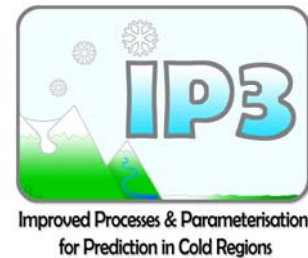


Report on the 1st IP3 Workshop

29 November 2006



Session I – Opening and Overview of IP3

Dr. Julie Friddell chaired the Launch of the Network and opening of the IP3 Workshop. The Launch began with **Mr. Bart Oegema** of the Saskatchewan Watershed Authority, presenting greetings and best wishes for IP3 from the **Honourable John Nilson**, Minister of the Environment for the Government of Saskatchewan. The Province of Saskatchewan lies downstream of the cold regions headwaters of the Saskatchewan River system and so has great interest in the results of IP3.

Dr. Tim Aston of the Canadian Foundation for Climate and Atmospheric Sciences, Ottawa described the Foundation, the review process that led to approval of IP3 and the great interest of the Foundation in the success and results from IP3.

President Peter MacKinnon of the University of Saskatchewan warmly welcomed all to Saskatoon and the University and detailed the long history of hydrology at the University from the Division of Hydrology to the Centre for Hydrology, the accomplishments of Professor Don Gray in guiding the development of Canadian hydrology from Saskatoon, the involvement of hydrology in the University's innovation agenda and integrated plan, the close relationship between Environment Canada and the University, the importance of climate and hydrology to society on the prairies and the great interest the University has in the success of IP3.

Professor Ming-ko Woo, of McMaster University, Chair of the IP3 Board of Directors discussed the governance and accountability of IP3 and the importance of scientific advances in the area of cold regions hydrology and meteorology given the developmental and environmental challenges facing Canada. He charged the investigators and students of IP3 to take on the great scientific challenges that remain in Canada's cold regions.

Dr. John Pomeroy, Chair of the IP3 Scientific Committee and Principal Investigator gave a presentation on the objectives, overview, and current Status of IP3 including its thematic structure and linkages to national and international science programmes. IP3 will operate from 2006-2010 and is headquartered at the University of Saskatchewan. IP3 is targeted towards:

a) Understanding the key climate system processes relating to the hydrometeorology of cold regions,

b) Parameterising land surface hydrology processes that control the coupled atmospheric-hydrological system in cold regions;

c) Validating and improving models for weather, water and climate systems leading to better prediction and simulation of related atmospheric impacts on water resources and surface climates in cold regions.

IP3 is organised into three themes, Theme 1 - Processes, Theme 2 - Parameterisation, and Theme 3 - Prediction. Using these themes, IP3 is developing an improved understanding of cold regions hydrometeorology and testing advances in atmospheric and hydrological prediction in the Rocky Mountains and the Arctic along a transect of high latitude and high altitude instrumented research sites that characterize the cold regions of Canada. IP3 is a component of the International Polar Year, the Global Energy and Water Cycling Experiment and the International Decade for Prediction in Ungauged Basins. IP3 makes a contribution to better weather and climate prediction, to estimation of streamflow from ungauged basins, to predicting changes in Rocky Mountain snow and water supplies, to calculating freshwater inputs to the Arctic Ocean and to sustainable management of mountain and northern water resources. These issues are of key importance to agriculture, urban and industrial development in the Prairies and northwest.

Session II – Processes

Session two was chaired by **Dr. Sean Carey** who summarized process experiments to be conducted under the IP3 network; however it is important to note that there is substantial overlap in research with Session III – Parameterisation. All investigators in Theme 1 (processes) are involved in Theme 2 (parameterisation), with a large fraction of Theme 2 investigators participating in Theme 1. Process research can be summarized into three broad categories: terrestrial, open water and snow.

Dr. Sean Carey opened the session with a summary of the Wolf Creek Research Basin, Yukon Territory and the research that has occurred regarding runoff processes in the last ten years highlighting the importance of organic soils, permafrost disposition and ecosystem properties (i.e. shrub vegetation) in controlling lateral delivery of runoff to the stream. Dr. Carey presented two objectives:

- (i) Determine how connectivity in the drainage network controls streamflow response at the larger (HRU) scales, and
- (ii) Improve understanding and characterization of frozen soil infiltration and hydraulic properties, particularly for organic soils.

To assess objective (i), a nested watershed approach will be used whereby the integrated basin response will be monitored using hydrometric quantities, ion chemistry and stable isotopes. The role of different ecozones, topology and channel processes will all be examined, and high-frequency water quality data will be used to provide new insight into basin-wide hydrological functioning. To assess objective (ii), field and laboratory studies of organic layer infiltration and percolation will be conducted. Infiltrimeters, column experiments, pressure plates, and image analysis will all improve our current state of understanding regarding organic soils and provide detailed physical information for the

development and testing of numerical parameterisation schemes. Results from these experiments will be focused on representing processes centered on the concept of the HRU, which is a central feature of the Cold Regions Hydrological Model (CHRM).

Dr. Masaki Hayashi outlined his research program at the Lake O'Hara Research Basin, British Columbia. The fate of meltwater has typically been ignored in studies of glacierized basins and the temporal and spatial redistribution of glacier meltwater within catchments is largely unknown. Dr. Hayashi will examine glacier and snow processes in association with Dr. Shawn Marshall [WC²N Network, U. of Calgary] and Dr. John Pomeroy, while his group will focus on surface/subsurface flow interactions. Lake O'Hara will be closely monitored to evaluate inflows and outflows, while hydrometric and water geochemistry and temperature will reveal pathways and transmission times of water through the basin. The contribution of glaciers versus snow at the Lake O'Hara and larger scales will be assessed.

Dr. Raoul Granger began the third talk exploring several hydrological “myths” with regards to evaporation; particularly that land surface methods of evaporation can be translated to open water and that lake evaporation is controlled by energy supply. Data was presented for Quill Lake that demonstrated land and open water evaporation were unrelated, and introduced several reasons as to explain why there would be differences in the physical processes of evaporation, highlighting advection and penetration of energy into the water column. As part of IP3, Dr. Granger will examine improved methods of estimating evaporation from lakes. Principally, the Weisman and Brutsaert (1973) method that involves energy advection from land to open water will be used and extended to include parameterisation for stable atmospheric conditions common over lakes. The modeling of energy exchanges can be also be aided by formulating non-dimensional equations that allow for inherent relationships to be observed in the model over a certain input range of interest. Dr. Granger's experiments will require knowledge of water and land surface temperature and atmospheric fluxes combined with a boundary layer model capable of representing the advection of energy. Experiments will be conducted on Crean Lake, Saskatchewan due to the suitability of the lake for micrometeorological measurements.

Mr. Richard Janowicz discussed the transferability of northern hydrometeorological processes for engineering design applications in cold regions. Mr. Janowicz organizes and coordinates research within the Wolf Creek Research Basin, Yukon Territory and has been involved in examining all aspects of its hydrology. Recent research has explored the utilization and the transferability of northern hydrometeorological process information obtained in Wolf Creek to an abandoned mine in the Yukon. The Faro mine complex was introduced as a case study, which is a large abandoned lead zinc mine where concerns over acid-rock drainage exist. The objective of this research was to develop a complete waste-rock structure water balance using process information obtained from previous northern hydrological research studies and incorporated into the CHRM. CHRM was used to model the hydrology of this mine by dividing the waste rock dumps up into HRUs. In each of the rock dumps the researchers placed two meteorological stations, and snow surveys and water balance calculations were performed. Results indicated that the

CHRM model was able to predict various aspects of the water balance, validating its sub-routines developed explicitly for cold regions. The importance of scientific research for practical applications was highlighted as a continuing goal for researchers in northern regions and should be considered an important and integral part of IP3.

Session III – Parameterisation

Session Three was chaired by **Dr. William Quinton**, who summarised the current state and directions of parameterisation within the IP3 network. It is important to note that all researchers involved in the parameterisation theme, are also active in one or both of the other themes. As a result, there is some overlap between the material presented in this session with that presented in the other sessions.

Dr. Philip Marsh opened the session with a discussion of snow and lake hydrology at the boreal forest – tundra interface. This began with an update of the data collection infrastructure at Trail Valley and Havikpak Creeks, NWT. This includes meteorological stations that have been in place since 1991. Meteorological flux data has also been collected from the NRC Twin-Otter aircraft. This data set has been partially analysed in order to correlate with ground-based measurements to derive meteorological “foot prints”. Stream discharge is available from the Water Survey of Canada. Recently, LIDAR data has been acquired for Trail Valley, and will form the basis of a digital elevation model for Trail Valley. Dr. Marsh then outlined key areas for parameterisation at the Trail valley and Havikpak research basins. They include parameterising the spatial variation of surface energy fluxes, snow distribution and the effect of shrubs on both of these phenomena.

Dr. Scott Munro discussed research on the Peyto Glacier, Alberta in the context of the 25 m resolution used by Landsat. Six automatic weather stations are located on or near this glacier. The off-glacier stations provide background data for trends and the regional context, as well as the driving variables for spatial and temporal modelling. The on-glacier stations were used as focus sites for ablation and accumulation process work, and provided model validation data. Current research is focussed on eddy covariance confirmation of closure between bulk and between bulk and parameterised heat transfer, and on determining the nature of the glacier cooling effect.

Dr. John Pomeroy discussed parameterising snow processes, including snow accumulation, blowing snow, interception, sublimation and melt. This discussion began by focussing on the re-conceptualisation of snowpack layering and control volume boundaries to include longwave exchange at surface, shortwave penetration into the snowcover, and windpumping through the porous structure. Some process descriptions are in need of further field study. These include turbulent transfer problems in complex terrain, and radiation under canopies. Progress has been made in evaluating different parameterisation strategies in Marmot Creek Research Basin, Alberta. For example, the aggregate and distributed approaches to computing basin runoff response were compared to observed basin runoff in the Wolf Creek basin. Current development of

parameterisation schemes include representation of blowing snow, multi-layered snowcovers, and snow-atmosphere exchanges or the purpose of interfacing CRHM (Cold Regions Hydrological Model) with MESH.

Dr. Bill Quinton discussed hydrological process parameterisation in wetland-dominated basins containing discontinuous permafrost near Fort Simpson, NWT. In this region, the peatlands are predominantly peat plateaus, channel fens and flat bog predominate. Each of these cover types have a distinctive function in the overall cycling and storage of water: bogs store water, plateaus generate runoff and channel fens convey water to basin outlets. This distinction forms the basis of a conceptual model for runoff from drainage basins in this region. Current studies are focussed on runoff generation (peat plateaus), and on physically-based methods of parameterising runoff from individual plateaus to basins.

Dr. Ken Snelgrove discussed the representation of groundwater in the CLASS model. The GRACE gravity variation was explained in the context of the Western Canada Drought Study. Model calibration and validation was discussed using the example of the Assiniboine Delta Aquifer. CLASS serves as the intermediary between the atmospheric model (MM5) and the groundwater model (Modflow). This coupling framework was used to derive a distributed water balance, assisted by the twin GRACE satellites. Preliminary results were presented for the Mackenzie River basin, including atmospheric, hydrologic and GRACE-based change in storage relative to the mean Geopotential for the water years 2002-2004.

Dr. Chris Spence discussed the hydrological connectivity within basins of the Canadian Shield, specifically Baker Creek, NWT. His field studies have shown that lakes occur along the drainage way of basins, and as a result have a capacity to abstract runoff water that would otherwise take part in basin runoff. This effect is overcome when their storage capacity is exceeded so water can spill from their outlet into the downstream drainage system. The runoff response from drainage basins in this region is therefore not characterised by gradual increases and decreases in discharge as the source area for runoff gradually expands and recedes. Instead, large and abrupt changes in basin discharge are typical since the “fill and spill” mechanism in the lakes enables dramatic changes to the runoff contributing area over short time periods. Current research is focussed on the development of numerical representations of the fill and spill process, and incorporation of these into existing and new basin runoff models.

Session IV – Prediction

This session was chaired by **Dr. Alain Pietroniro** and compiled information from the process and parameterisation themes towards the goal of improved prediction.

As the first speaker, **Mr. Dan Bewley** discussed the main objectives of the research in **Dr. Richard Essery**'s research, focusing on parameterisation of radiation, turbulent transfer and snow distributions. Snow processes at the landscape can be captured using

detailed physical process models and sophisticated LiDAR information. It was clear that scaling these results for prediction will be a difficult but important challenge for the prediction program within IP3. The role of shrubs in the terrain investigated had a stringent control on the energetics of the system, demonstrating that landscape and terrain influences can dominate the hydrological response. This talk clearly highlighted the necessity for a flexible prediction system that could deal with variation in landscapes and terrain.

Dr. Murray Mackay related his experiences in developing the RCM under the Canadian MAGS program. Two main projects were presented: the first was a 10 year-run of current simulations using realistic forcing with CLASS 2.7. The idea is a planned run with CLASS 3 in the early phases of IP3. The second run which is anticipated to be done within the IP3 timeframe would likely be based on 100 years of recent past and near future simulations (1960-2060) for scenario studies using CLASS 2.7. These data could be made available to IP3 investigators. Both projects include the use of the current Climate model with CLASS 3 at a grid spacing of about 50 km. However, with both projects there is the possibility to downscale to different grid sizes (e.g. 15 x 15 km) using a nested version of the RCM, if requested by IP3 investigators. Also a model for numerical prediction on lakes (LAKE 1D) was presented. This model will be incorporated into CLASS to deal with resolved and unresolved lakes. The model is currently being tested and coded. Results from IP3 studies may very well feed into the development of this model.

Dr. Al Pietroniro introduced the MESH modeling system. It was noted that the proper description and quantification of the importance of sub-grid variability is one of the goals of IP3. The current version of the model is based largely on landscape-derived tiles, however the flexibility of the MESH system allows for transfer of water and energy between tiles (within a grid) and between grids as well. Also the importance of multi-objective automatic calibration was showed in order to help define specific parameterisations that could potentially be related to landscape or tile units. The hydrological routing algorithm within MESH (WATROUTE) was also described. The WATROUTE technique routes water and account for bank and stream flow with variable roughness with several options to link streamflow routing to groundwater, unsaturated zone, and sub-surface flows.

Dr. Ric Soulis spoke about modelling sub-grid processes in a meso-scale in a hydrological model. It was shown that the present and future requirements for further development of tile concept with hydrology-land-surface schemes should consider runoff generation processes for overland flow and interflow. The need for validation was highlighted along with the necessity to move away from hydrograph-based validation and instead use internal state variables for validation. The presentation highlighted key objectives in the prediction program, including the need to:

- (i) Integrate process studies at the basin scale,
- (ii) Parameterise sub-grid processes for MESH,
- (iii) Establish a common framework for the microscale hydrology and finally
- (iv) Develop physically based parameters that are transferable to ungauged basins.

Dr. Diana Verseghy introduced and described the evolution of Canadian Land Surface Scheme (CLASS) and its relation to the MESH modelling system. The versions of CLASS have been as follows:

- CLASS 2.7 (1997),
- CLASS 3.0 (2002),
- CLASS 3.1 (May 2005),
- CLASS 3.2 (May 2006)
- CLASS 3.3 (Nov 2006).

Dr. Verseghy highlighted the major recent changes in CLASS. The major changes in CLASS 3.3 related to programming aspects are that it is now compiled using FORTRAN90 and can be run using single precision. In terms of changes to the physics within the code, a number of changes were highlighted including moving from three soil layers to multiple soil layers, modelling liquid water in snow pack, the ability to unload snowfall for canopies and recent abilities to support the treatment of snow and soil calculations independently. The issue of version control was also mentioned and the science committee was encouraged to ensure that procedures for proper version control were being followed.

Dr. Bryan Tolson discussed enhancing model development and predictions with the Dynamically Dimensioned Search (DDS) Algorithm. Dr. Tolson noted that this algorithm was developed as a global optimisation tool for modeling calibration. Its salient properties are that it is fast, suitable for large number of parameters and its easy implemented. The DDS algorithm provides a good solution rather than a global optimum focus and attempts to mimic manual calibration procedure by first changing several parameters while later when a good solution is reached, modifying only a few. The DDS algorithm scales the search according to the set *a priori* at the computational time. Comparative tests with other well known calibration techniques used in the hydrological literature (i.e. the SCE algorithm and GLUE) methodology were presented. Also a Sensitivity analysis comparing DDS performance when varying 9 and 20 parameters was shown. It was clear that this algorithm would provide an important component in the overall computational toolbox within IP3.

Session V – Recent MEC, MESH and CRHM Development

Mr. Bruce Davison summarized recent advances in the MESH (MEC Surface Hydrology) modelling framework. He provided a discussion on progress of the MESH model to date and how it relates to other models such as CLASS and MEC. He pointed out that MESH is a subset of the current MEC system developed at RPN. It has two main components, a tile connector and a grid connector. MESH is closely associated with MEC, and it is intended to be deployed as a community model where input is given by members of IP3. MESH is closely associated with the development of other modeling endeavours such as CLASS and WATFLOOD, and it is the collation of these previous other models. Mr. Davison pointed out that one of the challenges with MESH is

developing a version control system so that consistent and rational code changes could be incorporated in a systematic way.

Dr. Vincent Fortin described « Le système de modélisation environnementale communautaire » MEC and discussed the thinking within Environment Canada on its development. He pointed out that the idea behind MEC was to make the surface scheme an independent component from the atmospheric model. By doing this it is possible to increase the spatial resolution of the land-surface scheme without changing the resolution of the atmospheric model. Dr. Fortin also noted that it is possible to run this model in an offline model (de-coupled from the atmosphere) to allow the land-surface to develop unconstrained. Examples were given of snow water equivalent estimates in southern Quebec derived from MESH in a stand-alone model as compared to observations. Dr. Fortin also described the current state of MEC source code development. The CLASS 3.2 driver was just completed and a number of bug fixes have been made. The department is moving towards MEC 2. This code will be available to the IP3 modeling community.

Dr. John Pomeroy and Mr. Tom Brown gave a presentation on the Cold Regions Hydrological Model (CHRM). This model is diagnostic software that provides a simulation platform for physically based hydrology. The Objective of the CRHM system is to develop a *hydrological cycle simulation system* that:

- (i) Can segment a basin or a hillslope such that the water balance for selected surface areas can be computed;
- (ii) Is sensitive to the impacts of land use and climate change;
- (iii) Does not require the presence of a stream in each land unit;
- (iv) Is suitable for testing individual process algorithms; and
- (v) Does not require calibration.

Dr. Pomeroy pointed out that CRHM was first developed as an experiment into model construction, and it has evolved into more of a research tool that can be used in the current context of the IP3 network. It developed from suggestions made by Drs. Don Gray, John Pomeroy, and Raoul Granger that were related to various challenges implicit in the modeling of cold regions. Dr. Pomeroy pointed out that the interface to CRHM consists of a native Microsoft Windows application written in a modern object-oriented language, C++. All of the observations made in the field are placed into an observation file. These variables can either be graphed or linked into the model. In the same manner as the components of an electronic circuit, various modules can be linked together in CRHM to form a much larger model. This can be done in a simple fashion, and does not require code re-write or re-compilation. Thus, various groups of researchers can place their model or algorithms into the program. The data is moved between each of the components. In addition, more advanced users can write macros in an interpreted language that is similar to C++, and these macros can be used to extend the model, and even change its structure. The data is plotted as the model runs, and the results can either be exported to a text file or an EXCEL spreadsheet. The exported data can then be taken into other programs which are used for post-processing of the data, or the data can be used to drive other models such as CLASS. The CHRM model can be run in either a distributed or lumped fashion. The basic unit of calculation in the model is the HRU

(Hydrologic Response Unit). During this presentation, a run of the model was successfully completed in front of the audience.

Session VI – Links to Related and International Initiatives

Session VII – Themes: objectives, actions, challenges, participants

Theme 1: Processes

Dr. Sean Carey provided a brief overview of Theme I presentations, highlighting again the importance of working with Theme II and the necessity of close dialogue between the two themes. The first general objective of Theme I is to provide a better understanding of terrestrial processes (runoff, infiltration, groundwater), particularly to link plot and hillslope scale findings with larger basin response. Terrestrial processes will be examined at several research basins and complimentary methods including hydrometric, hydrochemical and isotopic analysis applied. The second general objective is to obtain an improved understanding of open water evaporation processes. The research conducted initially at Crean Lake with respect to the adaptation of the Weismann-Brutsaert model and will hopefully be expanded to other lakes within select research basins in following years. The third objective is to obtain improved process knowledge of snow processes. This involves understanding the processes of turbulent transfer, internal melt energetics, flow processes within the pack, and meltwater delivery to the base. Dr. Carey encouraged the investigators involved with this network to begin their studies immediately as the first field season is 2006. In addition, if fine scale DEM or vegetation data is required, then IP3 will have to examine obtaining LIDAR for research basins. Consequently, DEM data should be available for each of the basins.

Theme 2: Parameterisation

Dr. Bill Quinton stated that the objective of this theme is to improve the basin-scale parameterisation of cold regions processes for small to medium scale modelling. The three main objectives are to:

- (i) Develop appropriate basin parameterisations and strategies to represent complex sub-grid HRU interactions of runoff and streamflow at the HRU tile scale;
- (ii) Consider the effects of sub-grid square lakes / ponds on regional scale fluxes; and
- (iii) Develop large-scale parameterisations of surface mass and energy balances for complex snow covered landscapes.

The parameterisation theme is unique in the sense that each of its researchers also plays key roles in the process and/or prediction themes. This theme consists of taking processes that are too complex to model in a complete fashion and finding simplified, but

physically-meaningful approaches to represent them at the hillslope and basin scales. Parameterisation schemes across the network are therefore in various states of development. Increased interaction among the different research basins was encouraged so that process descriptions would proceed in a consistent manner across the network.

Theme 3: Prediction

Dr. Alain Pietroniro noted that the modelling platforms for IP3 are CRHM and MESH. It was clear from the presentations that CHRM will be used for model diagnostic and testing. It was also clear that CHRM may be able to assist in basin segmentation and parameterisation. MEC and MESH (The surface hydrology of MEC) are based on NWP standards and require much more effort to re-code. CHRM provides a good testing mechanism for any prototype development. In order to test any developments in MEC/MESH a prototype of MESH is needed within the near future to help in driving the development of other models. This will allow for coding changes to be evaluated at the basin scale and save much overhead in the development of MESH.

Session VIII – Break-out Groups on IP3 Themes

Theme 1 - Processes

As part of the Theme 1 breakout, several milestones were identified as requiring immediate action:

- (i) getting all field sites running,
- (ii) identifying students to be associated with research projects, and
- (iii) obtaining a high quality DEM (preferably from LIDAR) for all research basins.

Following this, the discussion focused on the specific processes groups: open water, snow and terrestrial:

Open Water Processes:

The need for surface water temperature measurements was highlighted by Dr. Granger for application of open-water parameterisation schemes, and where possible this should be measured in all basins. Other measurements of interest include the adjacent land-surface energy balance, which allows quantification of energy available for advection. The issue of lake ice development and decay was discussed, as it is important for extreme events (Wolf Creek was given as an example where Coal Lake outlet freezes occasionally, causing large spring flood events). The investigators were unsure as to whether lake ice will be investigated as part of the IP3 network and more assessment as to costs and approaches will be needed.

Snow Processes:

Advances in snow hydrometeorology are still required. Snow redistribution, unloading and hypsometric relations are required for basins and current algorithms within CRHM have not been widely tested across the research network. The blowing snow algorithm in CRHM needs to be more robust and tested on larger data sets. New turbulent transfer

terms for snow, particularly in alpine areas, must be developed along with advection and boundary (rough to smooth) transitions. Albedo remains an important parameter, yet the IP3 network will not focus on the spectral properties of snow, but concentrate on the influence of vegetation on the albedo decay function. Within the snowpack, more information on changes in snow properties and energetics is required. For example, changes in snow depth, density and internal energy along with percolation of meltwater with time all require research within IP3.

Terrestrial Processes

With regards to terrestrial processes, research is required to link plot and hillslope behaviour with basin responses. New hydrochemical and time-series techniques should be utilized, and the investigators must be cognizant of the importance of working within an HRU framework when setting up their experiments. With regards to infiltration and percolation of meltwater, new techniques (both lab and field) will be necessary to understand the relation between liquid and frozen phase during snowmelt infiltration. TDR should be used where possible in all basins, and new methods explored where possible. The applicability of conceptual and numerical models for temperate climates must be thoroughly tested before being applied to the cold regions of the IP3 network.

Theme 2 – Parameterisation

During the Theme II breakout session, it was agreed that parameterisation schemes should operate at the same scale as weather models. The need for CLASS 3.3 runs for the research basins (forced with field data where possible) was discussed, as were guidelines for tile connection basin / landscape classification. Dr. Pietroniro suggested that modellers be assigned to each basin. Modelling training sessions were also suggested to assist with the set-up of MEC for each basin, and to provide model documentation. Furthermore, it was suggested that a web-based system be developed to facilitate data distribution, and agreed that data quality control is the responsibility of individual investigators. Once CLASS can compile on a Windows platform, it will be made available to be run in point mode for the research basins. Frank Seglenieks volunteered to assist with model set-up for research basins. Specific processes were identified for improved representation within CLASS. These included the movement of wetting fronts (infiltration into frozen/organic soils), and the development and removal of soil frost, particularly in organic soils. Thermal properties of snow and representation of snow layers were also seen as necessary to improve the physical representation of CLASS. New tiles need to be developed to represent the landscapes at the study sites that are seen to be important hydrologically, such as channel fans, small (i.e. sub-grid) lakes, and shrub-covered terrains.

Theme 3 - Prediction

In the development of the models it was noted that it would be necessary to define, and establish tiles, and tile connections. Clearly there would be challenges in scaling from point to area within the tile world, and testing and validation at the basin scale would be a significant challenge. It was understood that some common framework for research

basins, including meteorological information, physiographic data and coordinate systems would have to be established.

In terms of scaling, it was clear that there would be requirements to work at a scale where the conceptual models make sense and perhaps work at nested scales. It was also noted that the modelling objectives must be defined. It was felt that we would try to close both the water and energy budget at the basin scale using both models and measurements.

It was observed that there would be challenges for both experimentalists and modellers and perhaps basin teams could be formulated to bring the groups together. A possible set of objectives was to:

- Estimate hourly streamflow at approx 100 km² scale (10 x 10 km grid).
- Provide regional GEM atmospheric fluxes at the scale of 10 x 10 km.
- Physiographic, forcing and parameterisation (1 x 1 km)

There is a need to develop conceptual models to capture heterogeneity of landscape and processes at the tile scale but develop universal or global processes that are transferable. One mechanism may be through the use of statistical representation of the tile variability (e.g. snow cover distributions or soil moisture distributions). There is the issue of capacity – we may need assistance in the transfer process within the basin teams.

It was concluded that some form of data management and repository was required and this would include:

- Common framework for research basins
- meteorological data, physiographic, coordinate systems
- initial run for all basins as a starting point

Thank you to the students of the Centre for Hydrology who reported on the meeting in various notes that were used in compiling this document:

Laura Comeau, Chris DeBeer, Pablo Dornes, Chad Ellis, Warren Helgason, Nicholas Kinar, and James MacDonald.

The editors who edited and compiled this information to the current document were:

Sean Carey, Bill Quinton, Al Pietroniro, Steen Westergaard, and John Pomeroy