Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

Final Progress Report

Project Title: (Insert Title)

DRI Investigator: Masaki Hayashi

1.0 Project Work

1.1 **Provide a summary description of a) the objectives of the study, b) the scientific findings and c) the project work undertaken.**

The overall objective of the Drought Network Initiative (DRI) is *to better understand the physical characteristics of and processes influencing Canadian Prairie droughts, and to contribute to their better prediction, through a focus on the recent severe drought that began in* 1999. To address this overall objective, the Network is focussed on complementary and cross-cutting research objectives that correspond to the following themes:

1. **Theme 1: Quantify the physical features of this recent drought:**
a) spatial and temporal features;
b) flows of atmospheric and terrestrial water and energy into and through the region, and their storage and redistribution within the region.

Theme 1 (20 %)
Case studies at two locations, Irricana and Acme, in southern Alberta showed that the groundwater level at these two areas steadily declined during the 1990's, into the drought period. However, the declines were primarily caused by over-pumping, rather than the meteorological forcing. This suggests a need to distinguish the effects of pumping and reduced recharge during the drought. The analysis of groundwater level recorded in the West Nose Creek watershed indicated that the recovery of water level from the 1999-2002 drought took two to three years.

2. **Theme 2: Improve the understanding of the processes and feedbacks governing the formation, evolution, cessation and structure of the drought.**

Theme 2 (70 %)
The main objective is to understand how the meteorological forcing factors (e.g. reduced precipitation) affect groundwater during and after droughts. Our field observation at the West Nose Creek watershed indicated that majority of groundwater recharge occurs under topographic depressions that fill up with snowmelt water. Therefore, the focus of our process study was on characterizing depression-focussed groundwater recharge. Our field monitoring and data analysis showed that evaporation during the growing seasons uses up essentially all soil moisture on uplands surrounding depressions. Snowmelt runoff generated

over the frozen soil is critical for filling depressions and causing subsequent infiltration and recharge. The groundwater level data from the West Nose Creek observation well network showed very little spring rise (i.e. recharge) in years with little snowmelt runoff. Groundwater recharge is strongly influenced by the amount and timing of snowmelt, which is dependent on the winter weather conditions (e.g. timing and amount of snowfall, occurrence of mid-winter melt).

3. Theme 3: Assess and reduce uncertainties in the prediction of drought and its structure.

Theme 3 (10 %)
Our objective for Theme 3 is to develop a groundwater recharge model and couple it with existing groundwater flow model. The coupled model will provide an effective tool for the prediction of drought impacts on groundwater resources. We selected the Versatile Soil Moisture Budget (VSMB) model as a prototype of recharge model. The VSMB is used operationally by the DRI partner, Alberta Agriculture and Rural Development (AARD). Therefore, any improvement made on the VSMB by DRI will directly benefit these partners. Using the field data collected at the West Nose Creek watershed, we have made improvements in evaporation, soil freezing-thawing, and snowmelt modules of the VSMB, incorporating our results in Theme 2. We have started setting up a detailed three-dimensional groundwater flow model of the West Nose Creek watershed.

1.3 **Describe the tangible results or the measurable outputs generated by the project and how these results have been taken up by user groups for policy development or operational improvements.**

The groundwater monitoring network at the West Nose Creek watershed was mainly built from existing water supply wells. The methodology has been adopted by the County of Rocky View to establish a larger-scale groundwater monitoring network. This is an example of direct contribution of the DRI project to water resource management.

2.0 <u>Impact</u>

2.1 Describe in broad terms how your work has contributed to the overall objectives of DRI and to our scientific understanding of drought.

Our work have shown that the hydrological drought regarding groundwater takes a longer response to the meteorological drought, compared to surface water, and takes a longer to recover from the drought condition. In addition to the amount of precipitation input, many other factors influence groundwater recharge, which occurs as a result of snowmelt runoff filling up depressions. The groundwater recharge model being developed by our group will provide the essential link between meteorological forcing and groundwater response, thereby improving our understanding of groundwater during and after droughts.

2.2 Describe the significance / impact of the results in terms of some or all of the following areas:

- **The impact of the project on government policy development (federal, provincial or municipal);**
  County of Rocky View is using the DRI methodology for groundwater monitoring.

- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**
  Collaboration with AARD and Rocky View.

- **Whether and how it has enhanced or improved the reliability of predictive methods related to the science;**
  Not yet.

- **The impact of the project on your own institution (e.g. helped attract new students or personnel);**
  The project helped attract several graduate students and postdoctoral fellows.

- **Whether it has improved or increased the acquisition of funds from other agencies, or led to new partnerships;**
  The DRI project helped us secure new fund ($0.5M) for a project on groundwater sustainability in the County of Rocky View.

- **Any links with international initiatives and the potential impact of these (e.g. profile of Canadian science, influence on international programs);**
  Not applicable.

- **Any commercial or social application the results may have had or could have;**
  Not applicable.

- **The anticipated impact of the work on Canadians and their well-being;**
  Improved management of water resources including groundwater.

4.0 Reverse Impact Statement

4.1 Provide a reverse impact statement, describing what would have happened in terms of the project, the resulting science and the impacts on users/stakeholders, if the work had not been funded by CFCAS.

Without DRI funding, the West Nose Creek study would have been discontinued. This could have resulted in the lost opportunities for: 1) understanding groundwater recharge processes, 2) development and introduction of the locally-based monitoring, and 3) improvement of the VSMB.

5.0 Follow-on Science

5.1. Based on the findings of your research identify any outstanding scientific questions that need to be addressed in future drought studies.

The timing of the DRI project was appropriate for observing the recovery of groundwater from the drought. Using the research infrastructure established during DRI, we will be able to conduct detailed observation of groundwater during the entire period of next drought including the beginning.

6.0 Dissemination

6.1 Provide information on the dissemination of the research results (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Brimelow, J.C., Hanesiak, J.M., Raddatz, R.L. and Hayashi, M. 2010. Validation of ET estimates from the Canadian prairie agrometeorological model for contrasting vegetation types and growing seasons. Canadian Water Resources Journal, 35: 209-230.

Burns, E.R., Bentley, L.R., Hayashi, M., Grasby, S.E., Hamlin, A.P. and Smith, D.G. 2010. Hydrogeological implications of paleo-fluvial architecture for the Paskapoo Formation, SW Alberta, Canada: A stochastic analysis. Hydrogeology Journal, 18:1375-1390.

Grieef, L.A. and Hayashi, M. 2007. Establishing a rural groundwater monitoring network using existing wells: West Nose Creek pilot study, Alberta. Canadian Water Resources Journal, 32: 303-314.

Hayashi, M., Jackson, J.F. and Xu, L. 2010. Application of the Versatile Soil Moisture Budget model to estimate evaporation from prairie grassland. Canadian Water Resources Journal, 35: 187-208.

van der Kamp, G. and Hayashi, M. 2009. Groundwater-wetland ecosystem interaction in the semiarid glaciated plains of North America. Hydrogeology Journal,17: 203-214.

Zaitlin, B., Hayashi, M. and Clapperton, J. 2007. Distribution of northern pocket gopher burrows, earthworms and effects on infiltration in a prairie landscape in Alberta, Canada. Applied Soil Ecology, 37: 88-94.

Presentations in major national and international conferences:

Hayashi, M. and Xu, L. Watershed-scale modelling of depression-focussed groundwater recharge in the Canadian prairies. Joint Assembly of American Geophysical Union, Canadian Geophysical Union, Geological Association of Canada, Mineralogical Association of Canada, and International Association of Hydrogeologists-Canadian National Chapter, Toronto, May 24-27, 2009.

Hayashi, M. and van der Kamp. G. Interaction of groundwater with prairie wetland ecosystems in Canada. 36th Congress of the International Association of Hydrogeologists, Toyama, Japan, October 26-31, 2008.

Hayashi, M. and van der Kamp, G. Effects of depth-permeability distribution on groundwater exchange and water balance of prairie wetlands. Ninth Joint Groundwater Specialty Conference of the International Association of Hydrogeologists - Canadian National Chapter and the Canadian Geotechnical Society, Edmonton, September 21-24, 2008.

Wozniak P.R.J., Hayashi, M., Bentley, LR., Grasby, S.E. and Eckfeldt, M. Characterization of the Paskapoo for sustainable groundwater development: A modeling approach. Ninth Joint Groundwater Specialty Conference of the International Association of Hydrogeologists - Canadian National Chapter and the Canadian Geotechnical Society, Edmonton, September 21-24, 2008.

Hayashi, M. and van der Kamp, G. Groundwater-wetland ecosystem interaction in the semiarid glaciated plains of North America. Annual Meeting of the Canadian Geophysical Union, Banff, May 11-14, 2008.

Xu, L., Hayashi, M., Jackson, J. and Bentley, L.R. Estimating groundwater recharge under upland and depression using a simple soil water balance model. Annual Meeting of the Canadian Geophysical Union, Banff, May 11-14, 2008.

Hayashi, M. and van der Kamp, G. Using prairie pothole analogues to understand the hydrological response of closed lake systems. Annual Meeting of the Geological Society of America, Denver, Colorado, October 28-31, 2007. [invited]

Jackson, J., Chen, R. and Hayashi, M. Testing the Versatile Soil Moisture Budget model for groundwater recharge estimation in a northwest Canadian Prairie setting. Joint Annual Meeting of the Canadian Meteorological and Oceanographic Society, Canadian Geophysical Union, and American Meteorological Society, St. John’s, Newfoundland, May 28 - June 1, 2007.

van der Kamp, G. and M. Hayashi. A watershed-scale approach to groundwater-surface water fluxes in prairie wetlands. Annual Meeting of the Geological Society of America. Philadelphia, October 22-25, 2006.

Burns, E.R., L.R. Bentley, M. Hayashi, S.E. Grasby, and D.G. Smith. A new paradigm for the Paskapoo aquifer system: Evidence, implications, and modeling. Joint annual meeting of the Canadian Geophysical Union and the Canadian Society of Soil Science. Banff, AB, May 14-17, 2006.

6.2 Describe data management/sharing activities including organization of the metadata. Also, are the data being archived, and how will they be made available to other researchers?

The data collected from the West Nose Creek watershed have been used by other DRI researchers (John Hanesiak and Alan Woodbury). The metadata have been entered in the DRI server, and the actual data are currently being compiled and will be uploaded to the DRI server by the end of November 2010.

6.3 Comment on any outreach or public information activities, including press interviews or other media interest or reports. Has the project helped to popularize science or increase public awareness?

We are developing a school curriculum (Grade 8 and 11) on groundwater. I had a field workshop for school teachers in July 2009 and July 2010.

7.0 Training

7.1 Quantify student and PDF involvement (indicate the level of each: undergraduate, masters, doctorate or PDF). If possible and within the Federal Privacy Act rules governing the collection of personal information, provide a general indication of their subsequent employment (i.e., university, industry, government, other, etc.), and indicate whether the employment was foreign or domestic.

Getachew A. Mohammed (PDF, university)
Ligang Xu (PDF, government)
Erick Burns (PDF, government)
Lisa Grieef (M.Sc., government)
John Jackson (M.Sc., industry)
Chris Farrow (M.Sc., university)
Sangeeta Guha (M.GIS, government)
Rui Chen (M.GIS, industry)
Nathan Green (B.Sc., university)
Matthew Eckfeld (B.Sc., industry)