1996 Annual Report

"Promoting the most effective use of our land resources"

UNIVERSITY OF GUELPH
The 1996 Morwick Scholarship was awarded to David Fallow. The presentation of the award was made by Jim Morwick.
The 1996 Morwick Scholarship was awarded to David Fallow. The presentation of the award was made by Jim Morwick.

A social gathering at Baumdale Farm. Back row: Pat Beirnes, Hilda Tel, Norbert Baumgartner, Gus Bryant, Ed Dickson, Janice Dickson, and Carole Gagnon. Front row: Linda Baumgartner, and Earl Gagnon.
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Foreword

The Department of Land Resource Science successfully completed its 51st year in 1996. This annual report provides a summary of our activities in teaching, research, and service to the many friends of the department who follow its activities from locations around the globe. With growing accessibility of information on the World Wide Web, we are utilizing the Internet to replace many printed copies of this report. The web copy of this report can be found, along with additional information concerning the department, at:

http://www.uoguelph.ca/lrs

After a short period as Chair of the Department, Professor Gary Kachanoski resigned his position at Guelph in September, and became Dean of Graduate Studies and Research at the University of Saskatchewan. His energy and exceptional reputation will be missed by the Department. Professor Terry Gillespie became Acting Chair when Gary left.

Despite continued fiscal pressure on our University, Land Resource Science fared well in 1996. We have successfully expanded our Distance Education program, increased our undergraduate enrolment, and held our graduate program nearly steady. Our research program is functioning well under new arrangements with the Ontario Ministry of Agriculture and Rural Affairs (OMAFRA). Some traditional sources of research funding, such as the Ontario Ministry of Environment, and Environment Canada, dwindled under government cutbacks during 1996, but many faculty have continued to find innovative grant and contract support for their research projects and graduate students.

In addition to Gary’s departure, the Department experienced another major personnel change in 1996 with the retirement of Professor David Elrick from the Soil Physics group. Fortunately, we were permitted to initiate a replacement search. The successful candidate was Dr Gary Parkin, who came to LRS in early 1997 from his post-doctoral position at the Department of Earth Sciences at the University of Waterloo. As the year ended we were also delighted to welcome Professor Beverley Hale, who transferred to our department from Horticulture. She specializes in the interactions of air and soil contaminants with plants. In addition, Professor Bev Kay returned to LRS after his well-deserved sabbatical leave.

As we leave 1996 and enter 1997 there will be some exciting opportunities associated with a major new partnership between the University of Guelph and the Research and Education divisions of OMAFRA.

The work of Terry McGonigle, Denise Brenner, Don Irvine, and Mark Evans in assembling the printed and electronic versions of this report is gratefully acknowledged.

Terry Gillespie
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Undergraduate Education

Land Resource Science continued to offer a strong undergraduate education program during 1996. The series of courses in Soil Science (87-series) underwent a major review and resequencing. These changes will enhance the flow of learning from our courses in the biological, chemical, and physical environments of soils, through to senior-level offerings in Soil Management and Soil Genesis. In response to growing popularity of the Earth and Atmosphere major in the B.Sc. (Environment) degree, senior courses in Physical Meteorology and Dynamic Meteorology were redesigned in 1996 to enhance their treatment of atmospheric monitoring and air quality issues. LRS, with its two majors in Earth and Atmosphere Science, and Natural Resources Management, is now the department with the largest number of students in the B.Sc.(Env) degree program.

Our suite of courses available through Distance Education was enhanced by the introduction of Land Stewardship (87-212) and Soil and Water Conservation (87-308) in a DE format. In both cases, the student response was strong. It is clear that students appreciate the DE option as a way to circumvent scheduling problems, or to pick up an extra course in the summer. The popularity of Distance Education has had the additional benefit of reducing student groups to more manageable sizes in the traditionally styled classes of these courses.

The second year cohort of students in the new B.Sc.(Agriculture) program arrived in 1996 to take our core course Resources and Agroecosystems. This is a new adventure for us, since Resources and Agroecosystems is our first full-year course. This course is built around a major challenge for each student to develop a resource assessment and land use plan for a site of their choice.

Finally, a new major in the B.Sc. program called "Earth Surface Science" was designed in collaboration with colleagues in Physical Geography. Students will be able to begin this major in the Fall semester of 1997.

Terry Gillespie
### Undergraduate Diploma and Degree Courses Offered During 1996

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James Cook  
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Nicole Donald  
Trevor Franklin  
Rick Gray  
Zoe Green  
Leveleen Grewal  
Marijan Grobbink  
Catharine Hoshel  
Susan Hunter  
Nancy Marcus  
Erik Nielsen  
Christina Pilz  
Shane Pulfer  
Tiffany Reid  
Donna-Mae Robinson  
Melanie Schiedel  
Kimberley Statham  
Tanya Stubbs  
Julie Swift  
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Sara Wallahah  
Sonja Wieland  
Darryl Boyd  
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EARTH SCIENCE

Kevin Buddell

EARTH & ATMOSPHERIC SCIENCE

Scott Bax  
Heather Brown  
Sylvie Cyr  
Jason Drogh  
Boua Sengdy  
Jenny Stanley  
Geoffrey Bell  
Jeffrey Krar

AGRONOMY

Kristen Callow  
Stephen Laeves  
Mario Longtin  
Christa Sanders  
Jeremy Tomlinson  
Angela Vogel  
Deborah Campbell  
Mark Brock  
Alan Morton  
Jim Nelson  
Bronwen Norton  
Tyler Papple  
Michael Sharpe  
Brian Switzer  
Cherie Thompson
Undergraduate in-course awards

W.H. Waddell Scholarship
Christa Sanders

Kae and Gordon Skinner Memorial Scholarship
Stephen Laevens

Bruce M. Cohoe Award
Christa Sanders

O.A.C. Centennial Scholarships
Shelley Peterson
Boua Sengdy

‘51 O.A.C. Leadership Award
Cheryl Somerville

Robert Keegan Memorial Scholarship
Kristen Callow
Christa Sanders
Graduate Education

The Department offers M.Sc. and Ph.D. programs in "Land and Atmospheric Science." The four fields of study comprise: (1) Atmospheric Science (2) Soil Science (3) Environmental Earth Science and (4) Land Resources Management. The cross-disciplinary nature of the new program, with its strengths in four fields, and emphasis on integration of these disciplines is unique in Canada.

Financial assistance in the form of scholarships, research assistantships, and teaching assistantships are available to qualified students. Research facilities available include well equipped laboratories for atmospheric science and agrometeorology, soil chemistry, soil mineralogy, soil physics, soil biology and biochemistry, and plant nutrition. Research instrumentation includes x-ray diffraction, mass spectrometry, liquid and gas chromatographs, and Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES), TDR analyzers, sonic anemometry, gas analyzers, data loggers, and agrometeorological field equipment. Greenhouses, growth chambers and 50 ha of field research plots are available for research projects. A graduate student has the opportunity to work with faculty in one of the many research projects underway in the Department. For further information contact the faculty members in the relevant area of interest or the Graduate Co-ordinator.

Graduate Co-ordinator for Land and Atmospheric Science, W. Chesworth
Graduate Students and Advisors
Winter Semester, 1997

ATMOSPHERIC SCIENCE

M.Sc. Students  Advisor  Ph.D. Students  Advisor
Barrett, Allison  T.J. Gillespie  Ausma, Sandra  T.J. Gillespie
Brown, Heather  C. Wagner-Riddle  Curren, Kristina  T.J. Gillespie
Furon, Adriana  C. Wagner-Riddle  Dias, Goretty  G.W. Thurtell
                      20                      20

SOIL SCIENCE

M.Sc. Students  Advisor  Ph.D. Students  Advisor
Cathcart, Jason  I.P. O’Halloran  Dagesse, Daryl  P.H. Groenevelt
Dadfar, Humaira  P.H. Groenevelt/ R.G. Kachanoski  Fallow, David  D.E. Elrick
Gingerich, Jon  M.J. Goss/ R.G. Kachanoski  Goorahoo, Dave  R.G. Kachanoski
Hosler, Kevin  R.P. Voroney  Hamlen, Cathy  R.G. Kachanoski
Hulshof, Bart  R. Protz  Lauzon, John  I.P. O’Halloran
Johannesson, Gundmundur  R.P. Voroney  Lobb, David  R.G. Kachanoski
King, Donald  P.H. Groenevelt/ G.J. Wall  McCabe, Don  R. Protz
Millman, David  M.J. Goss  Rashid, Tahir  R.P. Voroney
Peterson, Shelley  I.P. O’Halloran  Rodgers, James  N. Bunce
Quesnel, Francois  R.P. Voroney  Si, Bingcheng  R.G. Kachanoski
Roy, James  Wagner-Riddle  Uribe, Lidith  R.P. Voroney
Sengdy, Boua  L. Evans  Vandenbygaart, Bert  R. Protz
Land Resource Science

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<tr>
<th>Thurtell, Steve</th>
<th>R.G. Kachanoski/C. Wagner-Riddle</th>
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ENVIRONMENTAL EARTH SCIENCE

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<td>Bezner-Kerr, Rachel</td>
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LAND RESOURCES MANAGEMENT

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<td>Conboy, Mary Jane</td>
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RESOURCE MANAGEMENT

<table>
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<tr>
<th>Geoff Mann</th>
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<td>Lisa McLaughlin</td>
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<td>Steve Pennington</td>
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Graduate Degrees Defended in 1996

ATMOSPHERIC SCIENCE


ENVIRONMENTAL EARTH SCIENCE


LAND RESOURCE MANAGEMENT


SOIL SCIENCE

Land Resource Science


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<td>Soil and Water Chemistry</td>
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<td>52-640</td>
<td>Soil Nitrogen Fertility &amp; Crop Production</td>
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<td>52-642</td>
<td>Soil Productivity</td>
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<td>52-658</td>
<td>Special Topics in Soil Science</td>
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<td>52-676</td>
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<td>52-688</td>
<td>Special Topics in Land Resources Management</td>
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<td>22</td>
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Graduate Awards for Spring 1996, Fall 1996 and Winter 1997

CANADIAN BUREAU FOR INTERNATIONAL EDUCATION
Muftah Elgadi

CENTENNIAL GRADUATE SCHOLARSHIP
Shelley Peterson
Boua Sengdy

COMMONWEALTH SCHOLARSHIP
M. Tahir Rashid
Sudas Wanniarchchi

CSSS TRAVEL GRANT
Alain Plante

INTERNATIONAL DEVELOPMENT RESEARCH CENTRE
Lidieth Uribe

LATORNELL GRADUATE SCHOLARSHIP
Rachel Bezner-Kerr

LATORNELL TRAVEL GRANT
Alain Plante
Lori Rissling
Dan Fulton

MORWICK SCHOLARSHIP
David Fallow

NSERC
Gorety Dias - PGSB
Rachel Bezner-Kerr - PGSA
Shelley Peterson - PGSA
James Roy - PGSA
Pam Joosse - PGSA
Jackie Fraser - Industrial PG
Alain Plante - Industrial PG

ONTARIO GRADUATE SCHOLARSHIP
Sudas Wanniarchchi

PRETTY SCHOLARSHIP
John Lauzon

SODEN GRADUATE SCHOLARSHIP
Rachel Bezner-Kerr

UNIVERSITY GRADUATE SCHOLARSHIP (Departmental)
Rachel Bezner-Kerr
Shelley Peterson
Jon Warland
Boua Sengdy
Adrian Unc
Humaira Dadfar
Selma Magiotto
Sandra Ausma
Mary Jane Conboy

UNIVERSITY OF GUELPH GRADUATE FELLOWSHIP
Jinelle Webb
Mary Jane Conboy
Kristina Curren
Gorety Dias
Alain Plante

VISA SCHOLARSHIP
Zhuanfang Zhang
Mei Lin

WEIR MEMORIAL SCHOLARSHIP
Victoria Richards

WILLIAMS GRADUATE SCHOLARSHIP
Mary Jane Conboy
Jon Warland
Zhuanfang Zhang
Land Resource Science

Extension Highlights

I.P. O’Halloran

Extension activities within the Department of Land Resource Science continued to be a major avenue for the transfer of information and technology arising from research. In 1996, Land Resource Science staff were involved with: talks to farm and community groups; inservice training of OMAFRA and agri-business staff; forums; symposia; workshops; interviews and articles for the farm and popular press; publications of refereed papers and technical reports; and involvement on provincial expert committees.

Issues regarding the use of variable-rate technology has maintained the interest of producers and agri-businesses in the extension-research project in Site-Specific Crop Management. This project is a cooperative effort of OMAFRA staff, farmers, and LRS, and has now expanded to include 27 intensively studied farm sites, plus one additional site on the Elora Research Station. The principle objective is to evaluate the potential of varying crop management factors within fields for increased efficiency and decreased environmental risk. Although the primary focus has been on nitrogen management and corn yields, inter-relationships between yield patterns of different crops, elevation and soil properties (soil test phosphorus and potassium, pH, texture, organic matter content etc.) are also being examined. LRS staff associated with this project have also been involved in presenting workshops to assist farmers in the development of their own yield maps based on data they collect from their combine yield monitors and GPS units.

LRS staff remained active on provincial expert committees, such as the Ontario Soil, Water and Air Research and Services Committee (OSWARSC), and several of its subcommittees that have an important role in establishing provincial priorities for research and service. The department has been supportive of the establishment of an Ontario Certified Crop Advisor (CCA) Program. Industry feels that this program will improve the level of professionalism in the service they provide to farmers. Certification requires industry personnel to understand and be familiar with the latest agricultural research and technology. LRS staff have been involved on the initial steering committee, the Provincial Board, and the CCA exam committee. This past year saw the successful launch of this new program with the first writing of the provincial exam. Forty-six candidates wrote the exam in 1996 and 215 wrote the exam in February 1997. Dr. Ivan O’Halloran authored two sections of a study guide for the Ontario exam, a publication which was co-sponsored by Independent Study/OAC ACCESS of the University of Guelph and The Fertilizer Institute of Ontario.

Programs within the Centre for Land and Water Stewardship (CLWS) continue to evolve with nutrient management and water quality in agriculture emerging a major research theme. Other activities within the CLWS involve the development of several
key publications, such as “Greening the Land: Principles, Guidelines and Cases,” which aid landowners in making stewardship decisions, the initiation of a web page, and other outreach activities such as symposia. In particular, another very successful A.D. Latornell Conservation Symposium was held in 1996 with over 300 people in attendance. Further information on the activities of the CLWS and its various projects can been found in the section on the CLWS, and elsewhere in this Report.
Research Summary

The major change in our research activities during 1996 involved a new management system for the research contract from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), which is held by the University. The new structure has the OMAFRA contract divided into six programs:

1) Environment and Natural Resources Program
2) Plant Program
3) Animal Program
4) Food Program
5) Agri-Food Systems Program
6) Sustainable Rural Communities Program.

These programs replace the old structure, which was managed by the individual departments. The Program Leaders now work across departmental boundaries. We are making our major contribution to the Environment and Natural Resources Program under the leadership of Professor Michael Goss, who took over this responsibility from Gary Kachanoski. However, we also have some projects that are jointly funded with the other Programs.

The total value of grants and contracts supporting research in Land Resource Science in 1996 was about $3.0 million, with the department’s activities in the OMAFRA contract contributing about $950,000 over the same period.

Additional research and development revenue came from the following sponsors:
- Canadian International Development Agency
- Canadian International Development Research Centre
- Canadian Space Agency
- Carolinian Canada
- Dofasco Inc.
- Dufferin Aggregates
- Environment Canada
- Environmental Capacity Enhancement Project
- Federation of Ontario Naturalists
- Hudson Bay Mining and Smelting Co. Ltd.
- Human Resources Development Canada
- Indian Affairs and Northern Development
- Institute for Space and Terrestrial Sciences
- Ivey Foundation
- Laidlaw
- Lake Erie Steel Co., Ltd.
- National Rubber Co., Inc.
- Natural Resources Canada
- Natural Sciences and Engineering Research Council
- Nobel Pursuits Inc.
- Ontario Corn Producers Association
- Ontario Forestry Foundation
- Ontario Heritage Foundation
- OMAFRA
- OMAFRA Environmental Youth Corps Program
- Ontario Ministry of Environment and Energy (OMEE)
- OMEE Environmental Youth Corps Program
- Ontario Ministry of Northern Mines and Development Environmental Youth Corps Program
Summaries of our research projects during 1996 are presented on the following pages of this report. The reports are grouped as follows:
1. Land Characterization
2. Land Management
3. Land Stewardship
4. Environmental Geology

*Terry Gillespie*
Land Characterization
Zinc chemistry in waters and sediments adjacent to a zinc smelter in Flin Flon, Manitoba

Les Evans

Ross Lake is a small, relatively shallow lake adjacent to the Hudson Bay Mining and Smelting Company zinc smelter in Flin Flon, Manitoba. The concentrations of zinc in the waters of Ross Lake and its associated creek have risen to levels that are high enough to be of environmental concern. Six sampling locations were selected, five in Ross Lake and one in Ross Creek. Samples were taken at these sites on four occasions, so as to investigate the changes in the water chemistry from spring to fall.

The trace element that consistently occurred in the greatest amounts in the waters was zinc, with average contents ranging from 838 $\mu$g L$^{-1}$ in April, decreasing to 572 $\mu$g L$^{-1}$ in June, increasing slightly to 619 $\mu$g L$^{-1}$ in July, and falling again to 222 $\mu$g L$^{-1}$ in late September. The waters also contained large amounts of chloride and sulphate ions.

The speciation of zinc in the waters was investigated by adapting the computer program MICROQL to calculate the relative proportions of soluble zinc species. The input parameters for this model included the total concentration of zinc, [Zn]$_T$, chloride, [Cl]$_T$, sulphate, [SO$_4$]$_T$, dissolved total carbon, [C$_{org}$]$_T$, and dissolved organic carbon [C$_{org}$]$_T$. The predominant species in the waters was ZnSO$_4$, with other neutral species also being significant: ZnL$^+$, Zn(OH)$_2^-$, and ZnCO$_3^-$ (Fig. 1).

The speciation of zinc at the sediment-water interface is difficult to examine because of analytical problems with the analysis of hydrosulfide (HS$^-$) ions. Computer predictions estimated that almost 100% of the zinc will exist as the hydrosulfide complexes ZnHS$^+$ and Zn(HS)$_2$. These complexes are, however, very susceptible to oxidation to ZnSO$_4$ ions in the presence of even minute concentrations of oxygen.

![Fig. 1. Speciation of zinc in Ross Lake.](image)

A fractionation scheme was developed to extract different forms of zinc from the
sediments. These fractions consisted of an exchangeable fraction, an organically bound fraction, a fraction adsorbed to oxide minerals, and a fraction contained within oxide and hydroxide precipitates. Of the total zinc extracted in the fractionation scheme, only a very small proportion (<0.3%) was contained within the exchangeable fraction. The major portion extracted (51%) was in the organic fraction, with 37% specifically adsorbed to oxides. Aqua regia extracted large amounts of both zinc and sulphur, averaging 28,800 mg kg\(^{-1}\) for zinc and 40,700 mg kg\(^{-1}\) for sulphur. These results suggested that zinc sulphide is probably the major form of precipitated zinc in the sediments. A schematic diagram of the possible chemistry of zinc in the waters of Ross Lake is shown in Fig. 2.

Fig. 2. A schematic diagram of possible zinc transformations in Ross Lake sediments.
Chromium retention by Ontario soils

Les Evans

Chromium can occur in the two oxidation states Cr(VI) and Cr(III), with the former being highly toxic, and the latter being an essential element in the metabolism of animals. The reduction of Cr(VI) species to Cr(III) species in soils has been shown to be quite rapid, and to proceeds more rapidly in soils high in organic matter. Whereas the reduction of Cr(VI) ions in soils and sediments have been adequately shown, the corresponding oxidation of Cr(III) is still a matter of discussion. There is, however, evidence that oxides of Mn may be involved in the oxidation process. The work reported here discusses the effects of pH, electrolyte composition, and ionic strength on the retention of Cr(III) by Ontario soils, and it forms part of a much larger study on the soil chemistry of chromium.

A soil pH range from 3 to 9 was achieved by adding base (0.005 M LiOH to 0.05 M LiOH) to raise the pH of the soil, or by adding acid (0.004 M HClO₄ to 0.04 M HClO₄) to lower the pH. These acids and bases were added to centrifuge tubes that contained soil and one of the following: 0.01 M LiClO₄, 0.05 M LiClO₄, 0.005 M LiClO₄, 0.01 M Li₂SO₄, or 0.01 M LiCl. After shaking and equilibrating the suspensions for three days, 1 mL of 0.0135 M Cr(NO₃)₃ was added to obtain an initial metal concentration of 10⁻³ M. The solutions were then shaken for another day, centrifuged at 10,000 rpm for 30 minutes, and filtered through 0.22 μm membrane filters. The pH values of the suspensions were then measured, and the Cr(III) remaining in solution was analysed by atomic absorption spectroscopy.

Results on the retention of Cr(III) by an Ontario soil (Welland series; Humic Gleysol) show that the metal is strongly retained over a wide range of pH, but that the extent of retention decreases at very acidic and alkaline pHs (Fig. 1). Cr(III) in solution hydrolyses readily to form a series of hydroxo-complexes: CrOH₂⁺, Cr(OH)⁺, Cr(OH)₂⁻, and Cr(OH)₃⁻. These complexes are probably responsible for the decrease adsorption at higher pH values. The retention also appears to be independent of the ionic strength of the background electrolyte, suggesting that the retention involves the formation of inner sphere complexes with surface mineral and humic complexant sites.

The extent of retention of metallic ions by soils can be modified by the presence of soluble complexant ligands in solution. In this study, the role of both chloride and sulphate ions was examined because Cr(III) forms complexes with both ions, forming CrCl₂⁺ and CrSO₄²⁻ respectively.

Results showed that chloride ions had only a small or negligible effect on metal retention, whereas sulphate ions decreased adsorption at acidic pH’s (Fig. 2). This outcome is to be expected, because sulphate ions form stronger complexes with Cr(III) than with chloride ions.
**Land Characterization**

Fig. 1. Effect of pH and ionic strength of Cr(III) retention by the Welland soil.

Fig. 2. Effect of electrolyte composition of Cr(III) retention by the Welland soil.
Land Characterization

The utility of aggregate processing by-products in the rehabilitation of dolomite quarries

J. Fraser and R.A. McBride

A study has been completed which investigated the use of large quantities of silt-sized material, a by-product of dolomite quarrying, for site rehabilitation purposes. The Milton Quarry (operated by Dufferin Aggregates) is located on the Niagara Escarpment just north of the Town of Milton. The quarry is still in operation, but Dufferin Aggregates has initiated its rehabilitation plans in the excavated southeastern end. The rehabilitation plan has the quarry being transformed into a reservoir once extraction is complete and the quarry is decommissioned.

Since 1991, Dufferin Aggregates has been using a by-product of the aggregate washing operations, dredged from sedimentation ponds on site, to build up embankments along the quarry walls. This silt loam textured material is being emplaced by “ramping” the material up the embankment and compacting it to some degree. Because the quarry is located on the Niagara Escarpment and adjacent to the Bruce Trail, creating wildlife habitat is an important rehabilitation objective. The main objectives of this study were 1) to determine the suitability of the pond fines as a material for embankment formation, with the emphasis on shear strength and its effect on slope stability, and 2) to predict the effect that the proposed water table would have on this stability.

The embankment was first surveyed using an infra-red theodolite to determine existing slope gradients. Bore holes were drilled along the embankment, and dry bulk density and soil water content profiles were measured using a CPN density-moisture gauge. The standard Proctor density test was conducted on the soil material from four sites with notably different particle-size distributions. Using a direct shear box apparatus, shear strength testing of the material from these same four sites was completed using several initial soil water content and dry bulk density treatments. This was followed up with drop-cone penetration testing in the lab to allow the strength characteristics of this material to be assessed over an even wider range of initial conditions. The measured shear strength parameters were used in a slope stability computer model (based on the simplified Bishop’s method) to determine the stability of the present embankment with no water table, and then with a saturated (phreatic) zone.

When unsaturated, the shear strength parameters of the pond fines were found to be adequate to maintain a stable slope. The material had no measurable cohesion when saturated, and only slight cohesion at low soil water tensions. However, the angle of shearing resistance was adequate to maintain the embankment’s stability within the range of slope angles found on the embankment. Material with higher clay-sized particle content and lower sand content exhibited greater shear strength.
Factors of safety were calculated using the slope stability computer model for scenarios involving the presence or absence of a water table, as well as a range of slope angles, dry bulk densities and shear strength parameters. These factors of safety were found to increase with increasing shear strength and decreasing slope angle. For the scenarios including a phreatic zone, factors of safety were lower than those calculated for the unsaturated case. This indicates that submergence of the lower portion of the embankment does decrease its stability. However, estimates for the factor of safety values for the scenarios tested were still greater than the acceptable minimum of 1.2 for earthen embankments.

Fig. 1. Photograph of an embankment composed of pond fines at the Milton quarry.
Land Characterization

Determination of the hydraulic properties of compacted clay soils using early-time analyses

Brian P. Odell, D.E. Elrick, and P.H. Groenevelt

Clay liners are frequently employed at waste disposal sites as a means of minimizing the potential for groundwater contamination. It is commonly thought that if the hydraulic conductivity \( K_\theta \) of the clay is low and there are no structural defects, then the liner will provide an adequate barrier between the waste and the underlying hydrogeologic domain. Guidelines for clay liners commonly specify that in order to minimize the rate of advective contaminant transport, they should have a \( K_\theta \) less than \( 10^{-9} \) m s\(^{-1}\).

The estimation of hydraulic parameters from the traditional measurement of steady-state infiltration into slowly permeable media can take several months to complete. A new solution for sequential constant-head falling-head early-time infiltration has been developed and verified. This solution can be used for inverse parameter estimation procedures to obtain the hydraulic conductivity and matric flux potential of the clay liners underlying municipal landfills, after only a few hours of infiltration measurement. The expeditious determination of these hydraulic parameters should allow for improved compliance evaluation of landfill liners, thereby reducing the risk of leachate breakthrough.

Laboratory studies were conducted on six compacted clay cores, to compare early-time constant-head and falling-head derived flow parameters with their corresponding steady-state values. A pressure chamber equipped with a small Mariotte bottle made it possible to greatly increase the applied pressure head on these cores while still supplying a constant-head source of water. This increased pressure allowed for the measurement of steady-state hydraulic conductivity for each core after only a matter of days. Good agreement between all corresponding data was apparent, with \( K_s \) estimates averaging between \( 2 \times 10^{-10} \) m s\(^{-1}\) and \( 6 \times 10^{-10} \) m s\(^{-1}\). The sample means show the early-time constant-head \( K_\theta \) values to be 60% of the respective steady-state values, and the falling-head estimates were, on average, 75% of these values. Differences noted during these procedures may be due to swelling of the clay cores, the differences in the infiltrated soil volumes measured, or both.

We conclude that the early-time analysis of flow data offers a promising procedure for obtaining good estimates of the saturated \( (K_\theta) \) and unsaturated \( (\phi_m) \) properties of highly compacted media in a relatively short period of time, and without the need for extensive instrumentation or analytical methodology.
Fig. 1. *In situ* installation of a 30 cm pressure infiltrometer ring at the Halton Region Municipal landfill, for early-time flow parameter analyses.
Land Characterization

Water movement from a wastewater disposal trench

Zhuanfang Zhang, R. Gary Kachanoski, Bingcheng Si, Gary W. Parkin, and Peter von Bertoldi

Disposal of treated wastewater is an important part of alternative waste-disposal systems. The loading rate of a system is dependent on a number of factors, but primarily it is determined by the hydraulic properties of the soil, and the design characteristics. The theory for the three-dimensional movement of water into unsaturated soil is well understood, but it has not been fully applied to the problem of wastewater disposal. The objective of this project is to model and measure the three-dimensional unsaturated water flow from surface water sources, and to apply this theory to the practical problem of disposal of wastewater.

Fig. 1 is a contour of steady-state soil water content in the x-z plane (horizontal distance vs. depth) for water flow from a shallow trench. We can see that the highest soil water content is in the region that is closest to the source. The farther away from the source, the lower the soil water content. This means water moves both vertically and horizontally away from the trench.

A field experiment was conducted at CFB Borden on a sandy soil. A temporary greenhouse was built over the 3 m by 9 m experimental area to provide a shield from natural rainfall. A moving nozzle system in the greenhouse was used to provide a constant flux of water to the trench. Fifty sets of multi-purpose TDR (Time Domain Reflectometry) probes, one rod of each pair being hollow and with a stainless porous tip, were installed at a 15 cm spacing. Each set had probes of 20, 40, 60, and 80 cm in depth, located at a 10 cm spacing. A steel trough was made to direct water to a specific area, which was 4 cm wide and 8.8 m in length (Fig. 2). The overall length of the monitored area was 7.5 m.

About 40 hours after applying a constant flux of water, the steady-state water storage and pressure head were measured. Following the conclusion of this phase, the water in the constant flux nozzle system was replaced by 0.1% KCl, and the movement of the solute was determined using TDR to measure the changes in bulk electrical conductivity. The experiment was carried out using three different application rates.

From the experimental data, we can accurately estimate soil hydraulic properties using appropriate analytical solutions. The estimated saturated hydraulic conductivity of Borden sand is $2.8 \times 10^{-5}$ m s$^{-1}$ (10.1 cm hr$^{-1}$), and the Gardner $\alpha$ parameter is 12 m$^{-1}$. The soil hydraulic parameters are used to predict the maximum amount of water that can be applied to the trench without ponding of water.
Fig. 1. The contour of soil water content in the x-z plane.

Fig. 2. The moving nozzle system and steel trough used in the field experiment.
Land Characterization

Tropospheric ozone studies

K. Curren, A. Barrett, and T. Gillespie

Southern Ontario and the Lower Fraser Valley (LFV) are frequently afflicted by severe episodes of tropospheric ozone pollution during the summer months. Tropospheric ozone is a major component of urban smog, and it is injurious to the health of people, crops, and natural vegetation.

Tropospheric ozone is created by a series of reactions that involve the oxidation of volatile organic compounds (VOCs) in the presence of nitrogen oxides (NOx) and sunlight. Anthropogenic VOCs are emitted by automobiles, refineries, and industrial operations, while anthropogenic NOx are produced by all combustion processes. Recently, it has become apparent that certain crops and trees emit significant quantities of biogenic VOCs. Some of these natural compounds (e.g. isoprene) are very reactive in the troposphere, and they may significantly affect regional atmospheric chemistry and the production of ozone.

Isoprene fluxes over crops in the LFV were measured during the summers of 1994 and 1995 using the micrometeorological gradient method. The results of these studies indicated that common crops and natural vegetation such as blueberries, cranberries, blackberries, potatoes, pasture, cabbage, dandelions, Japanese knotweed, and hops were insignificant emitters of isoprene.

An extensive set of monitoring data for volatile organic hydrocarbons, which was collected by the Pollution Measurement Division of the Environmental Protection Service, Environment Canada, was analyzed to examine the seasonal and diurnal profiles of ambient isoprene. During the summer months, isoprene concentrations showed a positive correlation with temperature, indicating that the compound was derived at least partly from biogenic sources. However, significant concentrations of isoprene were measured on cool days when biogenic emissions would be negligible. This result suggests that an anthropogenic source of isoprene exists in the LFV. Winter concentrations of isoprene were not only significant, but often higher than those observed during summer months, yet they were not correlated with temperature. Since plants are dormant during the winter months, the isoprene observed during the winter must be from anthropogenic sources. A positive correlation between isoprene and selected VOCs that are known to be emitted from anthropogenic sources supports the hypothesis that isoprene is emitted by both biogenic and anthropogenic sources.

Emission of VOCs by plants is known to be influenced by light levels and leaf temperatures. Functions already exist to describe the temperature dependence of monoterpenes emissions, and the light and temperature dependence of isoprene emissions, regardless of plant species. In the Southern Ontario study, field measurements of VOC emissions were made in the University of Guelph Arboretum in the summer of 1996 for several tree species commonly used in urban landscaping in Southern Ontario. In order to determine the emission rates of monoterpenes and isoprene under standardized light and temperature
conditions, these measurements were normalized using appropriate functions. For each of thirteen species, leaves were isolated in a leaf cuvette for the purpose of obtaining air samples that were analysed for concentrations of isoprene, monoterpenes, and other VOCs. A rating system was developed for these species, and others studied in the literature, to describe their ground-level ozone forming potential, based on their measured isoprene and monoterpane emissions, and on published reaction rates for these compounds. Of the species studied, willow was the only high isoprene emitter (51.1 μg C g⁻¹ h⁻¹). Silver maple and Austrian pine were found to be moderate monoterpane emitters, with 6.5 μg C g⁻¹ h⁻¹ and 4.5 mg C g⁻¹ h⁻¹ for total monoterpane emissions, respectively. Willow, as a high emitter, was used as the basis for the ozone forming potential (OFP) rating. Additional Southern Ontario species found in the literature were included in the rating system, along with some trees from other parts of North America.
Land Characterization

Monitoring seasonal changes within subarctic peatlands using RADARSAT data

M. Murphy, I.P. Martini, and R. Protz

This study is being accomplished using imagery from the Canadian earth observation radar satellite RADARSAT, which was launched in 1995. Radar has a great deal of potential in northern countries like Canada, and we are taking advantage of this opportunity to determine what role it can play. Radar has several characteristics that make it useful. Radar signals can penetrate through most kinds of atmospheric phenomena, such as rain, fog, and cloud. Active radar sensors, such as found on RADARSAT, provide their own source of illumination, which enables them to collect images during hours of darkness. Both of these characteristics benefit northern countries, such as Canada, where these types of conditions prevail for much of the year.

There are two objectives of this study. First, we want to use radar to study the characteristics of the ice cover on the Moose River, which flows into the south-west corner of James Bay. This work includes determining if there are any ice features visible on the imagery that might indicate when the breakup of the ice cover will occur. Since breakup can be hazardous to people due to ice jamming and flooding, a prediction system can help to give an advanced warning of these events.

The second objective is to determine the effectiveness of RADARSAT data for detecting and monitoring seasonal changes in ice, snow, and water within the peatlands of the south-western portion of the Hudson Bay Lowland. This is an area dominated by fens, bogs and coastal marshes that are highly sensitive to environmental changes. Information such as this is useful for wildlife management purposes, and for monitoring long-range environmental changes, such as global climate change or any human impact on the peatlands.

Image collection occurred at approximately 3 to 7 day intervals during the spring of 1996 when the peatlands and the Moose River were undergoing rapid changes due to melting of the snow and ice. During the summer and fall of 1996, data collection was slowed to the taking of images at intervals of approximately 1 to 2 months.

The images show distinct changes with season. Summer peatland scenes show fairly homogenous shades of grey with very little spatial change. However, winter and spring scenes show quite the opposite, with a high degree of variability, meaning that some areas show very bright radar returns while other areas are very dark. Distinct patterns of these bright and dark areas are evident. Fens have been found to produce consistently brighter radar returns than bogs. Within the fens, drainage patterns are clearly visible because of slightly darker returns than surrounding areas. Within both fens and bogs other patterns are evident with areas of anomalously bright or dark radar returns.

The RADARSAT signal cannot detect dry snow, but it detects wet snow and ice because the signal is affected to a large
degree by the amount of moisture, and by the surface geometry (i.e. its smoothness or roughness). The patterns of bright and dark pixels seen within the imagery are a result of the interactions of moisture and surface roughness that both cause scattering, reflecting, or absorbing of the radar signal, and so they need to be interpreted accordingly.

Radarsat Standard Beam Mode - Moose River and Hannah Bay
May 8, 1996
Land Management
Crop response to nitrogen in manures with widely different characteristics

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⁵Environmental Soil Services, Arkell, Ontario

A three-year field and laboratory study was undertaken from 1994 to 1997 to obtain a better understanding of the availability of N in manures that vary substantially in several important characteristics.

The manure characteristics that were studied included: animal species, ammoniacal-N and total-N contents, and kind of bedding. A major objective was to determine how these characteristics affect the availability of manure N, especially during the early season, in synchrony with corn crop N requirement. Also studied were fall vs spring applications of manures, the influence of soil acidity on N availability with different manures, and the effects of the concentration and degradability of protein in the diet of dairy cows on the availability of manure N.

The research was conducted in five phases as follows:
1) corn crop response to fall- and spring-applied manure N on the farms on which the manures were produced;
2) corn crop response at the Elora Research Station to fall- and spring-applied manure N, comparing several different manures, rates of manure N, and bedding additions;
3) corn crop response to residual N from manure and urea applied the previous year;
4) a laboratory study to determine the effects of soil acidity and liming on N transformations with two manures;
5) a laboratory study to determine the characteristics and availability of N in urine and faeces of dairy cows that were fed diets varying in protein content and degradability.

The manures varied widely in ammoniacal N content, and included liquid dairy cattle (LC), solid beef cattle (SC), solid broiler-chicken with wood-shavings bedding (Pw), solid broiler-chicken with straw bedding (Ps), and liquid swine (LS) manures. These manures represent the range of manures commonly produced on livestock farms in Ontario. Different rates of the manures were compared with different rates of urea in the field experiments.

It was anticipated that manures with relatively low ammoniacal N content and high C/N ratios (e.g. SC manure) would result in a depression in available N early in the growing season. This depression was not clearly evident. Rather, there was little or no increase in available N during this period. With LS manure, which has a relatively high ammoniacal N content, release of available N
occurred well in advance of the major period of N uptake by the corn crop. Yields were related positively to the sum of soil mineral-N and plant-N in the early season (Fig. 1).

Soil Mineral-N + Shoot-N at 23 Days After Planting (kg ha⁻¹)

Fig. 1. Grain yield of corn at the 1995 fall harvest in the experiment at the Elora Research Station, in relation to the sum of soil mineral-N in the top 30 cm, and the shoot-N in the crop, as determined at 23 days after planting. Soil mineral-N is the sum of NO₃-N and NH₄-N extracted from soil by 2 M KCl. Values are means; n=4. The treatment codes are as follows:

- (1) Fall-plowed Control
- (2) Spring-plowed Control
- (3) Urea50
- (4) Urea100
- (5) Urea150
- (6) LC100
- (7) LC200
- (8) LC300
- (9) LS100
- (10) LS200
- (11) LS300
- (12) Ps100
- (13) Ps200
- (14) Ps300
- (15) Pw100
- (16) Pw200
- (17) Pw300
- (18) SC100
- (19) SC200
- (20) SC300
- (21) LC200+S
- (22) LC200+W
- (23) SC200+S
- (24) SC200+W
- (25) LC200F
- (26) LC200F+S
- (27) LC200F+W
- (28) SC200F
- (29) SC200F+S
- (30) SC200F+W

†50, 100, 150, 200, and 300 indicate kg N ha⁻¹
‡F=fall, and +S and +W indicate additions of straw and wood bedding, respectively.
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The ammoniacal N content of the manures was the major determinant of N availability. The relative importance of the organic N fraction in manures could not be ascertained. It was observed that extraction of soil inorganic N (nitrate and ammonium) did not account for ammoniacal N applied in manures or urea—even within a few days following application in the spring. In some cases, as little as 30 to 40 percent recovery occurred at this time. This apparent disappearance of N was probably due to ammonia volatilization, fixation by clay, and immobilization by soil microbes.

The rates of release of this N during the first two months of the growing season were inconsistent from year to year. Where substantial available N was released, it was generally related to ammoniacal N content of the manure. These differences in inorganic N recoveries coupled with variable release rates from year to year made it difficult to estimate the contribution of available N from the organic N fraction of manures, and difficult to assess the manure N mineralization-immobilization processes.

In spite of difficulties in comparing different manures, monitoring of soil inorganic N and plant N uptake, along with a $^{15}$N study, revealed that significant net immobilization of inorganic N occurred with the SC manure during the early part of the growing season. Furthermore, corn grain yields and N composition of mature plants suggested that there was a substantial release of N with the SC manure during the latter part of the growing season that was not evident with the other manures.

There was no clear indication that application of SC or poultry manure in the fall reduced corn crop response significantly compared with spring-applied manure. However, response to fall-applied swine manure N was decidedly lower than spring-applied manure in two field experiments. Thus, it appears that the efficacy of fall-applied manures may depend on manure N characteristics, such as ammoniacal N content.

The kind of bedding (woodshavings vs straw) in the Pw and Ps manures, or the additions of these beddings to SC and LC manures, appeared to have relatively little influence on manure N availability.

The rate of nitrification (ammonium to nitrate) was slower in acid soils but increased to a near normal rate when these soils were limed. Other than the nitrification rate, soil acidity did not appear to exert any significant effect on soil N transformations.

The feeding of a diet with high protein content and high protein degradability to dairy cattle resulted in a greater portion of excreted N present in the urine, with little change in the faeces N content. When urine or faeces were incubated in soil, differences in diet were not evident. About three-quarters of the urine N was present as ammonium, and it was eventually converted to nitrate in soil, whereas only 3-4 percent of faeces N was present as inorganic N. There was evidence that the concentrations of inorganic N with the faeces treatment actually decreased during the incubation period. This observed decrease indicated that the urine fraction of cattle manure contains most of the immediately available N for a crop.

It is anticipated that the findings of this study will be used to revise the manure application recommendations for crop production.
Improving the quality of cattle manures in Zimbabwe

P. van Straaten, H. Murwira, and T.R.C. Fernandes

The Environmental Capacity Enhancement Project financed by the Canadian International Development Agency supports two manure improvement projects in Zimbabwe. These projects are collaborative efforts of researchers from LRS, the Department of Research and Specialist Services in Zimbabwe, and the University of Zimbabwe.

The manure improvement projects address the need for soil amendments and fertilizers to increase the productivity of degraded soils in Zimbabwe. Smallholder farmers have practised soil maintenance and soil improvement techniques with local resources for many decades. Our work with Zimbabwean smallholder farmers builds on their knowledge and experience, and is a response to local requests to upgrade their traditional soil amendment, cattle manure. This “fertilizer of choice” bears the least risk for crop failure. However, the quality of the cattle manure used by most farmers in communal areas is poor, especially with regards to nitrogen and phosphorus. Because of the poor quality of soils, the vegetation growing on them is low in nutrients. Animals browsing nutrient-poor vegetation in turn produce nutrient-poor manure. These projects follow two strategies: nutrient conservation, specifically nitrogen, and nutrient enrichment, through the addition of phosphates.

The first strategy, nutrient conservation, focuses on the reduction of nitrogen losses from cattle manures. The quality of cattle manures for land application is substantially reduced due to nitrogen losses by volatilization and leaching, both in livestock enclosures and during field application. Gaseous ammonia (NH₃) is produced by the breakdown of urea in excreted urine, and by the drying of manures containing ammonium ions. The rate of NH₃ release is primarily a function of the concentration of NH₃ in the manure, the concentration of NH₃ in the surrounding air, and the rate of exchange across the liquid-gas interface. The equilibrium between gaseous NH₃ and ammonium ions is also influenced by pH and temperature.

Interventions to reduce NH₃ losses range from better urine management to the use of ammonium-capturing minerals, such as vermiculite fines, which are a waste product of local vermiculite mining. Reduction of NH₃ losses can also be achieved by decreasing the pH through the addition of acidifying materials, such as locally available single superphosphates (SSP) or phosphogypsum, which is a low pH waste material from the phosphate fertilizer processing plant.

The second strategy to enhance the quality of local cattle manures for land application is to increase their nutrient pool, such as by the addition of locally available phosphates. The traditional way of manure management in Zimbabwe is heaping and composting prior to land application. The approach that we are currently testing is to enrich the manure with locally available rock phosphates prior to composting. This phosphate composting technique builds on
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Table 1. Composition of manures taken from cattle pens.

<table>
<thead>
<tr>
<th>Summary Statistic</th>
<th>Total N %</th>
<th>P ppm</th>
<th>K ppm</th>
<th>Ca ppm</th>
<th>Mg ppm</th>
<th>Zn ppm</th>
<th>Cu ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1.11</td>
<td>2570</td>
<td>13500</td>
<td>8650</td>
<td>3090</td>
<td>43.8</td>
<td>11.3</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.38</td>
<td>1770</td>
<td>6820</td>
<td>4150</td>
<td>1740</td>
<td>23.0</td>
<td>8.9</td>
</tr>
</tbody>
</table>

Table 2. Chemical analyses of 17 untreated cattle urine samples from Buhera District, collected in April and May, 1996.

<table>
<thead>
<tr>
<th>Summary Statistic</th>
<th>Total N %</th>
<th>K %</th>
<th>NH₄-N mg kg⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.464</td>
<td>1.38</td>
<td>1470</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.104</td>
<td>0.39</td>
<td>430</td>
</tr>
</tbody>
</table>

and improves traditional manure handling techniques. SSP is also being tested for its effectiveness to fortify cattle manures.

During the first year of the project, an inventory of manure storage and handling systems revealed that the quantity of manures voided are in the range of 10-12 kg wet faeces day⁻¹, and 4-6 litre urine day⁻¹, for a cow of 150-200 kg live weight. The composition of cattle manures taken directly from the cattle pens (Table 1) varied widely. Higher than average total nitrogen values were analysed from moist manure samples and urine patches. The analyses of 17 urine samples are also presented (Table 2).

In most areas, the quality of manures was poor. However, in an area close to hills made up of alkaline rocks, the manure quality was markedly better. Here, the P, Ca, and Mg concentrations of manures were up to two times higher than from manures where cattle foraged on vegetation growing on nutrient-poor sandy soils derived from granites. The manure quality seems to be related to nutrient status of cattle forage which, in turn, is related to soils and parent materials.

Generally, manure samples from communal smallholder farms were lower in nutrient concentrations than manures from commercial farming operations. Manures and faeces collected from commercial dairy farms were higher in total N and P, and they were particularly high in Zn and Cu.

Samples taken from selected fields shortly before incorporation into the soils were up to 30 % lower in N than samples collected directly from the cattle pen. This means that up to 30 % of the N is lost during excavating, composting, and transporting the
manures to the field.

A clear increase of N retention and phosphorus concentrations of manures was achieved by the addition of acidifying local phosphate products. This practice, which was successfully applied in different manure handling systems in Europe and North America in the middle of this century, will be adapted to the manure storage and handling system in Zimbabwe.

Discussions with local farmers in regard to practical modifications of cattle pens for increased urine retention and nutrient conservation revolve around a number of ideas. 1) Designing pens with the cattle resting places being aligned in a row, so as to provide specific sites for faeces and urine deposition, and where inorganic amendments could be added. 2) Construction of a furrow and a pit outside the cattle pen for urine collection. 3) Construction of clay-lined floors for the prevention of leaching, and the reduction of the mixing of manure with the underlying sands. 4) Building rooves over cattle pens. 5) Use of stalk mulching to reduce manure dying. 6) Addition of locally available acidifying phosphates to liquid manure, in order to reduce NH₃ losses and increase manure P concentrations. As a result of these practical measures it is expected that the quality of the cattle manures will be enhanced, and the risks of soil degradation reduced.

The intent of using locally available organic and inorganic resources is part of an overall strategy to find technical solutions to make more efficient, and more ecologically balanced use of Southern Africa’s natural resources, in cooperation with, and for, the benefit of the rural poor.

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**Zimbabwe rock phosphate project goes into Phase Two**

P. van Straaten and T.R.C. Ferrandes

The rock phosphate project reported in earlier LRS annual reports is now moving ahead into Phase Two. The general focus of the Zimbabwe-Canada agrogeology project is to develop local materials and methods to improve soil fertility using indigenous minerals and organic resources. This project addresses problems related to the deteriorating situation of declining soil productivity and soil degradation in Zimbabwe’s over-populated so-called “communal areas.”

Based on requests made by farmers from communal areas, the first phase of the project funded by the International Development Research Centre tried to develop an inexpensive indigenous phosphate fertilizer. During that first phase, the team of researchers from the Institute of Mining Research at the University of Zimbabwe, and from LRS, developed agglomerated phosphate fertilizer blends using the locally produced Dorowa rock phosphates (DRPs) with acidifying fertilizers. On a laboratory scale, the project produced two types of alternative phosphate fertilizers. In the first method, a rolls compactor was used to prepare compacted phosphate blends (CPBs)
of mixtures of DRP and triple superphosphate (TSP) in DRP:TSP ratios of 80:20, 70:30, 60:40, and 50:50. It was found that compacted blends with a high mechanical strength, and a high free-acid content of up to 16 %, could be produced by blending fresh TSP with using fines from the phosphate mine at Dorowa, which were hitherto regarded as waste.

The second method of agglomeration used an inclined rotating-disc pelletizer to synthesize pelletized phosphate blends (PPBs). Through the rotating movement, and the addition of water, the materials are thoroughly mixed and agglomerated to form pellets that have a good strength and can be transported and applied with ease. A similar range of blends of DRP and TSP was used to prepare pellets of a size suitable for use as fertilizers. Trials were conducted using phosphate dust, a waste product from the drying operation of the phosphate industry, and locally available binders, such as residues from beer brewing operations, waste citrus juice, and water. All of the materials used as binders proved to be successful. It was established that agglomeration using a rotating-disc pelletizer is an economical, relatively uncomplicated, and effective method of producing granular particles of the blended powders.

Pelletized products were examined by mineralogical and chemical methods, and then tested for their agronomic effectiveness in greenhouse and field trial. Examination of the agglomerated products with the aid of an electron microprobe, and a scanning electron microscope equipped with an energy dispersive X-ray analyser, confirmed the presence of three solid phosphate phases: monocalcium phosphate (MCP) Ca(H₂PO₄)₂H₂O, dicalcium phosphate (DCP, CaHPO₄), and the residual apatite. One new phosphate phase and gypsum were also detected in the agglomerated material. These products result from the reaction of DRP and TSP. Finding these phases in the agglomerated material supports the hypothesis that hydrolysis-induced in situ acidulation of the apatite occurs on a laboratory scale.

The agronomic effectiveness of the agglomerated blends was tested in pot trials in greenhouses, in field trials at the Marondera Research Station, and on the granitic soils of farmers fields in the rural areas. Greenhouse trials were conducted using both CPB and PPB at application rates of 0, 20, 60, 100, 200, and 500 kg P₂O₅ ha⁻¹. In each case there was a basal application of fertilizer to supply nitrogen, potassium, and micronutrients. The test crop was maize, which was harvested after six weeks. A second crop of maize was grown in the same pots after the application of additional basal fertilizers but no additional phosphate, to test for any residual effects of the agglomerated products.

The dry matter yields of pots containing the agglomerated blends showed a significant improvement compared to those without the blends (Table 1). The highest yield was obtained with a PPB blend of 60:40 (DRP:TSP). The pot trials on the residual materials revealed that PPB performed better than CPB. Enhanced crop yields were also obtained with pigeon pea and winter wheat, the yield increasing as the ratio of DRP:TSP in the blends decreased.
Table 1. Effect of P-fertilizer material on dry matter yield, averaged across soils and across crops, and in ranked order, and their relative agronomic effectiveness.

<table>
<thead>
<tr>
<th>Ratio of TSP:DRP†</th>
<th>Fertilizer Category</th>
<th>Dry Matter Yield (g pot⁻¹)</th>
<th>Relative Agronomic Effectiveness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100:0</td>
<td>TSP</td>
<td>9.88 a‡</td>
<td>-</td>
</tr>
<tr>
<td>50:50</td>
<td>CPB</td>
<td>9.05 b</td>
<td>88.3</td>
</tr>
<tr>
<td></td>
<td>PPB</td>
<td>8.86 b</td>
<td>85.6</td>
</tr>
<tr>
<td>40:60</td>
<td>CPB</td>
<td>8.72 b</td>
<td>83.7</td>
</tr>
<tr>
<td></td>
<td>PPB</td>
<td>8.63 bc</td>
<td>82.4</td>
</tr>
<tr>
<td>30:70</td>
<td>CPB</td>
<td>8.63 bc</td>
<td>80.9</td>
</tr>
<tr>
<td></td>
<td>PPB</td>
<td>8.52 bc</td>
<td>74.1</td>
</tr>
<tr>
<td>20:80</td>
<td>CPB</td>
<td>8.04 c</td>
<td>61.1</td>
</tr>
<tr>
<td></td>
<td>PPB</td>
<td>7.12 d</td>
<td>36.9</td>
</tr>
<tr>
<td>0:100</td>
<td>DRP</td>
<td>5.40 e</td>
<td>-</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>2.78 f</td>
<td>-</td>
</tr>
</tbody>
</table>

†Abbreviations: TSP = triple superphosphate; DRP = Dorowa Rock Phosphate; CPB = compacted phosphate blend; PPB = pelletized phosphate blend
‡Means with the same letter are not significantly different at the 0.05 probability level.

The data obtained from greenhouse and field trials indicate improved yields upon application of the new agglomerated products to the three test crops: maize, pigeon pea, and winter wheat. Further agronomic and economic data are needed to evaluate the agronomic effectiveness of the fertilizer materials in the short and long term. These data, to be collected over a number of years, will form the basis of a cost-benefit analysis.

The thrust of future work will be to optimise the production of PPBs using rotating disc pelletisers for local small-scale and medium-scale enterprises in rural areas of the Buhera District. The disc pelletiser technology is uncomplicated, and so it can be adapted to various scales of production, requiring only the following: electricity supplies, and locally produced rotating discs and screens.

This technology, together with indigenous resources, will be developed by small- to medium-scale enterprises at the district and village level.
Land Management

Malthus, ghost acreage, ecological footprints, and the unsustainability of agriculture

Ward Chesworth

Thomas Malthus, some 200 years ago, argued that the geometric increase in population would ultimately outstrip the arithmetic increase in food supply, and that by the second half of the nineteenth century, famine would be endemic amongst the world’s people. Since it did not turn out that way, conservative economists claim that Malthus was wrong. A better case can be made for believing him to be merely premature. Last year for example, the FAO reported that bad harvests in Africa, Western Europe, and Australia put the earth within a few weeks of a general famine. According to Bill Mollison, the Australian inventor of “permaculture,” 1995 may have been the first year in human history in which the whole world was threatened by famine. Even so, we have still managed to keep ahead of Malthusian disaster, so how has it been done?

Optimists point to the triumphs of scientific agriculture as the reason. Fertilisers have been elaborated, pesticides developed, special varieties of plant and animal been bred—all giving a boost to productivity, and keeping Malthus at least at arm’s length. As hope for the future, genetic engineering is claimed by some to be the ultimate technological fix, and the way to beat starvation once and for all.

A combination of history, thermodynamics and ecology yields a darker view. First, consider the history. A major factor in the great increases in productivity during the nineteenth and twentieth centuries has been the extension of arable agriculture into new areas (the so-called virgin soils). The prairies of Canada and the U.S.A. are perhaps the most spectacular example of this. In other words, the European “discovery” of the New World, a one-time-only event, is one of the reasons we are still eating well.

Regarding thermodynamics, it is clear to everyone that modern agriculture is highly energy intensive. Not only is energy required directly in the physical activity of the farmer, but a complex infrastructure of farm machinery, drainage and irrigation systems, as well as transport, distribution and marketing networks, which are all absolutely necessary in feeding our present population, increases the energy demand tenfold. And the energy we are talking about here is in addition to the “free” energy that the growing plant exploits from the sun directly. What keeps modern agriculture working is fossil sunlight, the oil and gas that represents an energy capital we inherit from geologically earlier biospheres. Yet again, a one-time-only event, namely the discovery and exploitation of these non-renewable deposits, is helping us keep ahead of the population race. However, several workers have published energetic analyses of modern farming systems to show that for every calorie we get out of the system, we put between 10 and 20 calories in. If such numbers are reliable, we have already lost the race.
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How do things look from a broader ecological standpoint? A revealing way of examining agriculture is to consider how many "ghost acres" support one acre of farmland. The concept of ghost acreage was introduced by Georg Borgstrom in "The Hungry Planet" (1965). It has been further developed by William Catton in "Overshoot" (1980), and most recently by Mathis Wackernagel and William Rees in "Our Ecological Footprint" (1996). Generalising from the latter reference, if we are to support the population of the world at a level of nutrition and living standards enjoyed by Canadians, we would need the resources of two and a half more planet earths.

In conclusion, agriculture as practised in North America has achieved its successes in keeping us fed by two unrepeatable events: the opening up of the New World to farming, and the exploitation of fossil fuel. As currently practised, modern agriculture is unsustainable, relying heavily on a non-renewable energy source that is used in a process so inefficient that only about one tenth of the energy input is regained as nutrition. The extra two and half planet earths needed to give all people the standard of living projected for them in 1987 by the Bruntland Commission, whose report made "sustainable development" the oxymoron of the century, are nowhere to be seen.

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Apatite solubility

Ward Chesworth

Apatite is stable in any system in which log [Ca^{2+}]/[H^{+}]^2 is buffered by some other Ca-bearing mineral (Fig. 1). Most commonly this mineral is calcite, dolomite, a Ca-saturated smectite, or, least likely for kinetic reasons, plagioclase. Obviously (Fig. 1), apatite can be brought into solution by decreasing log [Ca^{2+}]/[H^{+}]^2 in the weathering environment. This decrease can be achieved by lowering [Ca^{2+}], for example by the destruction and removal of calcite, or by raising the acidity of the system, for example by prolonged weathering in a humid climate. By whatever means (and the processes mentioned in the last sentence are coupled together in many systems), weathering eventually leads to one of the compartments at the bottom of the diagram. If ambient conditions are relatively low in phosphate species or in Al^{3+}, that is, if conditions fall within the gibbsite or kaolinite volumes, all phosphate is in solution. Otherwise, phosphate will be fixed in a secondary Al phase. The diagram is therefore a useful model in discussing the behaviour of apatite in a variety of weathering systems: e.g. luvisolic soils (high Ca^{2+}, apatite stable), weathering granites (low phosphate, low Al^{3+}, all P in solution), and ferrallitic soils (low phosphate, high Al^{3+}, P fixed in secondary phosphates).

Fig. 1 is also useful in considering ways of manipulating apatite as a source of fertilizer P, apatite being the principal
feedstock of the phosphate fertilizer industry. Normal commercial ways of converting apatite into more soluble forms are energy intensive, a fact which, in terms of cost, puts them beyond the means of many farmers in the less developed parts of the world. Consequently, at Guelph we have invested a good deal of research time into investigating ways of solubilising apatite that are not energy intensive.

Items 1 and 2 represent normal weathering, in which the carbonic acid of rainwater, or acids produced from the natural organic materials in the upper horizons of a soil, provide $H^+$. Item 3 represents the action of some nitrate and phosphate fertilizers as they break down in an aqueous environment to produce $H^+$. Item 4 would be represented by the process that generates acid sulphate soils and acid rock drainage. Item 5 relates to the anodic production of $H^+$ in certain galvanic systems. All of the aforementioned items can be envisaged as "pushing" the reaction to the right. Item 6 refers to the uptake as nutrients of $Ca^{2+}$ and $P$ species by plants and micro-organisms. Items 7 and 8 represent $Ca^{2+}$ sinks of inorganic (mineralogical) or organic (peat, compost

Fig. 1. The solubility surface of apatite in relation to other minerals in the system: $CaO-AI_2O_3-SiO_2-P_2O_5-CO_2-H_2O$. 

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etc.) types. Item 9 is the undesirable process of phosphate fixation, which is found particularly at the acid end of the weathering spectrum. Items 6 to 9 all work by “pulling” the reaction to the right.

At Guelph we have investigated items 2, 3, 4, 5, 6, 7, and 8 as possible bases for low-cost technologies for producing phosphate fertilizer, and although some have shown promise in the laboratory, successful transfer to field conditions has not yet been achieved.

Fig. 2. A summary of the ways that, by the law of mass action, the reaction shown can move from left to right.

Agriculture and the major holocene weathering systems

Ward Chesworth

Weathering systems show three fundamental trends in Eh-pH space (Fig. 1). Soils in humid climates evolve towards acid end points, those in semi-arid and arid zones move along an alkalising trend, and those in waterlogged situations become hydromorphic (or gleyed). The end points of these three processes coincide notably (Fig. 1.) with nodes where pH is buffered, and where Eh is poised by mineral-organic matter-aqueous solution interactions, resulting in end-stage systems with considerable pedogenic inertia.

Historically, the first large-scale farming systems developed in semi-arid areas where saline soils or chemical duricrusts form naturally. The introduction of agriculture emphasised this tendency, and led to the abandonment of farming in both
Mesopotamia and the Indus valleys. Modern examples where irrigation has reinforced the natural trend towards saline soils are the Imperial Valley of California, and the cotton plantations in the Aral Sea region of Russia.

Large-scale agriculture fed by rain came along later and led to the colonisation of loessial soils in the Old World. Again, farming serves to reinforce the natural chemical trends towards acid end-points, unless corrective measures such as liming, are taken (Fig. 2). Indeed, many of the acid heathlands and moors in western Europe are now considered artificial, and to be related to Neolithic land clearance. In modern farming the use of many fertilisers has also been responsible for the artificial acidification of soil.

There are many examples, particularly from the classical Mediterranean world, of the clearance of forests for agriculture leading to erosion of upland soils, and concomitant deposition of sediment at river mouths. This process produces swamps and marshland, thereby generating areas of

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**Fig. 1.** Weathering systems in Eh-pH space.

**Fig. 2.** A schematic summary of the effects of farming on the earth-surface environment.
Towards regional scale monitoring of agroecosystems in Southern Ontario

Bart Hulshof, Richard Protz, and Matthew Wood

The success of agriculture is dependent on many variables such as crop type, soil moisture, nutrient availability, and soil type. Remote sensing data for monitoring these variables and providing accurate, up-to-date information on a regional scale will be available in a few years. This capability depends on the RADARSAT satellite, and the impending launch of up to 10 new satellites by the end of 1998. With the fusion of satellite data, the potential to provide a continuum of accurate agricultural data, over the entire growing season from snowmelt to snowfall, will be improved.

Providing accurate agricultural information from satellite data to end users requires objective ground truthing that is cognizant of spatial and temporal variations that occur on a regional scale. For example, two corn fields separated by 300 km do not have the same spectral properties due to a variety of environmental and management factors. Using one agricultural field as opposed to several fields to “train” or calibrate satellite data on a regional scale would decrease the classification accuracy. It is in this context that all large agricultural fields (those greater than 15 ha in size) were identified in Southern Ontario.

A rigid unsupervised classification procedure was developed to facilitate the identification of large fields from Landsat TM data. The spatial resolution of Landsat data was found to be limiting in the identification of large fields. A stratified random sampling scheme was used to randomly select a small number of individual fields in clusters to be used for ground validation and training of satellite data. Cross stratification of the study area was achieved using minor physiographic regions and county boundaries as strata. The sampled fields were integrated with a digital road network to allow rapid and efficient ground validation of satellite data over Southern Ontario. The resulting sampling scheme has been synthesized to provide an objective training framework for those intending to monitor agriculture on a regular basis.

Land Management
Pore characteristics are more important than bulk soil properties for the mineralization of legume-N

B. D. Kay and V. Rasiah

Forage legumes can represent an inexpensive source of nitrogen when followed by non-legume grain crops. The possibility of increasing profitability and reducing environmental risk by managing parts of a field differently (site-specific management) has highlighted the need to identify those soil properties that are of the greatest relative importance to the accumulation of organic-N, and to determine whether the relative importance of the different properties changes with time after the onset of mineralization of the legume-N.

The objectives of this study were to assess the relative importance of bulk soil properties, aeration, and the volume fraction of different size classes of water-filled pores for the accumulation of inorganic-N in legume-amended soils, and to determine if the relative importance of the different properties varied with time during the incubation period.

Seven soils with clay contents ranging from 8.5 to 36.7 % were packed to two different levels of relative compaction (RC), and incubated with red clover (Trifolium pratense L.) shoot biomass. Values of RC of 0.79 and 0.87 were used to simulate the effects of conventional and zero tillage on the bulk densities of soils of different texture. Soil porosity was characterized in terms of the volume fraction of pores (VFP) in different size ranges that were water-filled and the volume fraction of pores that were air-filled (expressed as a fraction of total soil volume). The VFP with effective diameter (μm) ranging from 20 to 10 (S1), 5 to 10 (S2), 3 to 5 (S3), 1.5 to 3 (S4), and < 1.5 (S5), were computed from the water content and tension data. The pores > 20 mm diameter were air-filled under the conditions of this experiment, and so the VFP in this size range represented the air-filled porosity (AFP).

Nitrate- and ammonium-N were measured at 14, 21, 32, 42, 56, and 70 d. The data were fitted to a two pool first order exponential model, i.e.,

\[ N_m = N_i \left[ 1 - \exp(-k_i t) \right] + N_r \left[ 1 - \exp(-k_r t) \right] \]

where \( N_m \) is the amount of inorganic-N measured at time \( t \), \( N_i \) and \( N_r \) are the amounts of organic N present as labile and resistant N pools, respectively, and \( k_i \) and \( k_r \) are the corresponding first-order rate constants. Stepwise variable selection analyses were used to identify the most important bulk soil properties and pore characteristics influencing the coefficients in the mineralization model. The data on inorganic-N measured at each incubation time were analysed in a similar manner, so as to determine if the relative importance of different properties changed with time.

Pore characteristics (the volume fraction of air-filled pores and water-filled pores with effective diameter < 1.5 mm), accounted for a larger proportion of the variability in the coefficients of the
mineralization models, and in the concentration of inorganic-N measured at different incubation times, than did bulk soil properties. The relative importance of different soil properties varied with the duration of incubation in the amended treatment, whereas these properties exhibited a comparatively consistent influence over time in the control. The greater importance of pore characteristics is compatible with the hypothesis that soil structure is the dominant control over microbially-mediated processes in terrestrial ecosystems. Under field conditions, pore characteristics of nonswelling soils vary with both bulk soil properties and management. The influence of management on pore characteristics was simulated in this study by variable compaction. Although the two types of pore characteristics were negatively correlated, and therefore had opposing relations with bulk soil properties such as clay content and organic matter content, AFP was the only characteristic that was strongly influenced by compaction. Given the relative importance of AFP to mineralization, it is not surprising that AFP accounted for more of the variability in the dependent variables than could be accounted for by the bulk soil properties alone. Successful replacement of the bulk soil properties organic matter content, clay content, or cation exchange capacity with S5 (the volume fraction of pores of diameter < 1.5 mm) reflects the positive correlation between these bulk soil properties and S5, and also reflects the more comprehensive effect on mineralization that can be described by S5 than can be accounted for by the individual bulk soil properties.

The relations involving AFP and S5 that were included in the regression equations can be interpreted in terms of soil-residue contact, aeration, and protection of different forms of organic-N from mineralization. Air-filled porosity reflected both the effects of aeration and that of residue-soil contact. The accumulation of inorganic-N increased with AFP in the amended treatment in the early stages of the incubation when oxygen demand was highest, but an opposite effect was observed later in the incubation when decreased compaction, higher AFP, and a concomitant decrease in residue-soil contact, caused reduced accumulations of inorganic-N. The influence of VFP for pores of diameter < 1.5 \( \mu m \) is believed to be through the physical protection of microorganisms from predation, and the protection of microbial metabolites containing N that is conferred by their adsorption. In support of this first interpretation, biomass carbon was found to be strongly positively correlated with the VFP for pores of diameter < 1.5 \( \mu m \).

The increased accumulation of inorganic-N in the later stages of the incubation in the amended treatment under high compaction, and the larger size of the resistant pool, are attributed to an increase in residue-soil contact. Compaction did not have a similar impact on the mineralization of organic-N in the control, and would not be expected to have the same effect where the legume residue is intimately associated with the soil matrix, as would be the case for undisturbed soils containing root material.

This study suggests that spatial variation in bulk soil properties, management, or both, may influence the rate of mineralization of legume-N in the field because of their influence on pore characteristics. Studies are currently
underway to examine this possibility. The results of this study also have implications for future laboratory studies. Details on pore characteristics are often ignored during the incubation of different forms of organic-N.

The influence of soil properties on the accumulation of inorganic-N in different soils can be better understood if information on pore characteristics is obtained.

Soil-vehicle interactions with high axle load traffic

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A field experiment was conducted with the objective of characterizing soil-vehicle interactions when AAFC's instrumented tractor pulled a water-filled tanker (Husky 18 kL) fitted with rubber tracks, high flotation turf tires or conventional rubber tires (the latter two were tandem axle). The experiment was carried out in late fall on a harvested soybean field (silt loam soil) at the Elora Research Station. Selected soil properties were measured after the traffic treatments, in addition to draft and fuel consumption. A soil compaction model (Jakobsen and Dexter, 1989) was used to simulate the experiment and estimate wheel rut depth for the pneumatic tire treatments. This model has been translated from the original Fortran to Visual Basic, and a graphic user interface has been added.

Analysis of variance indicated that the running gear had a highly significant effect on draft, with the tracks requiring the highest draft and the flotation tires requiring the least. On average, the conventional rubber tires left ruts about 4.5 cm deep, while the flotation tires left only a slight impression. A pedotransfer function, PTF2 (McBride and Joosse, 1996), was used to estimate the preconsolidation stress (26 kPa) and compression index (0.173) for the soil and, with these and other input data, the soil compaction model estimated these rut depths quite well. The PTF has been set up as an Excel spreadsheet program with a graphics interface (Fig. 1). The only ruts produced by the tracks were those of the track grousers (about 4.8 cm deep), but extensive soil shearing was evident. Soil cone penetrometer resistance for the track running gear was significantly lower than either wheel configuration in the 15 to 21 cm depth range.
Fig. 1. The graphics interface for the pedotransfer function.
Investigating crumb rubber as a waste-based soil amendment for sports turf

P. E. Grunthal and P. H. Groenevelt

Crumb rubber has been shown to be an efficient, economical, and environmentally sound soil amendment. Since the mid 1970's, research on the use of this waste product has lead to the development of no less than four patents. Research at the Department of Land Resource Science has shown that a soil amendment based on crumb rubber can enhance the physical properties of soils that are susceptible to the negative effects of compaction, while at the same time creating a more resilient turfgrass playing surface.

Data collected in 1996 at the Guelph Turfgrass Institute (GTI) supported previous findings on the benefits of the addition of crumb rubber to soils, and prompted the need for a larger-scale pilot project. In addition, observations of turfgrass health following winter brought to light another benefit of the amendment, namely, controlling the effect of "winter kill" on perennial ryegrass (Fig. 1).

Observations of the physical effects of rubber crumb on turfgrass revealed that rubber crumb decreases surface hardness both before and after compaction. Also, subsequent to sward establishment and following compaction, there was no significant difference in soil shear strength between soil with or without crumb rubber. Rubber crumb is also thought to increase infiltration, reducing the time needed for the closure of sports fields following rain. However, further investigation is necessary to discover how these factors are correlated, and to determine the most efficient admixture of rubber crumb and soil.

Environmental monitoring of soils with a rubber crumb amendment began in 1995. Leachate from turfgrass lysimeters at the Cambridge Research Station was collected and analyzed for metals, volatile organic compounds, and extractable organic compounds. Lysimeters were tested with alkaline soils, and acidic media with pH modifying compounds added. The 1996 data were consistent with previous findings. While concentrations of boron, barium, and zinc in leachate were slightly elevated for amended systems, these concentrations were far below government safety guidelines. Analysis of leachate for volatile organic compounds, and for base-, neutral-, and acid-extractable substances, revealed that none of the admixture constituents contributed significantly to the concentration of compounds described by the United States Environmental Protection Agency under lists 624 and 625, respectively.

The main economic incentive for the application of a waste-based soil conditioner to high-traffic sports turf areas is reduced maintenance costs. However, intangible benefits associated with waste reduction and improved turf quality, such as ball rebound and roll characteristics, must also be considered. Also, healthy turf may extend the playing season by allowing the course or field to become available earlier in the season. It is estimated that these combined benefits could pay for the amendment in just over two years.
In comparison to conventional inorganic soil amendments, an admixture based on crumb rubber has a number of additional advantages. Some of the documented benefits include durability and resiliency of the product—minimum calculated half life of 13 years—as well as decreased aeration, decompaction, fertilisation, and irrigation requirements of the playing surface.

Fig. 1. In the foreground, compaction caused by a vehicle contributed to "winter kill," leaving visible scars on a sward of perennial ryegrass. The tracks disappear as they cross over the rubber-crumb treated plots of perennial ryegrass shown in the centre, and the plots to the rear, which contain Kentucky bluegrass.
Partitioning of solutes between runoff, tile drains, and deep groundwater within an agricultural field in Southern Ontario

Gary Parkin\(^1\), David Rudolph\(^2\), Gary Kachanoski\(^1\), and Peter von Bertoldi\(^1\)

\(^1\)Land Resource Science
\(^2\)Waterloo Centre for Groundwater Research

Measurement of the hydrologic water balance of a privately owned agricultural field in southern Ontario (a hill slope comprised of loam soils near Kintore) was undertaken to determine the major transport pathways of contaminants (including nitrate, chloride, and atrazine) below the root zone and into a drainage ditch.

The study field was instrumented with a meteorological station and time domain reflectometry probes to measure precipitation, as well as potential and actual evapotranspiration. Water flow metering systems were installed at all tile drainage outlets, at upstream and downstream ditch stations, and groundwater monitoring wells were installed so as to be able to measure hydraulic heads below the water table. To quantify the contaminant flux, water samples were collected at all tile and drainage ditch monitoring stations, and from all monitoring wells, and soil samples were collected from the A horizon. Water and soil samples were analysed mainly for nitrate, ammonium, and chloride content; however, a limited number of samples were analysed for a standard suite of anions and cations, isotopes (N\(^{15}\) and O\(^{18}\)), and atrazine.

Results indicate that the tile drains are the primary transport path for nitrate to the drainage ditch (Fig. 1). There is good evidence that the process of denitrification substantially reduces nitrate concentrations beneath an uncultivated strip around the perimeter of the field. Groundwater contributes proportionately less nitrate to the drainage ditch in comparison to tile drains. There was only a minimal quantity of runoff from the field due to a low berm, which was constructed between the field and the drainage ditch.

![Water and Nitrate Distribution](image.png)

**Fig. 1.** Sources of water and nitrate for the drainage ditch during 1996.
The effect of fertilizer type on nitrogen oxide emissions from turfgrass

Jinelle Webb, Claudia Wagner-Riddle, and George W. Thurtell

The gaseous oxides of nitrogen are nitrous oxide (N\textsubscript{2}O), nitric oxide (NO), and nitrogen dioxide (NO\textsubscript{2}), with the formula NO\textsubscript{x} often being used to refer to NO and NO\textsubscript{2} collectively. These gases have raised recent concern due to their adverse effects on the atmosphere. Nitrous oxide is a greenhouse gas, being chemically inert in the troposphere but able to alter the earth’s radiation balance. In the stratosphere, N\textsubscript{2}O is reduced to NO, which in turns destroys ozone. NO\textsubscript{x} gases interact chemically in the troposphere to produce ground-level ozone, which was described as a health hazard in 1995 by the International Panel on Climate Change.

Until recently, industry was considered to be the main source of these gases. However, it has been shown that agriculture can be a major contributor to nitrogen oxide emissions through the use of chemical nitrogen fertilizers. However, it is not clear if there is an effect of fertilizer type on these emissions.

One of the problems associated with measurement of trace gases is the need for non-intrusive, continuous measurement techniques. Even dynamic chambers alter the environment, and they can only be used for limited periods of time. The introduction of new technology involving the use of tunable diode lasers has allowed the development of systems that provide ongoing real-time measurements when used in conjunction with micrometeorological theory.

The aim of this study was to relate turfgrass fertilization to emissions of nitrous oxide, nitric oxide, and nitrogen dioxide.

Measurements of fluxes of N\textsubscript{2}O, NO, and NO\textsubscript{2} were performed at the Guelph Turfgrass Institute using micrometeorological methods of trace gas measurement and a Tunable Diode Laser Trace Gas Analyser (TDLTGA), which was developed at the University of Guelph.

A field of dimensions 92 m x 88 m was planted with ryegrass on June 15, 1995, and divided into four equal plots. Beginning in September, 1995, fertilizer was applied to three of the plots at the recommended rate of 50 kg N ha\textsuperscript{-1} application\textsuperscript{1}. Urea (46-0-0) was added to plot 1, sulfur-coated urea, a slow-release form (31-0-0), was added to plot 2, ammonium nitrate (33-0-0) was added to plot 3, and plot 4 was kept as a control.

In 1995, N\textsubscript{2}O and NO flux measurements began on September 6 and continued until October 15. Fertilizer was added on September 21. In 1996, measurements of N\textsubscript{2}O flux began on May 8. In addition to measuring NO fluxes, NO\textsubscript{x} fluxes were also monitored, both starting on June 13. Fertilization occurred four times over the course of the summer, at a rate of 50 kg N ha\textsuperscript{-1} for each application. Dates of fertilization were June 19, July 30, August 30, and September 26.

The accumulated N\textsubscript{2}O flux for the study period in 1996 indicated that the plots fertilized with ammonium nitrate and urea emitted the most total nitrogen as nitrous oxide, with measurements of 1.3 and 1.7 kg N ha\textsuperscript{-1}, respectively. Fertilizing with the slow-release form of urea reduced N\textsubscript{2}O emissions considerably, the accumulated flux being only...
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5% and 7.5% of that from the plots fertilized with ammonium nitrate and urea, respectively. The control plot had the lowest measured emissions of N₂O, at less than 0.05 kg N ha⁻¹ over the measurement period.

Regardless of type of fertilization, fluxes of NOₓ were negative throughout the entire measurement period. Prior to calendar day 220, fluxes were closely correlated among all four plots. Throughout the measurement period, fluxes never varied more than 25% among plots. The rate of accumulation of flux was generally constant over the 1996 season.

The accumulated NO fluxes showed less clear trends than were seen for NOₓ fluxes. Nitric oxide emissions fluctuated around zero, generally with negative fluxes during the earlier part of the season until calendar day 240, but with positive fluxes in the later part of the season. This temporal pattern was seen in all plots, although it was much more pronounced in the plots fertilized with urea and ammonium nitrate. From these results it seems that there is a large downward flux of NO₂, which negates the effect of NO on NOₓ flux.

From this work, it can be concluded that type of fertilization has an impact on nitrogen oxide emissions. In addition, experiments conducted during a period with dry weather in 1995 showed that NO emissions after urea and ammonium nitrate additions were significant, and up to 20 times higher than from plots treated with sulfur-coated urea. Nitrous oxide emissions were negligible in 1995. Therefore, type of fertilizer has an impact on both NO and N₂O emissions, with the magnitude of emissions dependent on the soil moisture conditions at the time of fertilizer addition. Use of slow release fertilizer forms seems to have an effect in nitrogen oxide gas emissions.

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Nitrous oxide, nitric oxide and ammonia fluxes following a fall application of swine manure

C. Wagner-Riddle, G.W. Thurtell, G. Dias, and H. Brown

A number of environmentally significant gases are associated with livestock barns, manure storage, and the field application of manure. The potential impacts fall into three major areas: (1) in-barn or other containment effects; (2) local impacts; (3) global impacts. Within a barn, gases produced by animals and their excreta pose hazards to humans entering or working in a barn, and potentially impact the health and productivity of the animals. Gases released to the atmosphere from barns, manure management systems, and land spreading of manure as fertilizer may have local impacts, contributing to pollution of air, land, and water. Some of these gases are also of concern from a global perspective, since they contribute to global warming also known as the “greenhouse effect,” and to the destruction of stratospheric ozone, which shields the ground from harmful ultra-violet radiation.

Methane (CH₄) emissions are of
concern with respect to their contribution to global warming. Ammonia (NH₃) emissions are mostly from livestock manure, and they occur during the various stages of generation, handling, processing, storage, and use of the manure. Ammonia emissions lead to air quality effects and biosphere acidification. Other gases of concern include oxides of nitrogen (N₂O, NO₃), carbon dioxide (CO₂), and hydrogen sulphide (H₂S).

As part of our project, we will be quantifying gaseous losses of dairy cattle and swine systems during storage and field applications of manure. Here we present some preliminary results on NH₃, NO, and N₂O fluxes from field applications of swine slurry, and CO₂ emissions from solid dairy manure and liquid swine manure.

An experiment to monitor the emissions of N₂O, NO, and NH₃ before and after liquid swine manure application was established during the fall of 1995 at the Arkell Research Station, Guelph, Ontario. A trailer housing all the instrumentation was installed at the centre of four 1-ha plots, which were monitored sequentially on an hourly basis. The treatments applied to the plots were as follows: 1) a control plot with wheat stubble ploughed down, 2) wheat stubble, 3) oats, and 4) red clover; both the oats and the red clover were planted no-till through wheat stubble in September. The experiment was initiated on October 27, and manure was spread on October 30 on plots 1, 2, and 3, at a rate of 75 kg N ha⁻¹.

Fluxes were determined using the flux gradient method. Concentration gradients for N₂O were obtained using the tunable diode laser trace gas analyser (TDLTGA) as originally developed at the University of Guelph in 1994, and using a modified TDLTGA for NH₃ measurements.

![Graph](https://via.placeholder.com/150)

**Fig. 1.** Hourly ammonia fluxes measured from a plot of wheat stubble with clover to which manure had been applied, compared to a ploughed plot with no manure application, at Arkell during November, 1995. Air temperatures are also shown.
Fig. 2. Hourly $N_2O$ fluxes measured from a plot of wheat stubble with clover to which manure had been applied, compared to a ploughed plot with no manure application, at Arkell from November 1995 to April 1996. Air temperatures are also shown.

Characteristics of these instrumentation systems are as follows: high sensitivity, with noise levels of <30 pptv for NH$_3$ and <20 pptv for $N_2O$, adaptability for continuous monitoring, fast response, and high selectivity, with typical operation at wave numbers of 2236.225 cm$^{-1}$ for $N_2O$ and 930.757 cm$^{-1}$ for ammonia. For NO, a chemiluminescence analyser was set up for gradient measurements. Flux measurements for NH$_3$ were conducted until the end of November, while NO and $N_2O$ flux measurements continued until April, 1996.

Ammonia was the main form of nitrogen gas that was lost immediately following manure application (Fig. 1), with $N_2O$ emissions not being affected by manure application during the month that followed (Fig. 2). However, $N_2O$ emissions increased during periods of thaw, as indicated by the increases in temperature in Fig. 2. While some increase in emissions during thaw was also observed for the ploughed plot that did not receive any manure in October 1995, emissions from the manured plot were much larger.

Total nitrogen losses were mainly in the ammonia form during the month of November, but when the total measurement period from November to April was considered, $N_2O$ emissions exceeded the initial ammonia loss (Table 1). Nitric oxide emissions were generally low. Up to 70% of the total $N_2O$ loss during the measurement period occurred during spring thaw in March and April. Emissions were also up to 3.5
times higher for the manured plots when compared to the non-manured plot.

Continuous, year-around monitoring of N gas forms was successfully performed using micrometeorological methods. Monitoring of gaseous losses in the future will be integrated with studies on nitrate leaching and manure characterization. Results from environmental impact monitoring, animal feed composition, and economical assessments will be incorporated in a Decision Support System for Animal Manure Management.

**Table 1.** Total N loss as N$_2$O, NO, and ammonia, from plots receiving a fall application of swine manure compared to a control. Values are shown for the month of November 1995, and for the periods from November 1995 to April 1996 and from March to April, 1996.

<table>
<thead>
<tr>
<th>Plot</th>
<th>November 1995</th>
<th>November 1995 to April 1996</th>
<th>March to April, 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N$_2$O</td>
<td>NO</td>
<td>NH$_3$</td>
</tr>
<tr>
<td></td>
<td>kg N ha$^{-1}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stubble</td>
<td>0.07</td>
<td>-0.02</td>
<td>not determined</td>
</tr>
<tr>
<td>Stubble + oats</td>
<td>0.12</td>
<td>-0.04</td>
<td>0.21</td>
</tr>
<tr>
<td>Stubble + clover</td>
<td>0.09</td>
<td>-0.01</td>
<td>0.21</td>
</tr>
<tr>
<td>Ploughed (no manure)</td>
<td>0.03</td>
<td>-0.02</td>
<td>-0.03</td>
</tr>
</tbody>
</table>
Assessment of the calcium chloride extraction procedure for estimating nitrogen available to crops

Michael Goss and Peter Smith

Development of pre-plant soil tests for nitrogen (N) available to crops has proven problematic when animal manures or legume crops have been incorporated. In the early 1990's, Appel and Mengel used 0.01 M CaCl₂ as an extractant and obtained fractions of soil mineral and organic nitrogen that correlated with the N taken up by crops during the growing season. Following a critical review of the literature, we have developed and tested a similar yet modified CaCl₂ extraction procedure.

Soil samples (10 g) were extracted with 100 ml of 0.01 M CaCl₂ solution by shaking for two hours at 20°C. These extracts were then filtered with “NH₄⁺-free” filter paper. The filtrate was retained as the 20°C mineral-N (Nₘᵢₙ) fraction. The filter papers and remaining soil material were then returned to the original extraction bottles, 100 ml of 0.01 M CaCl₂ solution was added, and the samples shaken in a heated water bath at 80°C for 20 min. The filtrate from this extraction contains a more strongly bound organic N fraction. Sub-samples from both the 20°C and 80°C extractions were analysed for concentrations NH₄⁺-N and NO₃⁻-N on a TRAACS 800 automated colorimetric analyser.

An acid digest was performed on aliquots (20 ml) from the 20°C Nₘᵢₙ fraction. These aliquots were digested in 2.5 ml concentrated H₂SO₄ containing 3.5 g Se L⁻¹, together with 5 ml of 30% (v/v) H₂O₂ solution. The ammoniacal-N in the digest was taken to be the “reduced-N” fraction, because it is derived from soluble organic nitrogen plus NH₄⁺-N.

![Graph](image_url)

**Fig. 1.** Relationship between Nₘᵢₙ, the total mineral nitrogen (the sum of NO₃⁻-N and NH₄⁺-N) extracted with KCl or with CaCl₂ at 20°C. The regression equation is: y = 1.06x; r² = 0.99; P < 0.001.

There was a good correlation between the extraction with CaCl₂ and with KCl at 20°C for NO₃⁻-N and NH₄⁺-N (Fig. 1).

The use of the three CaCl₂ fractions as an indicator of mineralizable nitrogen available to crops was investigated by comparing the sum of these three fractions with results from Stanford and Smith’s accepted standard procedure for combined...
extraction and laboratory incubation. The total available N determined by the CaCl₂ extraction procedure was highly correlated with the available N obtained from the addition of Stanford and Smith’s mineralization potential value (N₀) and the KCl-extractable mineral N (Fig. 2). Based on this analysis, it would be possible to use the combined CaCl₂ analytical procedure as a soil test of available N. The available N would be given by the equation:

\[ y = 1.56x \]

Our results are based on 19 benchmark sites only. One site gave a much higher prediction than was measured by the incubation and extraction procedure. It is clear that more assessment is necessary before this can be recommended as a standard test.

**Fig. 2.** Relationship between available N (estimated from measured \( N_{\text{air}} + N_0 \)) and total available N estimated from CaCl₂. The regression equation is: \( y = 0.62x; r^2 = 0.97; P < 0.001 \).

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**Manure management with women farmers in Malawi, Africa**

Rachel Bezner Kerr

I am a graduate student in the Department of Land Resource Science, in association with the Collaborative International Development Studies (CIDS)
program. My advisor, Dr. Peter van Straaten, has undertaken agrogeology research in Tanzania, Zimbabwe, and other parts of south-east Africa. In the summer of 1997, I will be conducting participatory research with women farmers and a non-governmental organization (NGO) in Malawi, a small landlocked country, which is located in between Mozambique and Zambia in south-east Africa.

The Relief and Development Department of the Presbyterian Church in Malawi has had a training program for farmers in various soil conservation and fertility techniques. This program is attempting to improve food security in an area where many families are unable to produce sufficient food for their needs. Fertilizer costs have increased dramatically over the past several years—300% in 1995 alone—so farmers have to devise new ways to fertilize their fields. The Relief and Development Department has been promoting various methods of improving soil fertility, including composting, and the making of manure extract. Manure extract is made by taking manure, putting it in a burlap bag, and then soaking this bag in water for 2-3 weeks. The water is then poured over the crop as a type of liquid fertilizer.

This summer, we will be working with women farmers to investigate further the manure extract method in vegetable gardens, to determine how this manure management technique could be improved or modified. Our research will involve both on-farm trials and informal interviews. I will also be learning about the socio-economic conditions of these women farmers, including how they allocate their time, what kind of resources they have available, and how family decisions are made regarding the garden. Women farmers do the majority of agricultural labour in Malawi, including work with both food and cash crops. This is an exciting collaborative project between the university, a community development organization, and local farmers in Malawi, from which we all hope to learn and benefit.

The development of a standardized approach for describing and organizing data generated through land resource field research

G.C. Watson and R.A. McBride

Research was conducted to develop a standardized approach to manage data collected by field research on land resources. The requirements of a database for managing the large volumes of data generated through this type of research were documented. Data collected through the Tillage 2000 project were used as a representative data set for modelling purposes.

A conceptual data model was developed using the Entity Relationship Model, which described the semantics of the data. Conceptual modelling provided a way of capturing the users’ perception of the data.
in abstract terms, and it included generic entities that identified the general categories of data in the Tillage 2000 study. Two distinct levels of data were distinguished: supporting data, and “real” data. The supporting data are frequently termed “metadata,” while the “real” data are simply referred to as “data.” Fig. 1 shows the entity relationship diagram that was developed to depict the data-level. This model provides a tool for understanding the organization of data, and it can be used as a basis for formulating database queries.

A logical data model was developed from the conceptual data model and the consolidation of performance requirements for the database. Table structures were described, which could be implemented in a regional database management system. A prototype database based on the logical model was created in Oracle Personal 7.

The use of the conceptual and logical data models was demonstrated through a research project, which involved developing regression equations to estimate Atterberg limits for the soils of southwestern Ontario. This research facilitated the demonstration of several of the primary functions of the database: importing sets of data, exporting data, queries, and integration with external software packages.

The database structure and approach to managing data that were outlined here can be used to amalgamate data sets from multiple field-based projects on land resources.

Fig. 1. The conceptual data model.
Land Stewardship
Land Stewardship

Centre for Land and Water Stewardship

Stew HILTS

Programs in the Centre for Land and Water Stewardship continued to develop in new directions over the past year. Under the direction of Dr. Michael Goss, who holds the Chair in Land Stewardship, research related to nutrient management and water quality in agriculture continues to be a major theme.

The nutrient management project represents a partnership of several agencies and organizations in the province, examining how on-farm nutrient management can be modified to minimize water quality impacts.

The Community Woodland Steward Project has developed to the point where the first “Community Steward” workshop is scheduled for mid-April. This also is sponsored by several cooperating partners. Several key publications have been developed in support of this program, including a “Pocket Guide to Ontario Trees”. This project is spearheaded by Dr. Stewart HILTS, Director of the Centre.

The A.D. Latournell Conservation Symposium, a major outreach effort of the Centre, continues to grow. This year’s conference was held at the Nottawasaga Inn, in cooperation with the local Conservation Authority, and the Association of Conservation Authorities of Ontario. More than 300 people attended, and widely commented that the event was the best yet.

The success of the A.D. Latournell Conservation Symposium has led to the development of two new initiatives in the current year, in addition to the fourth annual Conservation Symposium, which will be held October 20-22, 1997. A series of workshops on specific topics is being organized as professional development events for Conservation Authority staff and others. And, in cooperation with several Conservation Authorities, a student field experience is being organized for May, 1997.

A number of other projects of the Centre are also described in this report.

Unfortunately, the Stewardship Information Bureau, a project funded by the Green Plan program from Agriculture and Agri-food Canada, will come to an end in March, 1997. This office, originally known as the Soil and Water Conservation Information Bureau, has provided information services and an electronic database for farm-related extension staff and organizations for eight years.

We wish the staff of the Bureau all the best in their future careers, and extend our heart-felt thanks for a job well done. Helen Lammers-Helps, John Kerr and Maria Cochrane have been with the office since it opened. Doug Robinson, our original Manager, died of cancer in 1994, but Jim Arnold has taken over and directed the office capably for the past two years.

Thanks also to the sponsors of the Information Bureau, Agriculture and Agri-food Canada, and the many cooperators we have worked with. Among these we single out the Innovative Farmers Association of Ontario for special mention. Their support and willingness to work with us on many projects has been important to us all.

The work of the Information Bureau
will continue to be available in at least two forms. The Information Bureau’s electronic web page will be maintained by the Department of Land Resource Science, and its library will be maintained elsewhere on the campus. We are working on other plans for future projects.

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The Centre now has a small web page of its own, currently accessed through Dr. Hilts’ individual home page a the University of Guelph. The address is:

http://www.uoguelph.ca/~shilts

Watch the home page of the Department of Land Resource Science for further developments:

http://www.uoguelph.ca/lrs

The home page of the Stewardship Information bureau is also accessible from here, or directly at:

http://sib.lrs.uoguelph.ca/sib3htm

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Greening the Land: Principles, Guidelines and Cases

Stew Hilts

At the end of a three year research project, the handbook “Greening the Land: Principles, Guidelines and Cases,” has been published. This project involved the development of guidelines for revegetation projects, especially the many local tree planting projects organized by community groups.

The guidelines produced were then tested by several organizations in actual tree planting projects. Organizations also contributed case histories of several past tree planting projects. The result is “a revegetation project handbook for community groups and landowners.” This book is available for $10.00, or $6.00 wholesale.

This project was primarily sponsored by the Laidlaw Foundation, with additional funding by the Richard Ivey Foundation and the Branscombe Family Foundation. Publication of the handbook has been sponsored by the Ontario Forestry Association and the Federation of Ontario Naturalists.

The Niagara Escarpment Stewardship Program

Stew Hilts

Based on earlier landowner-contact projects along the Niagara Escarpment, this project involved three workshops for landowners held in cooperation with local agencies and organizations. The workshops were based on the handbook “Caring for Your Land: A Stewardship Handbook for Niagara Escarpment Landowners.” These workshops were held in Grey County, in the Credit Watershed, and in the Niagara Region.

In addition, a slide set to accompany the handbook has been produced to be made available to interested local groups.

Carolinian Canada “Caring for Your Land”

Stew Hilts

Following the outstanding success of “Caring for Your Land: A Stewardship Handbook for Niagara Escarpment Landowners,” a new version of this
The Community Steward Project

Stew Hlts

Until recently known as the “Master Steward” project, this is an educational program to involve rural landowners as volunteers assisting other rural landowners. The program is being developed as a partnership with the Ontario Forestry Association, and involves an intensive weekend training event for participants followed by a commitment to community service. The Master Steward Project is modelled to some extent after the Master Gardeners Program.

“Community Stewards” will be knowledgeable about various aspects of land stewardship, targeting those natural features that are of interest to rural non-farm landowners, rather than agricultural features. The first module being developed is on woodlands; it is hoped to develop further modules on, among others, wildlife, and ponds and streams.

After participating in a weekend training event, landowners will join a network of “Stewards” around the province, working with other agencies such as local Stewardship Councils in their local area. The Community Stewards will assist with workshops, tours, displays, and other events.

Related independent study courses are also being developed to enable those interested to build their own knowledge on the management of woodland, wildlife, and ponds and streams. It is hoped that the program will spread across the province over the coming years to provide a major opportunity for volunteer community service for interested landowners.

Four major publications of this program are now available, in addition to the booklet “Greening the Land,” described above. These include:

1. A Pocket Guide to Ontario Trees and Some Woodland Plants
2. Taking Stock: Preparing an Inventory of Your Woodland
3. Management Options for Old Field Ecosystems
4. The Woodland Stewardship Handbook

We are developing a marketing plan to pay for the printing of such publications through sales. The main emphasis will be on selling these at a wholesale price, for resale to landowners by local organizations. Individual copies can also be purchased. If interested, or for a price list, please contact Peter Mitchell at the Centre (519-824-4120, ext. 8329).
Land Stewardship

Chair of Land Stewardship

Michael Goss

In light of the contraction in the number of faculty in the Department, Michael Goss agreed to take on the role of a regular member of faculty, while retaining position of Chair of Land Stewardship. The major thrust of the Chair program continues to be the evaluation of farming practices for sustainable production. Two studies are underway in conjunction with the farming community. The Ontario Farm Environment Coalition was formed in 1992 by the Ontario Federation of Agriculture, the Ontario Farm Animal Council, the Christian Farmers Federation of Ontario, and Ag Care.

The concept of a study to develop a cooperative partnership between farmers and municipalities through the establishment of demonstration sites on groundwater protection was agreed with the Deputy Ministers of the Ontario Ministry of the Environment and Energy, and the Ontario Ministry of Agriculture, Food and Rural Affairs, early in 1995. The specific objectives of the first study are:

1. To demonstrate the feasibility of improving nitrogen use efficiency on farms by pro-active operator implementation of current best management practices.
2. To assess the impact of adopting current best management practices on the quality of water moving to groundwater resources.
3. To investigate a cooperative process for the assessment of N-management concerns and subsequent implementation of farm-specific solutions that meet the needs of all stakeholders.

The study has two phases. In the first phase, nitrogen management concerns at the site will be assessed using a nitrogen balance approach. Changes in management practices will then be developed by the farmers, who will be supported by local agents of government ministries, and other technical experts. In the second phase, the effect of changes in nitrogen management on the quality of water leaving the rooting zone will be determined by direct monitoring. The economic consequences to the farmer from making the changes will also be determined.

Throughout the study, the process of developing cooperation between the farming community and local municipalities for the protection of groundwater is being observed by Stewart Hlts.

The first site was established on 31st October, 1996. This site comprises five farms in Wilmot Township, of the Regional Municipality of Waterloo. Two sites are dairy farms, the third farm has a beef feedlot, the fourth farm is a farrow-to-finish hog operation, and the fifth farm grows cash crops. Transects have been laid out on each farm, where monitoring of soil, crop and drainage water will take place at different landscape positions.

The second study has been linked to this partnership project, and aims to identify the concentration of nitrate leaching from soil when crops receive no nitrogen fertilizer or manure—baseline nitrogen leaching. Strips, which receive no nitrogen, will be established on fields of each farm, and the quality of water leaving the rooting zone will be monitored. Nitrate leaching from these
strips will be compared with that from the transects receiving fertilizer or manure.

These two studies represent a major commitment by the farming community to ground water protection. Farmers have adopted a pro-active stance to this issue, instead of having to react to legislated restrictions.
Environmental Geology
Stacked multiple small Gilbert-type deltas in the Pliocene extensional basin of Radicofani, Italy

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Numerous extensional basins have developed west of the Northern Apennines mountain divide, starting in late Miocene times in the Tyrrenhian Sea area, and becoming younger eastward. Large half-grabens developed with NW-SE trends, subdivided longitudinally by highs associated with transfer zones. One of the largest, composite examples (200 km long and 20 km wide) is the Siena-Radicofani Basin. Along the eastern side of the Radicofani Basin, near the master fault system, large, fault-bounded, clastic wedges about 400 m thick developed during the lower Pliocene. A 115 m high exposure along a fault plane displays a sequence of about thirty, stacked, small, basinward-oriented, tendentially planar foresetted layers of cobble to bouldery conglomerates and sandy conglomerates up to 5 m thick. We interpret these layers to be prograding transverse bars representing Gilbert-type deltas. The successions of stacked Gilbert-type deltas are subdivided into two halves by a very large, massive to laminated, coarse sandstone layer, which is several metres thick, and which is flat-based along the exposure, with occasional disperse pebble and cobbles. This sandstone represents the filling of a very large flat-bottom channel. Large channels with erosional bases that are metres deep are visible on an adjacent exposure cut perpendicular to the main section.

The foresetted units show both angular and gradational lower boundaries, the latter merging asymptotically into thin sandy units (bottomsets), and truncated (planed) top boundaries, over which rest outsized boulders both in clusters or isolated (topsets). Several foresetted units show thickness changes and thin out to disappear basinward. Some of their component carbonate clasts show perforation by lithodomi, indicating their source from shore settings. Sparse, comminuted plant matter is present in some sandy interlayers. Fossil fragments, mostly oysters, are rarely observed in the main body of the foresetted successions. However, the foresetted interval grades toward the top of the exposure, by alternation, to non-foresetted, locally well imbricated, thin, sandy conglomerates, and to coarse sandstones with few pebbles and cobbles. At some horizons, these upper cobbles have their upper surface encrusted by small colonies of balanids and by large oysters, locally isolated, in places forming a quasi-continuous colony. Foresetted units interlayered with these fossiliferous materials contain abundant oyster fragments, indicating reworking of nearshore deposits.

The entire clastic wedge becomes progressively finer upward, to terminate into highly fossiliferous and biotubated
sandstones. Essentially the foresetted units show an overall, but irregular, retreat toward the basin margin, being replaced in the study area by fossiliferous, shallow marine deposits.

We interpret this rock succession to represent the filling of a fault-bounded, persistent valley formed at the master-fault margin of the extensional basin during the punctuated, progressive transgression of the lower Pliocene that has affected the whole region. The depositional events have been modulated by the tectonic activity and by the overall transgression; however, the high-frequency foresetted events suggest also a climatic control that may have affected the sediment discharge into the valley.

Fluvial and sediment dynamics of Moose river, Moosonee, Northern Ontario, a subarctic estuary affected in part by human activity

Tania N. Poehlman and I. Peter Martini
Land Resource Science, University of Guelph

The upper reaches of the Moose River estuary have been analysed in terms of the present and past fluvial and sediment dynamics under winter, spring, and summer conditions. More specifically, the geometry of this environment was defined, the processes affecting it were identified and measured, the materials transported through it and deposited within it were analysed, the facies that characterize it were identified, and the human activities affecting it were identified and qualified. The information acquired through this study may be used for future management strategies designed for this area.

The upper estuarine reaches of the Moose River exhibit an anastomosing geometry with two main channels: the North Channel, with a well defined broadly meandering thalweg, and the South Channel, which lacks a well defined thalweg. These reaches contain numerous shoals and emerging bars, and a network of longitudinal and transversal secondary channels that are separated by vegetated islands. The river itself is bound by high, steep banks that climb up to 4 m nearly vertically.

The main natural factors acting within this environment are fluvial flow, tides from James Bay with a range of up to 2 m, isostatic uplift of up to 1 m per century, and meteorological conditions. The summer fluvial current velocities reach a maximum of 1.9 m s⁻¹ in the thalweg of the North Channel. However, flow in this reach is highly variable, in part due to the tidal influence from James Bay, which acts as a dam against the fluvial flow and forces water back-up the estuary every 6 hours. Although the salt wedge does not extend as far as Moosonee, the tidal influence is felt as a change in water level of 1 to 2 m, and a complete reversal of fluvial current direction. Meteorological conditions such as wind can
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enhance or almost eliminate either the flood or ebb stage of the tidal cycle, depending on its magnitude and orientation. In the study area, there also is both a geomorphological slope (channel bed), and a hydraulic slope that is set up from the South Channel to the North Channel. These slopes result in the transfer of water from the South to the North Channel via transversal secondary channels.

The materials deposited in the upper reaches of the Moose River estuary are predominantly sand. Some fines (mud) can be found in a few secondary channels. Tyrrell Sea clay substratum is typically exposed near the banks of Moosonee and some secondary channels. There are also areas of poorly sorted sandy gravel (ice rafted accumulations). Open work gravel is rare, and only found in some shoals and the uppermost measured part of the North Channel. Material in transport through the upper reaches of the estuary is greatest during the spring freshet and lowest during the summer, although variable fluvial conditions during the summer can result in highly variable local sediment transport rates. Migrational bedforms (dunes) and bars dominate the channel floors. Island growth is in a downstream direction, with the development of sand bars such as the Moosonee Bar. The surficial morphology of the Moosonee Bar is dominated by sandwaves with superimposed ripples. Ice rafted material is preferentially deposited and later reworked at the upstream end of the bar, while cohesive fines (mud drapes) blanket much of the downstream end. Vegetation is already stabilizing areas of higher elevation on the bar, thereby encouraging its development into an island.

The human activities affecting this environment include bank deforestation and degradation, shoreline protection, dredging, gravel excavation, transportation, flow regulation, and chemical loading. The already steep banks, which are naturally susceptible to failure, are weakened further by the removal of stabilizing vegetation and loading by buildings and traffic along the shores of the communities of Moosonee and Moose Factory. In an attempt to protect property from future loss, extensive shoreline protection structures have been built at the town sites. These structures, however, have locally acted to transfer the erosion problem to nearby unprotected banks. The material eroded from the banks is then added to the already shallow channels of the upper estuary. Dredging and gravel excavation can locally modify flow conditions by changing the channel geometry. Flow regulation by dams upriver from Moosonee can be felt in the upper estuary of the Moose River. Chemical loading may be a future problem given present population growth trends of Moosonee and Moose Factory. At the present time, however, the analysis of cores taken from selected sites where fine material was deposited indicated no major chemical contamination of the sediment.

In considering future development of the shallow and anastomosing conditions of the upper estuarine reaches of the Moose River, note should be taken of the fact that the vital transportation routes presently used by the inhabitants of Moosonee and Moose Factory will become increasingly hazardous as shallowing of the channels increases due to the natural processes of isostatic uplift, and the progressive capture of the flow of the South Channel by the North Channel.
Petrographic characteristics of selected Ontario peats: possible modern analogues for coals

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Despite the prevalence of modern cold-climate peats in the Northern Hemisphere, few studies have attempted to utilize petrographic and micromorphological properties to evaluate cold-climate peats as coal precursors. Such peats may serve as modern analogues to Permian Gondwana coals, and offer some insight into the processes of their formation.

Peat profiles were sampled from a raised bog and an interior fen located in the cold boreal Hudson Bay Lowlands, Northern Ontario, a cold temperate swamp in Eastern Ontario, and a cold temperate bog in Southwestern Ontario. Sampling locations were selected in order to provide a range in climatic, trophic, and vegetational conditions. Thin sections and polished blocks were prepared from the profiles at 15 cm intervals. Thin sections were examined in transmitted light to observe the micromorphology, while the polished blocks were used for petrographic analysis, using reflected white and ultraviolet light. Information derived from these analyses was used to infer the changes in trophic conditions during deposition, and the post-depositional processes leading to the formation of specific macerals.

Study results indicate considerable differences between the environments. The cold boreal bog consists predominantly of Sphagnum-derived textinite (profile average: 70.2%), with liptinite and inertinite group macerals making a significant contribution only at the base of the sequence. The cold boreal fen profile consists of macerals derived from diverse vegetation, which is reflected in the more significant liptinite group content (profile average: 15.65%). The cold temperate swamp shows evidence of extensive humification at the surface and at depth, with a maceral assemblage consistent with an input of partially oxidized woody materials. The cold temperate bog profile contains predominantly textinite (average: 56%), humogelinite (average: 16%), and humodetrinite (average: 10%), indicating fluctuations in the trophic conditions, with a corresponding change in the degree of post-depositional alteration. In all profiles, sclerotinite was persistent, ranging from 2.4 to 9.5% of the total maceral content, indicating that aerobic conditions generally prevailed at the surface at the time of deposition.

The petrographic study also demonstrated that no profile contained the high inertodetrinite and semifusinite contents associated with cold-climate cratonic Permian Gondwana coals. Since the high inertinite contents are believed to result mainly from surficial oxidation due to a fluctuating watertable, it is reasonable to assume that if the peats studied were to contain a similar maceral assemblage upon coalification,
inertinite precursors would be present at the peat stage. The differences between the recent peats and the Permian coals may be related to a number of factors. Watertable levels may have been subject to long-term decline in the Permian environments, following the cessation of peat formation, thus allowing oxidation to take place. The change in the peat-forming vegetation, from Permian *Glossopteris*- and *Gangamopteris*-dominated communities to recent *Sphagnum* and coniferous vegetation, changes the characteristics of the initial botanical starting materials, which may influence the resulting coal. Additionally, peatland ecology is, in part, controlled by the constituent vegetation, and so differences in vegetation will alter the trophic and pH conditions controlling the humification of the plant materials, thus changing the resulting maceral assemblage.
Deposition of gravelly bars at the junction of two regulated streams in Northern Ontario: Mattagami River and Adam Creek

Sarah-Jane Mosher and I. Peter Martini

The geometry, flow, and sediment transport patterns at the confluence of the Mattagami River and Adam Creek have been analysed with emphasis on studying the development of coarse-grained gravel bars formed at, and just below, the confluence area. The gravel bars, consisting of a junction bar and three alternating side bars, formed as a result of flow regulation of the Mattagami River and diversion of water through Adam Creek.

The Mattagami River and Adam Creek are part of the Moose River drainage basin, which flow northward, emptying into James Bay. Hydroelectric dams were built on the Mattagami River by Ontario Hydro in 1963 at locations on the Precambrian Shield near the boundary with the Hudson Bay Lowlands. The southernmost of these dams has a headpond to store water for dam use. When the ice and snow are melting during spring freshet, the headpond is not able to contain the excess water, which has to be diverted through an emergency spillway, Adam Creek. The creek rejoins the Mattagami River, 34 km downstream, 17 km below the last dam.

Each spring, a large volume of water is rerouted through Adam Creek, causing a flow of up to 4500 m$^3$ s$^{-1}$. The banks of the last 13 km of Adam Creek are composed of Pleistocene till and other soft sediments of the Hudson Bay Lowland, and so they are subject to erosion. To date, it has been estimated that over 52 million m$^3$ of sediment has been eroded from the creek. Approximately 2.5 million m$^3$ of that material is deposited at the junction in the four gravel bars consisting predominantly of coarse material: cobbles and pebbles with lesser boulders and sand. Such coarse material comprises less than 5% of the total volume of material eroded from the creek. The remaining 47.5 million m$^3$ of sand and finer material is transported further downstream.

The main body of the gravel bars is believed to have formed during the first few large floods following river impoundment and spillway use, when enormous amounts of erosion occurred along the Adam Creek spillway. Since then, various sections of the bars have been reactivated by subsequent floods, and have undergone numerous cycles of erosion and redeposition. Presently, the junction bar is lobate in form, and is comprised of three large chutes, which funnel flow from Adam Creek into the Mattagami River. The first two side bars are very similar in form. Both bars have an older section of the bar now seldom inundated, secondary chutes with chutes bars terminating onto the upstream section of the bars, a side channel separating the bar from inner bank, and a lower bar area which is reactivated more frequently than the higher older section. The third side bar differs slightly in that it is much lower in elevation, and it contains slightly finer sediments.

The alternating pattern of the gravel
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bars developed because of the formation of low-velocity, flow-separation zones, within the confluence area. These zones modify this reach of the Mattagami River from a long wavelength, meandering channel, to a shorter wavelength, deeper thalweg bounded by the gravel bars.

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Sedimentological facies analysis of alluvial, highly concentrated flow deposits

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The term “hyperconcentrated flow” refers to the continuum of transport and depositional mechanisms between debris flows, grain flows, and stream flows. Whereas the end members are fairly well understood, further subdivision and definition of hyperconcentrated flows escape unanimity, both in meaningful rheological terms and, more so, in terms of characteristics of their sedimentary deposits—particularly in alluvial settings. This research focuses on the analysis of three deposits that are possibly associated with highly concentrated flows: the first two developed in ancient, temperate, alluvial fans and fan deltas of Miocene-Pleistocene extensional basins of the Northern Apennines, Italy, and the third in Pleistocene glacial outwash plain of Ontario, Canada.

The sedimentological analysis of alluvial, highly concentrated flow deposits is still at its infancy, and remains qualitative in nature. However, as with other systems, such as with the study of flow regimes in open channels, and the study of turbidity currents, the study of highly concentrated flows will eventually resonate with rheological subdivisions. Once this development of the subject has been accomplished, the sedimentological analysis of facies can unravel the history of specific areas, and thus contribute significantly to their risk-assessment analysis.
Mercury pollution resulting from small-scale gold processing in the Shamva area of Zimbabwe

P. van Straaten, J. Chihota, T. Chirenje, L. Evans, and T.R.C. Fernandes

Serious health and environmental problems related to the use of mercury in gold mining are evident in some areas of Zimbabwe. The careless use of mercury for gold processing is widespread, and probably affects tens of thousands of gold miners in Zimbabwe, and in neighbouring countries in Southern and Eastern Africa.

Zimbabwe is a country well endowed with minerals. Mining and agriculture form the economic mainstay of this southern African country. There are two types of mining activities in Zimbabwe: the medium-scale to large-scale mining of gold, diamonds, nickel, asbestos, coal, lithium minerals, copper, and chromite, which are carried out by mining companies, and the small-scale to artisanal mining activities that are carried out mainly for gold.

Up to 300,000 Zimbabweans are seasonally involved in small-scale gold mining, and the number of people involved is still growing due to tough economic conditions that are experienced by the rural and urban poor. These small-scale mining activities also attract many people from neighbouring countries: i.e. Mozambique, Malawi, Zambia, and Tanzania.

Gold is mined from alluvial deposits along major streams, and from small but rich gold quartz veins, which are known as reef gold. The alluvial gold mining takes place along approximately 4600 km of rivers in Zimbabwe, although special mining permits have been issued in the past few years for the mining of only 620 km. Alluvial mining is very destructive. The miners remove the vegetation, resulting in increased soil erosion, river siltation, lowering of the water table and causing general land degradation. The land is usually not rehabilitated after mining ends.

Mining of reef gold is concentrated either in areas with small but rich gold quartz veins that are not being mined by large mining companies, or in areas with abandoned underground gold mines.

Two methods are used by small-scale miners for the recovery of gold. One is the simple washing of the gold-containing ores in wooden gold pans. The other method involves the use of a “sluice box,” consisting of a blanket or a woven rag, which is laid down on an inclined wooden frame with wooden riddles. A slurry of water and gold-bearing sediment is poured over the sluice, and the heavier gold particles settle behind the wooden riddles on the slope. In both processes the larger pieces of gold can be removed from the slurry by hand. The finer particles of gold and other heavy minerals, however, cannot be removed by this method.

Very fine gold particles are recovered by the use of mercury through the amalgamation process, which involves the physical mixing and alloying of gold with mercury.

While most of the alluvial gold operations use only the panning method, the use of the amalgamation process is almost
exclusively the method of choice for small-scale reef gold miners. The miners recover gold ore from small gold-bearing veins close to the earth surface, or from old abandoned gold mines, using simple digging tools. The gold ore is then carried to their homes on their shoulders or in wheelbarrows. There, the ore is crushed with hand-held tools, sieved, and the fine materials are panned in wooden washing pans. The heavy mineral concentrate, which includes the gold, remains at the bottom of the pans. This concentrate is subsequently mixed with mercury using unprotected hands. Fine gold particles, which cannot be recovered by simple separation techniques, are alloyed with mercury to form an amalgam, which consists by mass of 50 to 60 % mercury and 40 to 50 % gold. The amalgam forms an easily recoverable “bat,” or bead, which is then wrapped in a piece of cloth and squeezed to recover excess mercury for subsequent use. A common way of removing excess mercury is by pressing the amalgam in the palm of the unprotected hand (Fig. 1).

The gold from the amalgam bat is recovered by heating on an open fire. The amalgam is wrapped in a piece of paper and burnt in an open crucible or other small container, either in the open air in the immediate vicinity of the miners’ homes (Fig. 2), or even inside their homes. The burning of the amalgam is often carried out in the presence of family members, including small children. The miners carry out this process without any knowledge of the
harmful effects of mercury vapour.

As part of a project supported by the Environmental Capacity Enhancement Project of the Canadian International Development Agency, a preliminary study was carried out during 1996 in a reef gold mining area near Shamva, some 80 km NE of the capital Harare. The objective of this initial survey was to study the fate of mercury in the environment. The survey included sampling of soils, stream sediments, water, and air in the mining area, and in the downstream drainage area.

The preliminary study indicate that, during the heating process of the amalgam, up to 1 g of mercury is lost into the environment for every gram of gold recovered. Most of this mercury escapes as vapour into the atmosphere. Air samples taken during the burning of the amalgam using a Gastech precision gas detector revealed mercury vapour concentrations of up to 5 mg m\(^{-3}\). These concentrations pose a potentially serious health hazard to people exposed to them—the toxicity threshold limit value for mercury vapour in air is 0.05 mg m\(^{-3}\), with chronic intoxication at 0.5 mg m\(^{-3}\), and acute intoxication at 10 mg m\(^{-3}\).

Analyses of soil samples from gold processing sites revealed mercury concentrations of up to 25 mg kg\(^{-1}\), compared to average background soil mercury concentrations of 0.098 mg kg\(^{-1}\). A sample taken from a soot coating inside the roof of a miner’s house where amalgam had been burnt had a concentration of 104 mg kg\(^{-1}\). Samples of “tailings,” which were stacked next to the house of a miner, reached 1560 mg Hg kg\(^{-1}\).

The analytical data show not only alarmingly high levels of mercury, but also reveal high concentrations of arsenic, with up to 3300 mg As kg\(^{-1}\) in soils, and 3200 mg As kg\(^{-1}\) in the tailings next to the miners’ houses, compared to the average background arsenic concentrations of 11.3 mg kg\(^{-1}\) in soil.

The stream sediment and water samples collected during the dry season at sites downstream from the mining areas revealed relatively low levels of mercury. This indicates that, as yet, mercury has not been transported very far from the processing sites. This low dispersion may be due to the fact that the use of the amalgamation technique started only some five years ago. However, further sampling is planned during, and shortly after, the rainy season. In order to study the possible bio-accumulation of the toxic species methyl-mercury, this forthcoming survey will also include taking samples of fish.

The results from the initial survey of soil, stream sediment, water, and air around the area of a small-scale gold mining population of approximately 3,000 people revealed that small-scale miners and their families are at an extremely high occupational health risk. Practical measures to reduce this risk are being addressed by scientists and Zimbabwean officials.

A larger project to reduce mercury pollution in Zimbabwe’s small-scale gold mining areas is planned. We will start with discussions with miners to raise their awareness of the health hazards related to the handling of mercury. Detailed geochemical surveys will continue, accompanied by epidemiological studies, participatory research on health and environmental protection, and the development of a simple, locally produced mercury recycling device.
Publications and Seminars
Land Resource Science

Books


Chapters in Books


Papers in Refereed Journals


Land Resource Science


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Non-refereed Reports and Publications


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Seminars and Papers Presented


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