (3) to demonstrate the potential error associated with not including one or more extreme events in annual estimates.

Study Site

The study was conducted in the Strawberry Creek Basin, near Maryhill, Ontario (80°23'15"W, 43°33'10"N). Land-uses in the basin consist of woodlots, and cultivated and residential lands. Crops include corn, soybeans, winter wheat, and strawberries. Both organic (cattle, poultry) and inorganic fertilizers are applied in this basin.

Soils in the basin are classified as a combination of Gray Brown luvisols, Melanic Brunisols, and Humic gleysols (Presant & Wicklund, 1971). Surficial soils are a combination of loam and silt loam. At approximately 2 m depth, a layer of fine, clay-rich till is present, which acts as an aquiclude between shallow and deep soils in the basin.

Mean annual precipitation is 909 mm (Environment Canada, 2002). A total of 9 tile drains and surface inputs from two deciduous swamps, as well as a perennial groundwater source contribute to the flow of Strawberry Creek. Tiles do not flow during dry periods. Under exceptionally dry periods such as the summer of 2001, the streamflow ceases altogether. However, these dry periods are rare in the study basin.

Methods

Stream discharge was recorded continuously at the basin outflow over the two-year period. Stream stage was measured by a potentiometer in an enclosed stilling well and recorded at 5-minute intervals by a Campbell CR10 data logger. Stream discharge was estimated from a stage-discharge relationship curve that was developed from manual discharge measurements taken at the basin outflow over a 5 year period. Discharge values predicted by the stage-discharge relationship are generally within 13% of measured values. Precipitation was measured continuously using a tipping-bucket rain gauge and recorded on a Campbell 21X data logger.

In this paper, events are defined based on hydrograph response rather than precipitation events. An event was considered to have started once the hydrograph began to rise following precipitation or snowmelt. An event was considered to be finished once conditions had

returned to baseflow. Baseflow was determined using the constant slope method (McCuen, 1998) where individual events could be isolated and stable flow was apparent during both pre- and post-event flow. If two or more successive events occurred, the hydrologic contribution of individual events was determined using a synthetic recession curve.

Water samples were collected both manually and using an automated ISCO sampler during 64 events between February 2000 to February 2002. Event samples were generally collected at 2-6 hour intervals throughout the event hydrograph. Samples were collected less frequently between events, with the longest period between sampling periods being less than one month.

Water samples were filtered (0.45 μm) immediately and stored in the dark at 4 °C. Samples were analysed on a Technicon Autoanalyser for NO_3^- -N, using Automated Cadmium Reduction and SRP and TP using Ammonium Molybdate-Stannous Chloride Reduction (Environment Canada, 1979). Analytical precision based on replicate analysis of 5% of all samples was generally \pm 5% of reported values.

Nutrient concentrations for periods where samples were not collected were interpolated using either 'simple' or 'discharge-proportionate' (Q-C relationships with $r^2 > 0.50$) (Scheider *et al.*, 1979; Vanni *et al.*, 2001; Hill, 1981).

Results

Temporal Variability in Nutrient Export Patterns

Extreme Nutrient Loading Events

Not all events are equal in their nutrient export. Rare events are extreme in their export of nutrients. The mean export coefficients of the 64 events over the study period were 0.01 ± 0.02 kg TP ha^{-1} , 0.002 ± 0.01 kg SRP ha^{-1} and 0.90 ± 1.20 kg NO_3^- -N ha^{-1} . Events that were extreme in their export of nutrients were identified as those that were more than 2 standard deviations above the mean (based on the range of events observed over the entire study period). Such events exported quantities of nutrients that were much higher than all other events and accounted for a significant proportion of annual nutrient export. Export coefficients equal to or greater than 0.04 kg TP ha^{-1} , 0.01 kg SRP ha^{-1} and 3.39 kg NO_3^- -N ha^{-1} per event were classified as *extreme* based on the data collected in the current study.

Annual Hydrochemical Export Patterns

Hydroclimatic conditions were variable between the two study years. Total precipitation was similar in both study years (743 mm in 2000, 633 mm and 2001), but lower than the 30-year mean annual precipitation for the Waterloo region (908 mm) (Environment Canada, 2002). However, the distribution of rainfall and runoff varied substantially between the study years (Fig.1).

Flow rates during low flow periods ranged from 0 (ephemeral) to 30 L s^{-1} , and event-related flow ranged from 30 to 450 L s^{-1} . In general, the highest nutrient concentrations were observed during discharge peaks in both study years (Fig.1). Nutrient losses were higher in 2000 (0.40 kg TP ha^{-1} , 0.12 kg SRP ha^{-1} and 39.06 kg NO_3^- -N ha^{-1}) than in 2001 (0.27 kg TP ha^{-1} , 0.06 kg SRP ha^{-1} and 29.50 kg NO_3^- -N ha^{-1}) (Table 1). Nutrient losses were strongly related to snowmelt and storm events. Twenty-seven events occurred in 2000, accounting for 80%, 83%, and 73% of annual TP, SRP and NO_3^- losses, whereas 28 events occurred in 2001, accounting for 70%, 83%, and 67% of TP, SRP and NO_3^- losses (Table 1). These events accounted for only 64% and 63% of annual hydrologic losses in 2000 and 2001.

Winter events in 2000 and 2001 accounted for a substantial portion of annual TP (25% and 37%), SRP (48% and 42%), NO_3^- (13% and 36%), and hydrologic losses (13% and 32%).

Three of the 64 events over the study period have been classified as *extreme* in water discharge and nutrient export (Table 1). Two of the three extreme events were winter thaw events (February, 2000 and February, 2001) and the third extreme event occurred in June, 2000 following more than 120 mm of rainfall that fell over ten days.

Extreme events accounted for substantial proportions of annual nutrient export in both study years (Table 1). For example, 58% of the annual export of SRP in 2000 occurred during the two extreme events, whereas 25% of annual SRP losses in 2000 were lost during the remaining 25 events. If either of the extreme events had been missed, annual estimates of SRP losses in 2000 would have been significantly underestimated.

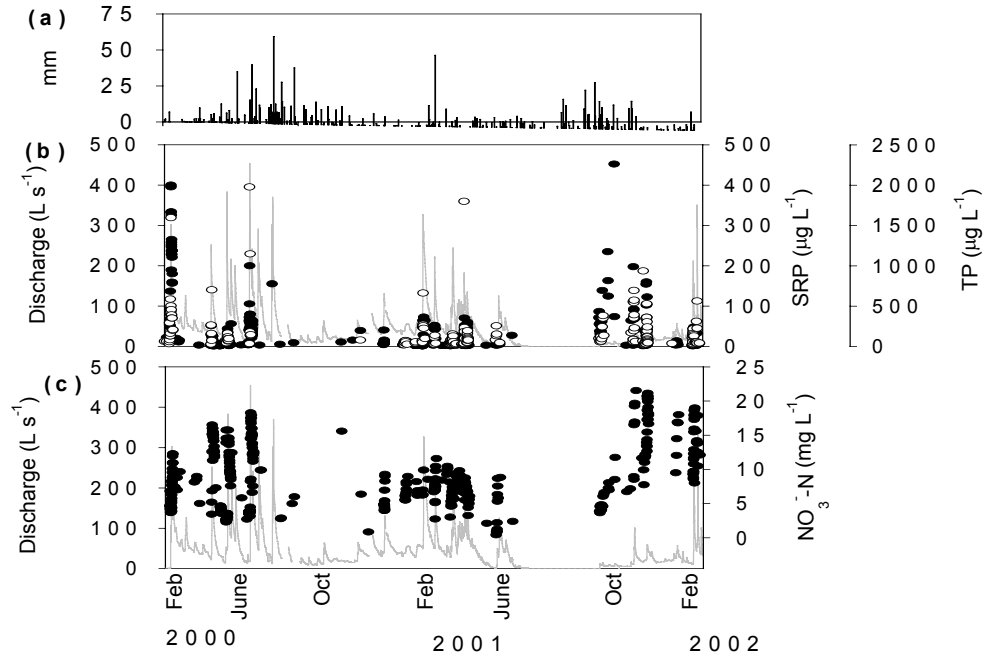


Figure 1: Daily precipitation is shown in (a). Basin discharge is shown on the left y-axis of (b) and (c). Streamwater concentrations of SRP (black circles) and TP (white circles) are shown on the right and offset right axis of (b). NO_3^- -N is shown on the right axis of (c).

	kg TP ha ⁻¹	kg SRP ha ⁻¹	kg NO ₃ ⁻ ha ⁻¹	Basin Discharge (mm)
2000				
Σ all events	0.32 (80%, 27)	0.10 (83%, 27)	28.62 (73%, 27)	320 (64 %, 27)
Σ extreme events	0.17 (43%, 2)	0.07 (58%, 2)	9.38 (24%, 2)	97 (20 %, 2)
Σ normal events	0.15 (37%, 25)	0.03 (25%, 25)	19.24 (49%, 24)	223 (44 %, 25)
Σ baseflow	0.08 (20%)	0.02 (17%)	10.44 (27%)	182 (36 %)
Σ annual losses	0.40 (100%)	0.12 (100 %)	39.06 (100%)	502 (100 %)
2001				
Σ all events	0.19 (70%, 28)	0.05 (83%, 28)	19.75 (67%, 28)	226 (63 %, 28)
Σ extreme events	0.05 (18%, 1)	0.00 (0%, 0)	3.87 (13%, 1)	34 (9%, 1)
Σ normal events	0.14 (52%, 27)	0.05 (83%, 28)	15.89 (54%, 27)	193 (54%, 27)
Σ baseflow	0.07 (30%)	0.01 (17%)	9.75 (33%)	135 (37%)
Σ annual losses	0.27 (100%)	0.06 (100 %)	29.50 (100%)	361 (100 %)
Study Period (Feb/00- Feb/02)				
Σ all events	0.55 (75%, 64)	0.15 (83%, 64)	52.99 (69%, 29)	580 (63%, 64)
Σ extreme events	0.22 (30%, 3)	0.07 (39%, 2)	13.25 (17%, 3)	131 (15%, 3)
Σ normal events	0.33 (45%, 61)	0.08 (53%, 62)	39.74 (52%, 27)	449 (48%, 60)
Σ baseflow	0.18 (25%)	0.03 (17%)	23.56 (31%)	347 (37%)
Σ losses	0.73 (100%)	0.18 (100 %)	76.55 (100%)	927 (100 %)

Table 1: Annual Hydrochemical Export from Strawberry Creek. The contribution (%) of each event to total mass export and the number of events are shown in brackets.

Discussion

Annual Patterns of Nutrient Export

Our results are consistent with studies of other agricultural systems which report that NO_3^- and particulate P are the predominant forms of nutrients exported (e.g. Vanni *et al.*, 2001). Annual estimates of nutrient export from Strawberry Creek (0.27-0.40 kg TP $\text{ha}^{-1} \text{yr}^{-1}$, 0.06-0.12 kg SRP $\text{ha}^{-1} \text{yr}^{-1}$, 29.50-39.06 kg $\text{NO}_3^- \text{N} \text{ha}^{-1} \text{yr}^{-1}$) are within the wide range of estimates of nutrient losses that have been provided in the literature (0.02 – 48 kg TP $\text{ha}^{-1} \text{yr}^{-1}$, 0.01 – 2.2 kg SRP $\text{ha}^{-1} \text{yr}^{-1}$, 0.04 – 44.77 kg $\text{NO}_3^- \text{N} \text{ha}^{-1} \text{yr}^{-1}$) (Vanni *et al.*, 2001; Cooke & Prepas, 1998; Douglas *et al.*, 1998; Hill, 1981; Sharpley and Syers, 1981; Schuman *et al.* 1973).

Twenty winter thaws occurred during the two-year study period. These thaw events accounted for a significant proportion of nutrient losses in both study years. In Southern Ontario, agricultural fields are vulnerable to nutrient losses during winter thaws. The three major winter thaw events examined in the current study were significant in terms of overall nutrient export, and two of the three events were *extreme* in their export of nutrients. Mid-winter or spring runoff events coupled with the application of organic fertilizers can result in excessive losses of SRP (Cooke & Prepas, 1998; Schuman *et al.*, 1973). At Strawberry Creek, manure was applied to 15% of the basin a few days prior to the February 2000 thaw event. In the winters of 2001 and 2002, manure was applied at least one month prior to both thaw events.

The Significance of Extreme Events in Annual Estimates of Nutrient Export

The dominance of a few major events in annual estimates of nutrient mass exports has been reported elsewhere (e.g. Ulen & Persson, 1999; Douglas *et al.*, 1998; Zuzel *et al.*, 1993; McCool *et al.*, 1982; Hill, 1981; Schuman *et al.*, 1973). However, these studies have been conducted on larger basins in different geographical regions and at larger scales. The study basin is a small first-order agricultural catchment in Southern Ontario, and is likely representative of many headwater streams draining agricultural basins in this region.

This paper has shown that the bulk of SRP, TP and NO_3^- exported during the study period were lost in a few extreme events. If one or more of these events had been missed, annual estimates of nutrient losses would be significantly underestimated. This illustrates the danger and associated error of extrapolating data collected during a small number of events to estimate annual nutrient export from a basin.

Conclusions

Intensive sampling over a 25-month period has demonstrated inter-annual variability between two years, and shown that the majority of nutrients were exported during winter and summer events. Two winter events and one summer event were extreme in their hydrochemical export. The intensive monitoring programme in this study has shown the significance of a few events in annual nutrient losses and has demonstrated the potential error associated with not including such events in annual estimates.

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On the Estimation of Variance Components Using GPS, Geoid and Levelling Data

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OVERVIEW

In this paper a well-known approach for estimating the variance components of heterogeneous groups of observations is used in the combined adjustment of GPS, geoid and levelling data. Specifically, the minimum norm quadratic unbiased estimation (MINQUE) algorithm [Rao and Kleffe, 1988] is employed to determine the individual variance components for each of the three height types. This method is explored in order to address the question of '*What accuracy level can be achieved using the GPS-levelling method?*' Over the past decade, numerous advances have been made which have placed us in a position where we can begin to address this issue with more confidence, namely (i) improved data processing capabilities, (ii) increased data availability/quality for computing gravimetric geoid models, and (iii) refined mathematical models/techniques for dealing with GPS data.

The general model applied for the 1D multi-data vertical network adjustment is:

$$h_i - H_i - N_i = f_i + v_i \quad (1)$$

where h_i , H_i and N_i refer to the known ellipsoidal, orthometric and geoid height values at each of the network points, f_i describes the correction term for the systematic errors and biases inherent among the different types of height data (usually modeled by a parametric surface) and v_i describes the zero-mean random errors in the GPS, levelling and geoid data [see Fotopoulos et al., 2003 for more details]. The combined second-order statistical properties of the observational errors, v_i , are described by the covariance matrix:

$$C = \sum_k \sigma_k^2 Q_k \quad \text{where } k = [h \ H \ N] \quad (2)$$

Fully populated empirical covariance matrices (Q_h , Q_H and Q_N) are computed from a-priori information about the accuracy of the three height types and used as initial input into the MINQUE algorithm. These a-priori covariance matrices were successively 'updated' by the corresponding estimated variance components $\sigma^2 = [\sigma_h^2 \ \sigma_H^2 \ \sigma_N^2]$ in an iterative procedure. The iterations stop and the final estimated

factors are computed once a pre-specified convergence criterion is met.

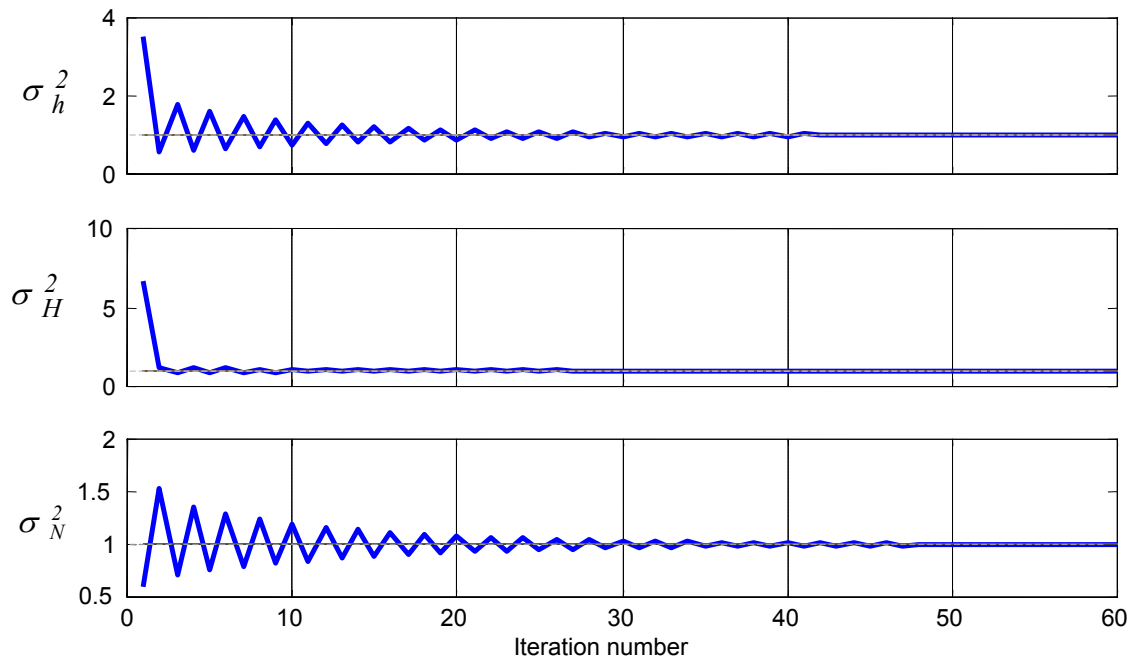
In order to apply this algorithm in practice through a combined adjustment of GPS, geoid and levelling data, there are a number of issues that must be addressed, namely (i) the effect of the a-priori covariance matrices on the final estimated variance components, (ii) the provision for estimating only *non-negative* variances, (iii) the effect of using fully populated versus diagonal covariance matrices and (iv) the role of the parametric model type on the estimated variance components. These challenges were encountered when implementing the MINQUE algorithm in practice using balanced data for a GPS/levelling network in Switzerland [Marti, 2002]. A brief sample of some of the results is discussed in the following section.

RESULTS

A network of 111 GPS/levelling benchmarks covering all of Switzerland was used for the numerical tests. The following figure shows the estimated variance factors at each iteration as they ultimately converge to unity. From top to bottom, the three subplots represent the estimated variance factors for GPS, levelling and geoid heights, respectively. Upon inspection of the graphs it is evident that the estimated variance factor for the levelled heights converges at a much faster rate, approximately 40% (27 iterations) as compared to 42 and 47 iterations for GPS and geoid heights. This can be attributed to the fact that the initial accuracy estimates for the levelled heights were more realistic than the available covariance

matrices for the other types of height data. In fact, for this case, it was found that the GPS covariance matrix resulting from an independent GPS network adjustment

was too optimistic, while the a-priori covariance matrix for the geoid proved to be too pessimistic overall.



CONCLUSIONS

The analysis conducted for this paper provides some indication into the practicality and usefulness of estimating variance components in mixed vertical networks. Notably, the estimation of realistic variance components provides us with important insight with regards to the GPS-levelling problem in addition to other uses of combined GPS, geoid and levelling data, such as assessing the accuracy of a gravimetric geoid model.

ACKNOWLEDGMENTS

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Magnetization On Impact Structures: More Than Just a Susceptibility Depletion

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The magnetic anomaly over impact structures is characterized by high amplitudes and short wavelengths, in contrast to the magnetic low due to a reduction in susceptibility proposed by [1]. For large structures this can be the aggregate of three effects: (1) A secondary remanent magnetization (shock remanent magnetization, SRM) induced by the high pressures of the impact (>30 GPa), if there is enough occurrence of NRM carriers on target rocks (e.g. Manicouagan [2], Slate Islands [3]); (2) recrystallization of non-magnetic rocks towards more magnetic facies (therefore melt will have a higher magnetic susceptibility than the pre-impact target rocks), increasing magnetic susceptibility (e.g. Chicxulub). Biotite and amphibole can decompose to an assemblage of phases that often contain magnetite, when they are exposed to high postimpact temperatures [4], which will also produce high magnetizations; and (3) hydrothermal alteration processes favoured by impact-induced brecciation, the impact and/or the melt layer as a heat source and the presence of fluids. This lead to the acquisition of a chemical remanent magnetization (CRM) in the direction of the ambient field [1]. Fracturing of the target rocks permits the circulation of hydrothermal fluids, and the presence of oxygen favours higher magnetization intensities [5].

The above has been quantified on the Chicxulub impact crater, where a meteorite hit a non-magnetic carbonate platform, but still large magnetic anomalies can be seen. Remanence magnetization intensities are small (10^{-4} A/m, [6] and magnetic susceptibilities can be as large as 1200×10^{-5} S.I. towards the base of the suevite packages, suggesting alteration due to a hydrothermal system [6]. The melt layer shows

magnetic susceptibilities one order of magnitude smaller than that, which can be interpreted due to the non-magnetic nature of the pre-impact rocks.

For smaller structures ($4 < D < 20$ km) numerical modelling can be used to predict maximum pressure and temperature distribution [7]. Pressures larger than 30 GPa (SRM) are approximately restricted to $r < 1.5$ km and depths < 2.5 km. Pressures higher than 70 GPa (rock melt) are confined to $r < 1$ km and depths < 1.4 km. Therefore, SRM and melt are confined to small areas, sometimes not even discernible by a regional airborne magnetic survey, and easily removed by erosive processes. Hydrothermal alteration induced by fluids circulation on the brecciated and fractured rocks can still increase or reduce magnetic susceptibilities due to recrystallization, and lead to the acquisition of a CRM. No matter the type of sediments that fill the crater magnetic susceptibilities will be smaller than on the pre-impact target rocks and the main feature will be a disruption of main pre-impact magnetic trends (e.g. Deep Bay [1] and Wanapitei Lake in Canada [8]).

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The Wetland Object Model (WOM): a geographic object-based simulation framework for studies in wetland ecohydrology

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Introduction and Theory

Wetland environments are widely recognized as critical environmental junctures where hydrology and biogeochemistry interact at various spatial and temporal scales, producing important ecological functions within the landscape (Branfireun et al. 1996; Cirno and McDonnell 1997; Hill and Devito 1997). Yet the underlying complexity of these interactions is still

beyond the descriptive and predictive capabilities of current computational models of wetland hydrology and ecology (Cirno and McDonnell 1997). Ecohydrology is a burgeoning science that provides a suitable framework for analyzing wetland hydrology and biogeochemistry. Currently there are no ecohydrological models designed specifically for studying the spatial and temporal distributions of hydrological and biogeochemical

interactions occurring in wetlands. To capture internal wetland heterogeneities of ecohydrological processes, such a model would require a fine-scale (<10m) spatially distributed dynamic hydrology component, coupled with microbial and biogeochemical modules to simulate ecological and chemical dynamics at various spatial and temporal scales. This presents a challenging technical and conceptual problem, since existing groundwater, contaminant transport and spatial hydrology models are not designed in such a way that facilitates the integration of these various ecohydrological components within a spatially distributed framework.

Increasingly, the object-oriented approach to complex system design is being explored as a powerful and flexible abstraction tool for constructing and integrating hydrological and ecological models (Robinson and Mackay 1996; Bennett 1997). In this research, we invoke this approach to develop a novel, prototypical, object-oriented simulation framework for studies in wetland ecohydrology. The Wetland Object Model (WOM) consists of an object-based data architecture that is highly amenable to the hierarchical representation of the landscape, such that ecohydrological processes

can be easily accommodated within the model framework at various spatial and temporal scales.

Methods and Results

The WOM architecture

Java, an object-oriented programming language, was used to design a suite of object-based data structures (object classes) that serve as the structural and functional building blocks. In WOM, two fundamental object classes - ControlVolumes and ExchangeSurfaces - are assembled into a 3-dimensional model of wetland hydrology. These objects are analogous and compatible with the raster data model of geographic information, but provide a more flexible framework for capturing structural and functional information, and its variations over time and space (Figure 1). Importantly, ControlVolume and ExchangeSurface classes are used as base classes for creating more specialized objects that can implement *any structural or behavioural conceptualization of a wetland environment*. The ExchangeSurface class can be used to regulate fluxes of mass and energy across the landscape, for example, the lateral and vertical movement of water between adjacent Surface and Subsurface ControlVolumes.

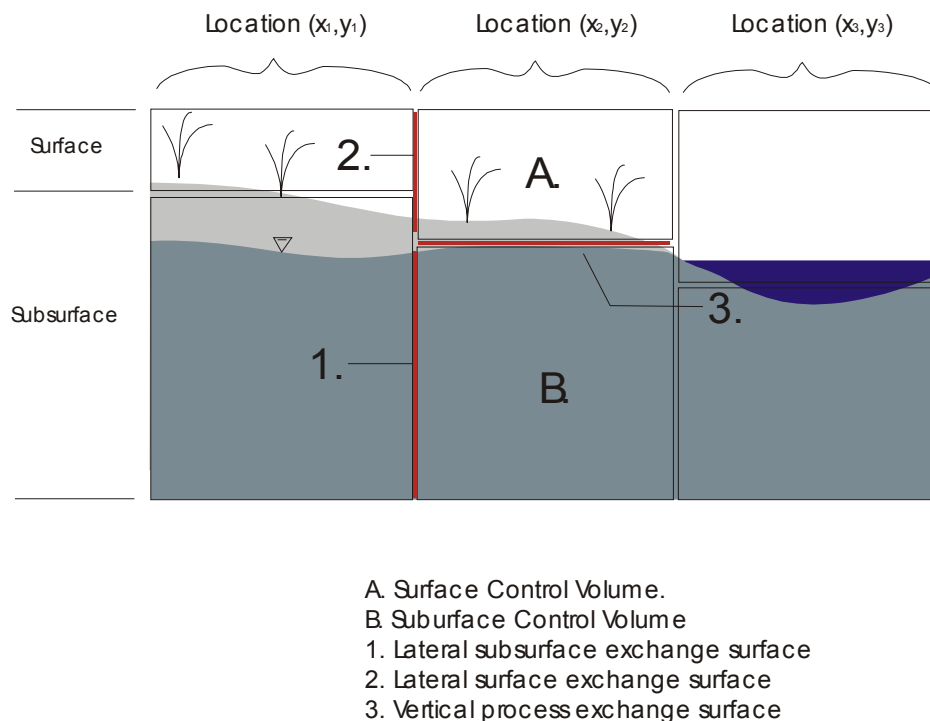


Figure 1: Schematic representation of the main structural object classes used in the Wetland Object Model. The ControlVolume and ExchangeSurface classes are used as base classes for more specialized classes such as the LateralSubsurfaceexchangeSurface, which implements Darcy's law to drive the lateral subsurface movement of water.

Currently in the WOM, behavioural object classes are used for the encapsulation of physico-mathematical equations (e.g. Darcy's Law or the mathematical representation of depth-variable hydraulic conductivity and porosity), temporal data handling (e.g. hydrographs) and boundary condition specification (e.g. Dirichlet, von Neumann conditions).

Simulating wetland hydrodynamics with the WOM

To establish the initial technical implementation of the WOM, a simulated wetland environment was setup to demonstrate three simple subsurface hydrodynamic principles using different boundary conditions and several descriptions of depth-variable hydraulic

conductivity (e.g. linear vs. exponential decline with depth). Three main scenarios were established to successfully represent the conditions of 1) kinematic-wave propagation; 2) water table equilibration and 3) transmissivity feedback. A sample of the scenario 3 results is provided in Figure 2, which depicts the transmissivity feedback principle (2b) resulting from a steadily increasing inflow hydrograph (2a) and an exponential decay in hydraulic conductivity with depth below surface. The rapid increase in saturated hydraulic conductivity as the water table approaches the surface results in a decreasing rate of water table rise despite a linearly increasing rate of discharge.

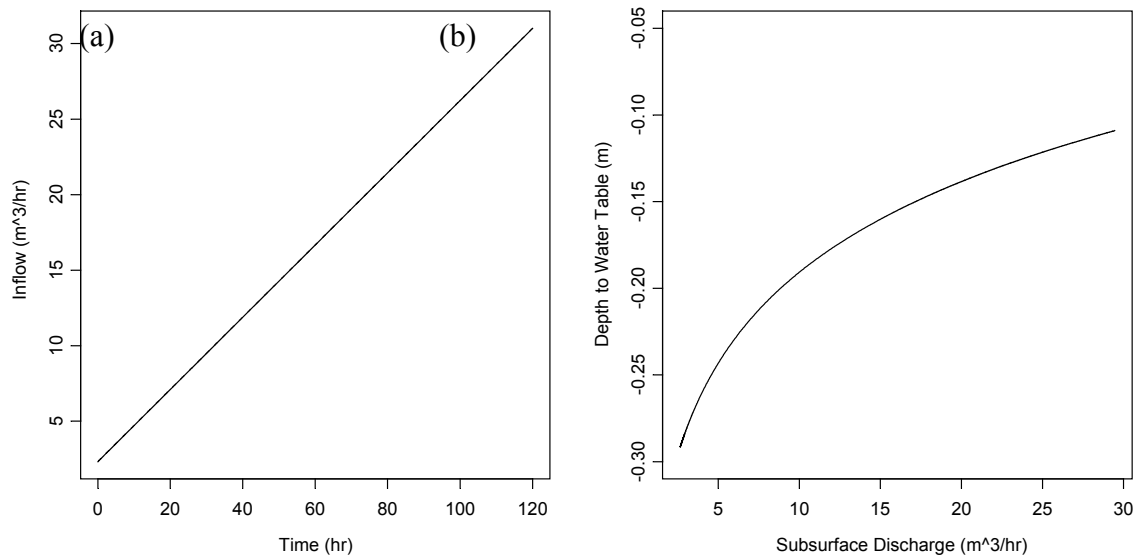


Figure 2: Water table position versus subsurface discharge (b) at the outflow boundary condition of a simulated wetland environment. This simple demonstration of the transmissivity feedback principle was accomplished by simulating a 20 cm rise in water table position using a steadily increasing hydrograph at the inflow boundary (a), and an exponential decline in saturated hydraulic conductivity with depth.

Conclusions

The successful demonstration of basic subsurface hydrodynamics using the WOM prototype serves as the first technical implementation of a new geographic, object-based approach to simulating wetland ecohydrological processes. Rather than presenting a new mathematical solution to subsurface flow modelling, this research adopts existing numerical approaches to simulating wetland hydrological modelling using a unique object-oriented structure designed to enhance flexibility, extensibility and long-term tractability of the model framework. The model

architecture consists of a structural object class (ExchangeSurfaces) designed to explicitly control ecological fluxes between adjacent landscape units (ControlVolumes). These structural object classes serve as base classes for more specialized objects that can be assembled into a modular, hierarchical representation of wetland environments.

By attributing special importance to the boundaries between adjacent landscape units, the WOM structure is highly amenable to an ecotone-based conceptualization of local and regional ecology of wetland systems. The object object-oriented approach to system design

provides a mechanism for integrating dynamic hydrological information with the temporally static data structures used to represent geographic information. As a result, spatial variations in landscape structure and function can be more clearly identified and characterized using a conceptual and computational schema that is specifically tailored to the modeler's research objectives. Future research goals include field-based validations of the spatial hydrology component presented here, as well as the development of a biogeochemical module and an ecotone-based landscape analysis module.

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