



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

2007 DRI Progress Report

- University Investigators -

Title:

Large Scale Hydrological Modelling of the South Saskatchewan River

Principal Investigator:

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and

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Co-Investigators:

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1.0 Progress (beginning January 2007 to end January 2008)

1.1 Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2006-2007. How are the original milestones being met? List the key objectives and results achieved to date as well as any relevant application(s) of the results.

Theme 1: *Quantify the physical features of the recent Canadian Prairie drought*

The first step towards the better understanding of this drought involves the quantification of its atmospheric, hydrologic, and land-surface physical features at a variety of spatial and temporal scales.

Schedule & Milestones:

Year 2: Produce initial Network products on CDs and continue to update on a regular basis

Acquisition of data:

An Information Manager (Matt Regier), funded through the Hydrometeorology and Arctic Laboratory (HAL), represents an in-kind contribution to DRI for ½ of this year. Matt has moved on an accepted a full time position in the private sector. Brenda Toth (HAL) has tried to fill some of these duties. Most of the datasets required for DRI have been made available on the web.

Current datasets are available on the DRI website (<http://www.drinetwork.ca/data.php>). Additionally a previous CCIAD-funded study on water availability in the South Saskatchewan

River Basin (SSRB) generated significant data sets. A legacy data set, primarily physiographic data, has been archived (see Appendix A).

Additional datasets are being pursued and have been put on the web. As well, time series data of CMC observed temperature and precipitation from 1990 to 2005 has been downloaded and gridded at 0.2° by 0.2° lat/long grids across the SSRB. These gridded products are available as hourly matrices for the extent and are contained in monthly files. The observation stations involved in the gridding process are presented in Figure 1.

Observational Stations used in the Gridding Process across the SSRB

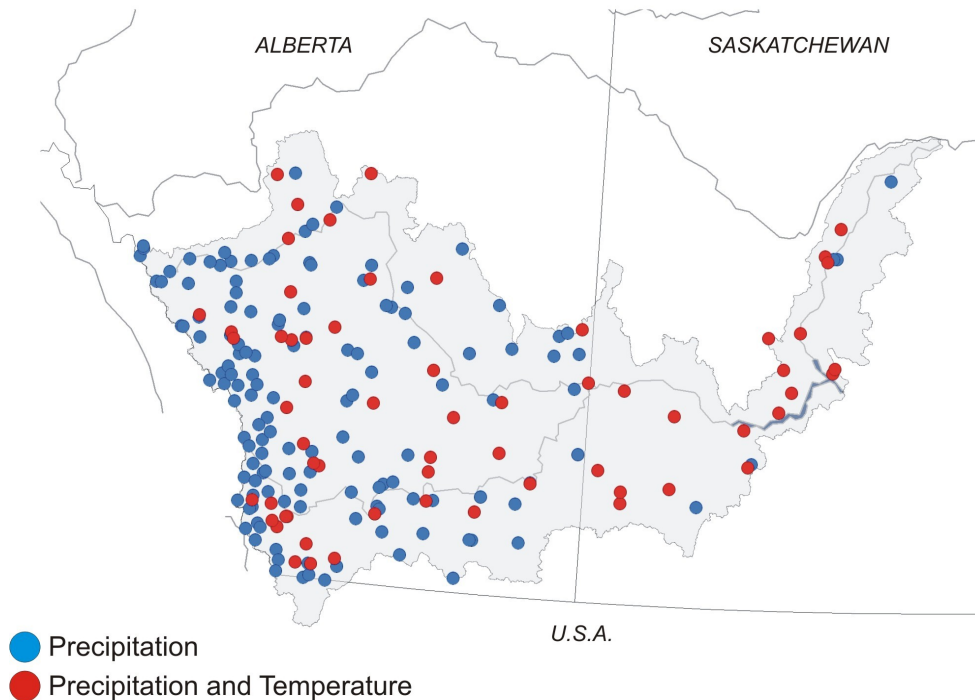


Figure 1. Climate stations utilized in the 1990 – 2005 gridding process. Note the temperature stations represent complete records, while the precipitation gridding canvasses shorter term records.

Theme 2: Improve the understanding of processes and feedbacks associated with the recent Canadian Prairie drought

Given that the 1999-2004 drought and its features will be quantified in Theme 1, the next issue is to better understand the processes and the feedbacks responsible for the drought's initiation, persistence, and termination.

Schedule and Milestones:

Year 2-3: Initiation or continuation of enhanced observations of atmospheric, surface and groundwater processes in research sites, data acquisition from collaborating agencies, data rescue from previous observations, selection of numerical models.

Project 4. Land Surface Hydrology and Streamflow Processes (Pomeroy, Granger, Papakyriakou, Pietroniro). This project will develop understanding of the primary physical surface processes underpinning Canadian Prairie drought, their sensitivity to land use, spatial scale and atmospheric conditions.

PhD work undertaken by Dean Shaw in the area of variable contribution area is supported by extensive field work in the St. Denis area, a hummocky terrain characterized by potholes that episodically contribute to stream flow. The field study included:

- Measured wetland water levels on a small-scale prairie basin, (spring 2002-2005).
- Measured groundwater levels on a small-scale prairie basin through piezometer readings, (spring 2002-2005).
- Snow surveys on a small scale-prairie basin (spring 2002-2005).

The field measurements taken during 2002-2005 have been used to quantify runoff volumes. Surface runoff during the spring melt is influenced largely by infiltration (Gray, et al., 2001). Using snow survey data as an input to a small-scale hydrological model, Shaw shows infiltration rates can be manipulated to satisfactorily model measured wetland water levels.

A separate initiative is funded by the NAESI (National Agri-Environmental Standards Initiative) Water Availability project. A SWE/soil moisture mesoscale observation network is in the process of being established and the collected data will also be used to support the calibration and validation of the modelling efforts within the DRI project. The fieldwork is conducted in the Saskatchewan portion of the SSRB watershed.

- A network of 10 soil moisture stations have been installed in various crop types in the fall of 2006 and 14 additional stations were installed in the spring of 2007. These stations were coupled with rain gauges.
- Bi-weekly surveys of snow depth and density are underway for 2006/07 along 13 established transects in various crop types were completed.
- Meteorological equipment has been purchased for a complete energy flux/ meteorological tower, which will be co-located with the mesonet in the spring of 2007. These data are now available
- A deep observation well (geological weighing lysimeter) will be installed within the mesonet in the spring of 2007 to measure regional soil moisture values. These data along with other lysimeter and deep well information have been collated.
- A data report is in the process of being completed for NAESI and will be made available to all DRI investigators. This will include all of the data described above.

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

Given that the 1999-2004 drought and its features have been quantified and the fundamental responsible processes better understood, the next issue is to assess and improve predictive techniques. The modelling tools used are being developed into community-based models becoming accessible to a variety of researchers across the country. WATFLOOD, WATCLASS and CLASS are being combined to create MEC (Modélisation Environnementale Communautaire), along with a surface hydrology component (MESH). These community models are developed in conjunction with RPN in Dorval. The hydrological models are driven by output from the atmospheric models, ongoing research sites and available reanalysis data. Atmospheric modelling spans scales from global to regional to watershed scales characteristic of the prairies, while hydrological modelling is accomplished using a hierarchy from small scale detailed process models to large scale models run on the South Saskatchewan.

Schedule and Milestones:

Year 2-3: SSRB flow assessment; CRHM redevelopment; testing of process algorithms

Project 3: Hydrological Modelling. This project will model the hydrology of large basins using a MESH prototype at a resolution of 15 km and smaller basins with CRHM at a resolution of 1 km. Full process model runs with enhanced soil, groundwater, ET and snow routines will be used to predict small scale runoff, soil moisture, ET and water balance without calibration of parameters. Large scale prediction using the MESH prototype model will be driven using atmospheric model output at the appropriate scale to generate South Saskatchewan River Basin flows from medium to large scales over hourly to seasonal time scales. Improvements to MESH will be made based upon new coupled modelling with groundwater simulations and results of CRHM simulations.

Characterization of surface water flow regimes and hydrologically significant variables, large scale modelling in the SSRB:

Currently, the gridded temperatures and precipitation as well as the physiographic datasets (see Theme 1) are utilized as inputs to the hydrological model WATFLOOD to estimate daily naturalized streamflow for 1990 – 2005 at 13 nodes across the SSRB. The current resolution is approximately 15 km by 15 km on an hourly time scale. Additional output (hourly AET, soil moisture, SWE) is available and is being examined and evaluated. WATFLOOD is the initial modelling framework; future modelling efforts will be accomplished with the MESH prototype. This modelling effort is undertaken by PDF Saul Marin.

Current process descriptions of frozen ground infiltration utilized within CLASS (the land-surface scheme used in MESH) are under code review. The understanding gained from this process will aid in the implementation of improved process descriptions of frozen ground, the estimate of snowmelt runoff, and the quantification of subsequent soil moisture reserves at the start of the summer growing season. The data collected within the NAESI field study (Theme 2) will be instrumental in the development of these conceptual models and the validation the MESH prototype.

The MEC system is being tested for the entire South Saskatchewan River basin and a preliminary run is complete. The MESH prototype is completed, including new physical representations of overland flow and interflow. The MESH prototype will provide an intermediate stage of model evaluations, bridging the WATFLOOD model runs with the MESH model runs.

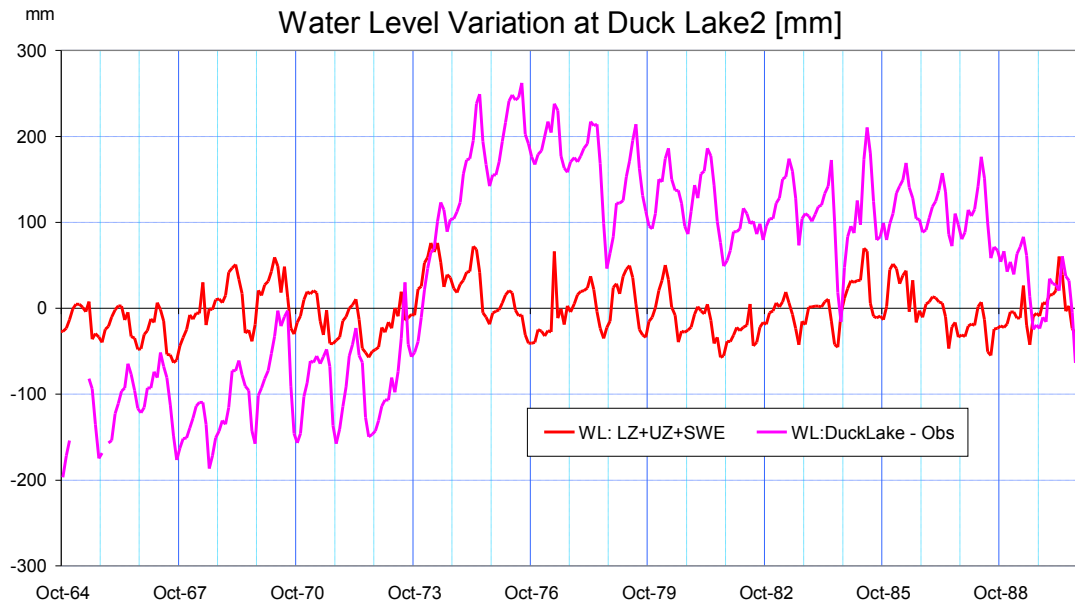
A targeted workshop on the MEC/MESH system was slated for January 2007. This was held and a number of DRI investigators have attended.

Estimates of glacier contribution to flow within the South Saskatchewan basin have been completed. Two journals in preparation looking at historic contributions and changes in areal extent of glaciers within the SSRB are nearing completion. This work will contribute directly to DRI, but was funded through other initiatives.

Comparison of long-term groundwater and recharge rates in the SSRB against the MESH modelling system were undertaken. In this case comparison of water balance components were examined, in particular the role of groundwater. The comparison measured groundwater storage to modelling of lower zone storage uncovered significant findings applicable to the understanding of the development of drought and our ability to model long term groundwater variability.

Long-term (30 year) records of deep observation wells in Saskatchewan, Canada, exhibit a clear relationship to changes of total vertical water balance at time scales from hours to years. Comparison of the well records and WATFLOOD ground water level outputs are done focusing in two times scales, monthly time scale in a period of 30 years (1961 – 1990) and hourly time in a three-month period (Jun 2003 – Aug 2003).

Monthly time scale results showed that the model has a good performance with the seasonal variability but it seems that there is a weak related to the low frequency variability (hydrologic long memory). shows the WATFLOOD groundwater level output and the observed level at the DuckLake2. The model misses the large change present around 1973-1975 and the long trend showed after 1976. Factors such as the record high snow year of 1973/74 and the possibility of external issues such as pumping for a high irrigation periods, changes in the way to measure the data may have influenced the well level data.



Analysis for the shorter periods as 1964 – 1972 or 1979 – 1988, was undertaken. For these ten-year periods, simulated and observed data show a reasonable match, as it may be seen in Figure 1 and Figure 2. These two figures demonstrate that while the observed data has larger amplitude the model is reasonably estimating yearly trends during dry or wet periods.

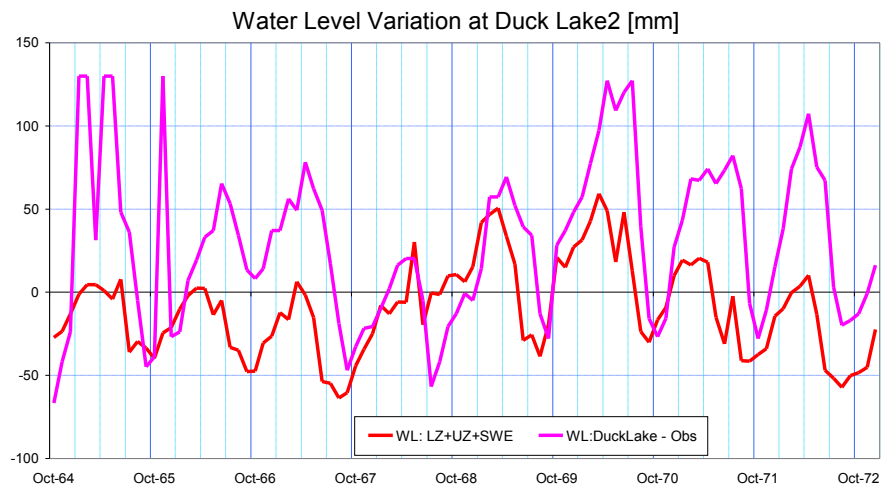


Figure 1: Observed and simulated ground water level, Oct 1964 – Oct 1972

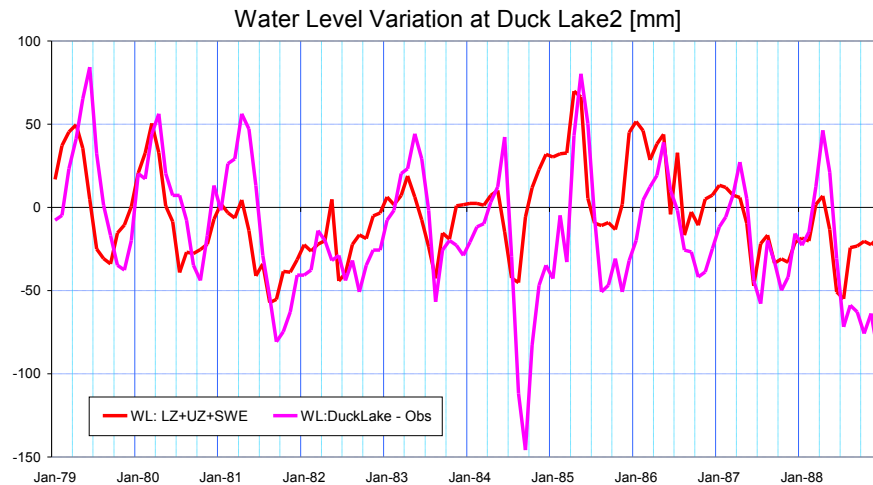


Figure 2: Observed and simulated ground water level, Jan 1979 – Jan 1988

Finally, vertical mass balance in an hourly time scale was analyzed for the period June-2003 to August-2003. This time period was chosen due to the availability of hourly observed data together with hourly barometric pressure which is required to eliminate the effects of barometric pressure changes and earth tides on the observed data.

Figure 5, shows the hourly evolution of WATFLOOD groundwater level storage and upper zone storage together with the observed data after the barometric pressure changes and earth tides effects have been removed (left vertical axis). In addition this figure includes the input precipitation events (right vertical axis). The water level variation shows that both, the observed and simulated data, respond accordingly to the presence of the precipitation events. Some discrepancies appear between both water levels where the most notorious seem to be related to the fact that the simulated water level is less depleted than the observed one (lysimeter data). The discrepancies that appear between both water levels, simulated and observed, could be a shortcut in modeling the actual evaporation and/or in modeling the evolution of the available moisture in the upper and lower zone storages. To deplete more the simulated water level it will be necessary to affect the evolution of the zone storages, e.g., evapotranspiration and/or runoff should be increased.

Figure 6 shows that the simulated evapotranspiration reaches values of zero with certain frequency which could be a signal of a deficiency of available water to evaporate in the upper zone storage.

In summary, though the monthly time scale shows an acceptable agreement between the lysimeter data and the simulated data, the hourly time scale highlights some model deficiencies that should be related with the forcing data and/or the simulation parameters, such upper and lower zone storage sizes. To look for better agreement between these data, WATFLOOD model should be tuned focusing in groundwater level correspondence which will improve the evaluation of the vertical fluxes.

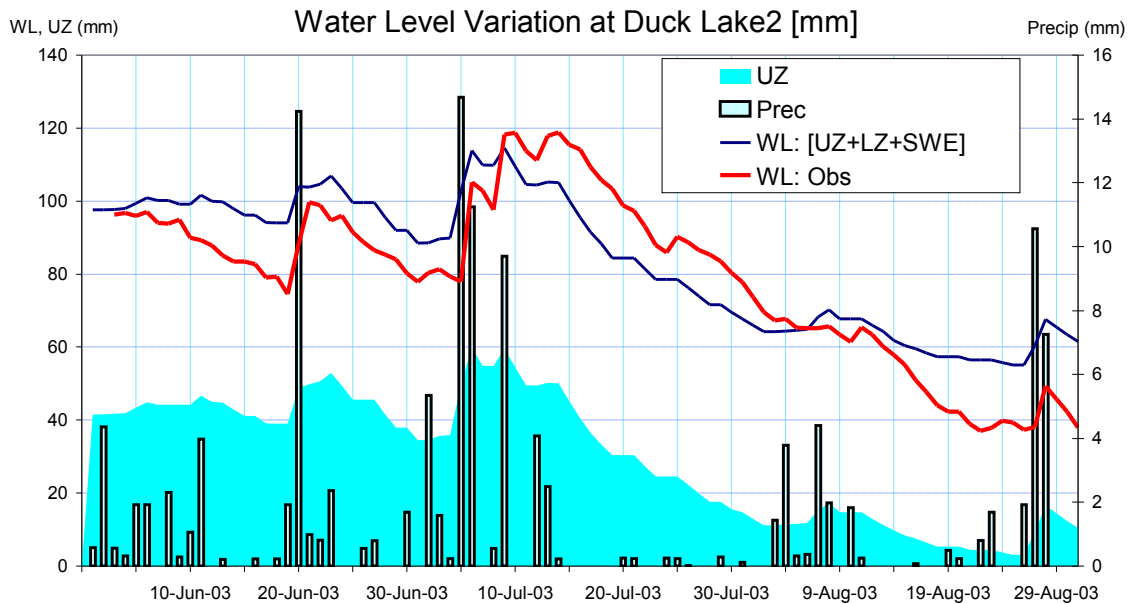


Figure 5: Observed and simulated ground water level, Jun-Aug 2003 – hourly evolution #1

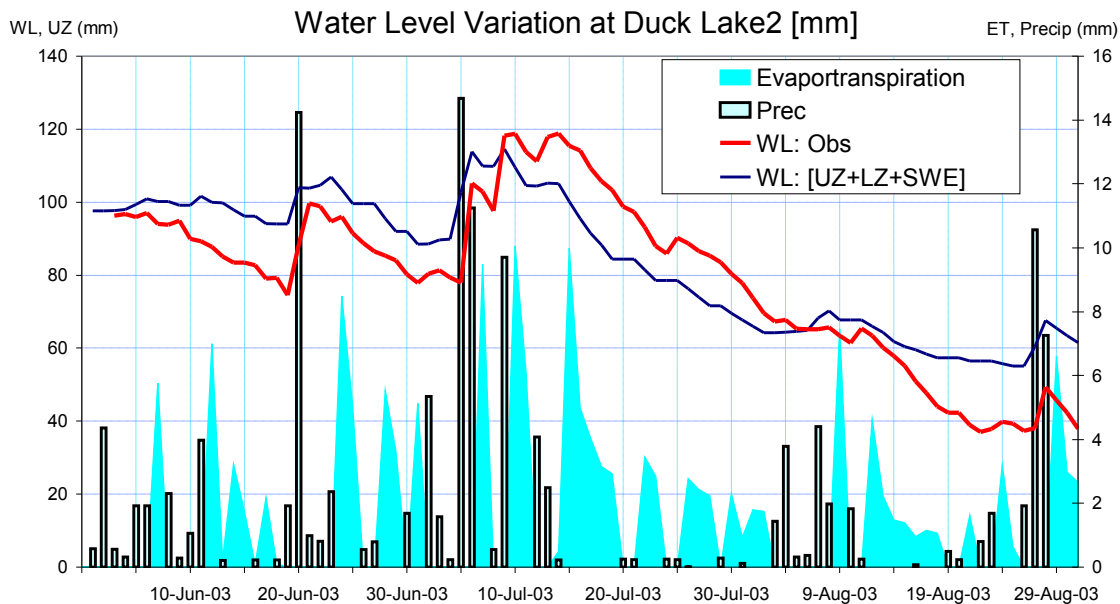


Figure 6: Observed and simulated ground water level, Jun-Aug 2003 – hourly evolution #2

Further enhancement to the modelling framework that links NWP with hydrologic modelling was also accomplished this past year. Collaborative work on the CaPA project allowed a comparison of precipitation products; vital to the development of an effective prediction system. Comparisons of the primary sources of precipitation forcing for hydrological modelling was performed for the South Saskatchewan River Basin (SSRB); namely

- Canadian Precipitation Analysis (CaPA)
- Global Environmental Multiscale Model (GEM)
- National Hydrology Research Center (NHRC), gridded observations from the AES archive.

Initially three WATFLOOD simulations are done using as input CaPA, GEM and NHRC input data and Figure 7 shows the output hydrographs in the Oldman basin.

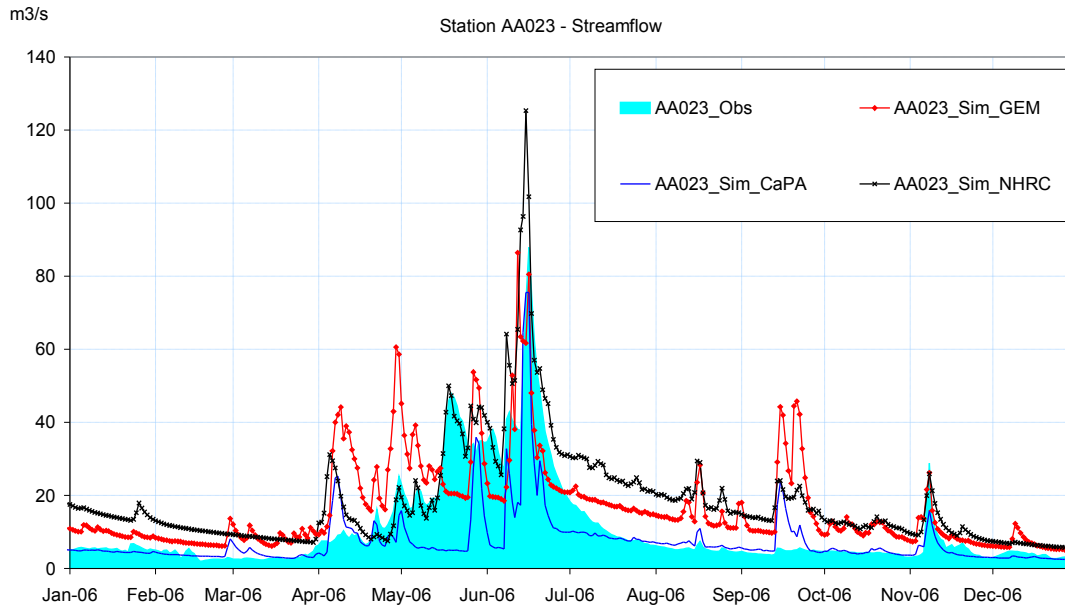


Figure 8: Comparison of flow discharge at Old-man River station – GEM, CaPA and NHRC data

In general there is good resemblance of the seasonality variability, however, all the simulations present large discrepancies in some periods. The CaPA data shows the best resemblance for low stream flow periods while the NHRC data shows a good agreement at the beginning of the events, e.g. when the stream flow discharge starts to rise, but the NHRC data provides an overestimation of the discharge flow at the recession of the event. With root mean square error coefficient as an indicator, the best fit corresponds to CaPA, then NHRC and at the last place is GEM data.

We need to keep in mind that the above comments are valid for the set of parameters used in the simulations. We can work with any of the three sources of data in order to get a better agreement between observed and simulated discharges, but the final “good” set of parameters will depend of the input data source used in the calibration process.

By far the most significant result of this comparison was the benefit both the hydrologic and atmospheric modelling communities gained from working together. This is as a result of several advancements in the documentation of code, the development of a systematic organization of a source code management techniques, access to each other’s modelling platforms and regular meetings via teleconference.

Small scale hydrologic modelling – process algorithm for depression storage:

Within the current modelling framework, the area of the SSRB that is currently deemed to contribute to flow is the planar area less the PFRA estimation of the non-contributing area; however it is recognized that the non-contributing areas may episodically contribute to flow. This underscores the need to quantify depression storage, identified as a key issue for Theme

1. PhD work by DRI-supported student, Dean Shaw (see Theme 2) is directly applicable to a better parameterization of the area contributing to flow.

The analysis of the variable contribution area was conducted by examining the effect of infiltration on spring-melt surface runoff (using variable infiltration rates) for a small-scale prairie basin using input snow water equivalent (SWE) values from snow surveys and validated using wetland water levels.

Initially the effect of depression storage on the timing and magnitude of flood events was examined using a small-scale hydrological model - based on TOpographic PArameterization software (TOPAZ). Modelling the 'fill and spill' of depressions (wetlands) in the landscape, using current methods, has produced results that illustrate issues that arise using existing methods to determine how wetlands 'fill and spill'. Efforts at scaling these algorithms to deal with variable contributing areas in the prairie pothole regions that dominate much the Western Canadian prairie are underway.

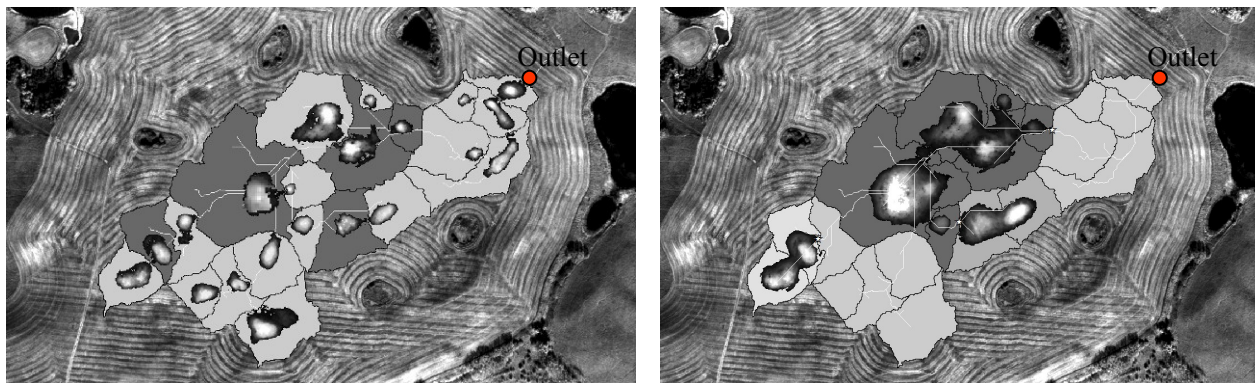


Figure 9a – Displays the volume of runoff that can be stored in a subwatershed before it will spill to the next subwatershed. Darker shaded subwatersheds 'spill' to an upstream subwatershed. The upstream/downstream relationship between the subwatersheds is defined by a channel network (white line) defined by TOPAZ.

Figure 9b – Displays the volume required to 'spill' downstream the subwatersheds identified as spilling upstream in Figure 9a.

Attempts to scale the work completed in 2006 were underway this year. The Ph.D. student is currently writing his thesis and we expect 2 journal papers to be developed over the next 8 months.

2.0 Impact

2.1 What short and medium term objectives have been achieved, or are anticipated;

Theme 1 Deliverables:

- Collective dataset(s) archived on CDs characterizing the drought
- Outreach to DRI community and stakeholders through workshops and conferences

Deliverables Achieved:

- Datasets available on DRI website, through DRI Information Managers and SSRB legacy dataset CD

Theme 2 Deliverables:

- Improve the understanding of the large scale setting of drought
- Improve the understanding of surface-atmosphere feedbacks of energy and water
- Improve the understanding of ET at various scales from prairie land and water surfaces

Deliverables Achieved:

- A field study that examined the effect of infiltration on spring-melt surface runoff (using variable infiltration rates) for a small-scale prairie basin using input snow water equivalent (SWE) values from snow surveys and validated using wetland water levels
- Establishment of a SWE/soil moisture mesonet, co-located flux towers and a deep observation well.
- Data report to be complete by the end of 2007 includes all soil moisture, flux and SWE data collected in 2007.

Theme 3 Deliverables:

- Improvements to the land-surface scheme CLASS, used within the MESH prototype, from appropriate inclusion of groundwater, frozen soil, ET, snow, contributing area change and other processes
- Assessment of drought characteristics simulated by CRCM
- Assessment of skill and uncertainty of seasonal forecast of drought indices
- Improvements to small-basin to field scale hydrological modelling capability for drought simulation
- Assessment of prairie basin runoff changes during development and termination of droughts

Deliverables Achieved:

- SSRB modelled at a 15 km resolution on an hourly basis with daily streamflow output
- Comparison of WATFLOOD modelled lower zone storage with observations show that yearly trends are well represented in WATFLOOD, however longer term trends may be missed as the model may not carry interannual additions to or depletions of groundwater. Also, at times the model may not be replicating evapotranspiration at the dry end as the modelled storage is depleted and the model deems that evapotranspiration has ceased. Improvements to model physics in replication of a variable lower zone storage is needed.
- Knowledge and quantification of contributing area change and an improved 'fill and spill' algorithm developed that explored the spatial pattern and distribution of wetlands under synthetic runoff events. This work is largely complete. Scaling methodology and completion of thesis and journal manuscripts are expected by April, 2008.
- CLASS code review of vertical fluxes (snowmelt infiltration) and sloped CLASS routing (overland flow, interflow and baseflow)
- MEC/MESH development and link to NWP through RPN in Dorval. We have made significant progress in developing and using software engineering processes to improve our ability to collaborate with DRI network participants. First and foremost, we have successfully implemented an accessible software configuration management (SCM) system for effectively working with code developers and modellers across the country. The system revolves around a central repository of model code, documentation and run files that can be downloaded by anyone with a computer, internet access, username and password. The repository has three main directories: a trunk directory for the latest version of the model, a tag directory for tagged releases of the

model, and a branch directory containing sub-directories for each developer or model user to do his or her work. The trunk and tag directories can only be altered by a very limited number of people. To date, successful training, implementation and use of the SCM system has been completed with individuals at the Hydrometeorology and Arctic Laboratory (HAL), Recherche Prévision Numérique (RPN), the University of Waterloo and the University of Saskatchewan. Other advances in the implementation of software engineering include improved documentation and the beginning of regular code reviews of MESH subroutines. We have also begun to organize monthly conference calls amongst model developers and users.

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2.2 Describe the significance / impact of the results achieved to date and how this new knowledge has influenced research policy, enhanced research collaboration or competitiveness, or helped attract or train skilled personnel.

Address the following items, as appropriate:

- **The impact of the project on government policy development (federal, provincial or municipal);**
 - Linkages of NWP to MEC/MESH to aid in forecasting land surface variables
 - Underscored the need for the development of distributed data products
- **How the project has expanded contacts in partner organizations, or increased cross-disciplinary cooperation;**
 - Dr. Berg with the University of Guelph, remote sensing and satellite verification links to the NAESI field study.
- **Whether and how it has improved the reliability of predictive methods;**
 - CLASS and MEC/MESH code review and improvements, links to NWP through RPN
- **The impact of the project on your own institution;**
 - Synergy of activity in arid region research (i.e. DRI and NAESI)
- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**
 - New partnerships with University of Guelph, increased involvement with RPN in Dorval
- **Any current (or potential) commercial or social applications, which the results may have;**
- **Links with international initiatives and the potential impact of these;**
 - Direct implications of NAFE'06 to the DRI project:
 - University of Melbourne developed equipment for soil roughness, soil moisture and GPS data collection. We will be able to adapt their set-up for our own data collection.
 - The NAFE'06 data sampling scheme will be adjusted to fit the resolution and objectives of the NAESI/DRI soil moisture network.
 - Attending the field experiment provided a chance to inform the international community about our soil moisture networks in Saskatchewan as well as the modelling efforts.
 - The NAESI/DRI field plan was shared with the scientists at NAFE'06 and we are expecting valuable feedback.
- **Anticipated benefits of the work for Canadians**
 - Improved understanding of water availability for the agricultural industry

- Better understanding of cold regions hydrology; contributing area change, generation of spring runoff, SWE/soil moisture relationships

3.0 Dissemination

3.1 Provide information on 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.

- Datasets available on DRI website, through DRI Information Managers and SSRB legacy dataset CD
- Tentative presentations scheduled for January 2007 DRI Workshop by: Pietroniro, Regier, Shaw, Marin.
- MEC Workshop held in Saskatoon on January 25th and 26th 2007. The workshop helped familiarize DRI researchers and other collaborators with the system. The workshop included a discussion around the idea of community-based modelling, information about the modelling theory being undertaken, and exercises to start the participants with their modelling work.
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