Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
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2010 DRI Progress Report

Large Scale Hydrological Modelling of the South Saskatchewan River

Principal Investigator:
Dr. Alain Pietroniro,
University of Saskatchewan, Department of Agricultural and Bioresource Engineering
and
Hydrometeorology and Arctic Lab (HAL)

Co-Investigators:
Dr. Lawrence Martz, University of Saskatchewan, Department of Geography
Dr. John Pomeroy, University of Saskatchewan, Department of Geography

1.0 Progress (beginning January 2009 to end December 2009)

1.1 **Describe progress towards meeting the project objectives for those theme areas where you have received funding for 2008. How are the original milestones being met (be specific)? List the key objectives and results achieved to date as well as any relevant application(s) of the results.**

1.1.1 Objectives

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:**

Acquisition of data:

Brenda Toth (HAL) and Anthony Liu continue to provide support on data and modeling activities for DRI. Most of the datasets required for DRI have been made available on the web including soil moisture and flux information derived form the Kenaston data set.

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 A legacy data set, primarily physiographic data, has been archived. This was highlighted last year and the current status is that we respond to queries or updates.

Continued observations at the field scale at Kenaston are also available on request and are being collated as part of the DRI data program. These include flux, soil moisture and precipitations measurements along with snow measurements in some years. They also include deep well lysimeter measurements at the site.

Also, NARR and GEM operational forecast data (with the Canadian Precipitation Analysis – CaPA) is being archived in the HAL lab for this region and many other basins in Canada. Comparisons between NARR and GEM with CaPA for Canada have been undertaken and publication is expected in 2011. These information sets can also be made available.

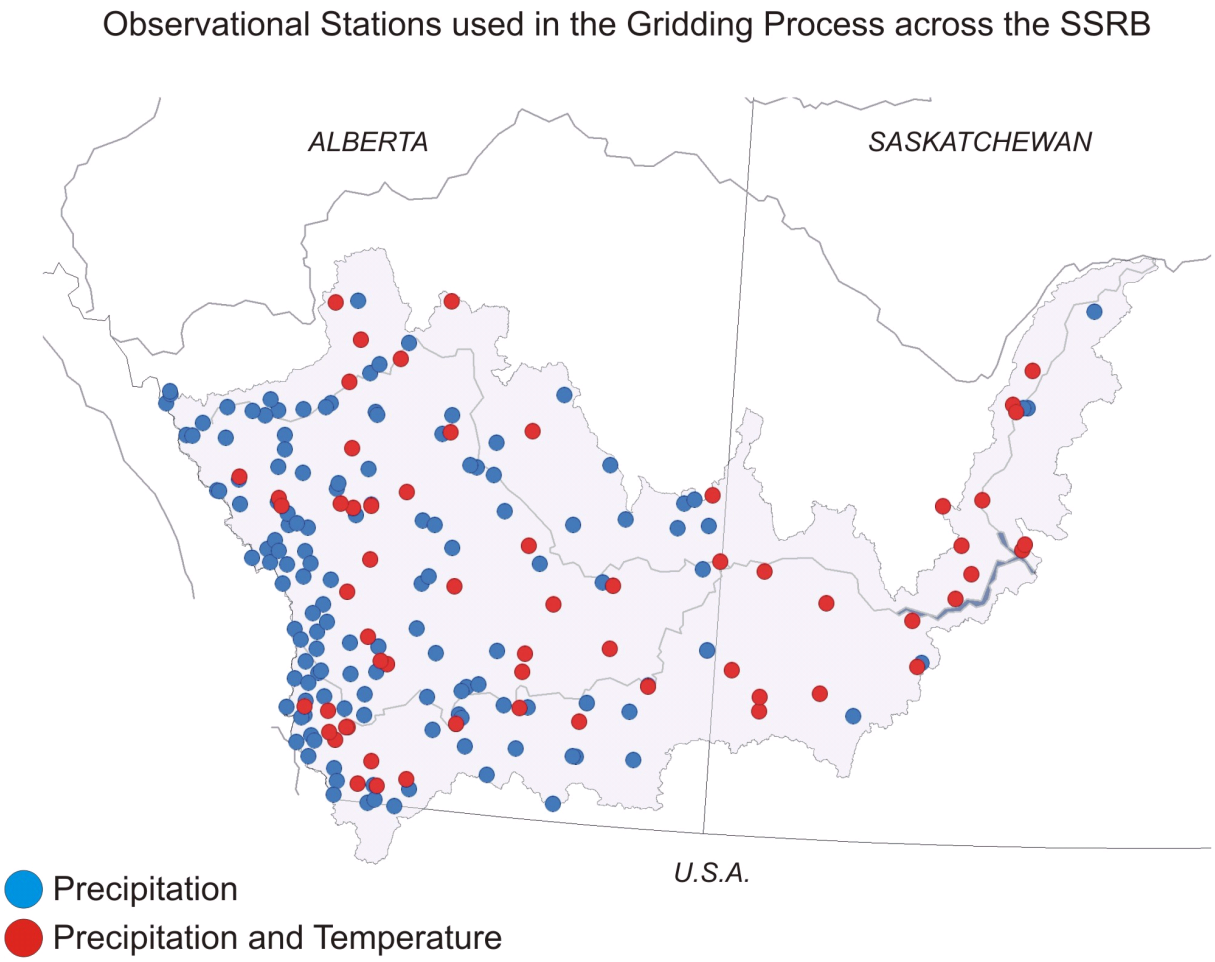

Figure 1. Climate stations utilized in the 1990 – 2005 gridding process. Note the temperature stations represent complete records, while the precipitation gridding canvasses shorter term records. NARR data for this domain for the past 40 years, and GEM with CaPA data from June 2004, is also available through the HAL lab.

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

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 is developing understanding of the primary physical

surface processes underpinning Canadian Prairie drought, their sensitivity to land use, spatial scale and atmospheric conditions. A number of data collection initiatives were undertaken as part of a few projects and are described.

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 peizometer 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. Dean Shaw has 3 publications now completed and will be presenting at the DRI meeting in January. Thesis was complete in the fall of 2009.

As mentioned last year, a separate initiative was funded by the NAESI (National Agri-Environmental Standards Initiative) Water Availability project. Continued funding for this data was undertaken by HAL lab using a-bases resources this past year. 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. These data are continually being collected and made available upon request
- Bi-weekly surveys of snow depth and density were completed for 2006/07/08 along 13 established transects in various crop types were completed. Scaled back surveys were carried out in spring of 2009.
- A complete energy flux/ meteorological tower, which was be co-located with the mesonet in the spring of 2007. These data are now available and have continued through the summer of 2009.
- A deep observation well (geological weighing lysimeter) was installed within the mesonet in the spring of 2007 to measure regional soil moisture values. These data along with other lysemeter and deep well information have been collated and were continued for 2009.
- A data report is was completed last year for NAESI and is available to all DRI investigators. Date for 2009 is being compiled and likewise will be made available.

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

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. As described in previous reports, 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.

Project 3: Hydrological Modelling. This project is simulating 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 is being 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.

Major improvements have been made in representing important physical processes, automating model testing, model input/output processing, visualization and general model development practices.

1. The CRHM's Frozen Soil Infiltration Algorithm has been smoothly incorporated into MESH and has produced considerable improvements in the head waters of the South Saskatchewan River basin and in the Upper Assiniboine River basin. An abstract has been submitted for the 2011 CWRA conference and publication is expected in 2011,
2. The interflow algorithm is aligned with the advanced interflow algorithm from the University of Waterloo and Recherche Prévision Numérique (RPN),
3. Adaptation of the well tested automated testing system that has long been in use at the Institut National de la Recherche Scientifique (INRS), Quebec University, into the MESH modeling system,
4. Many of the tools to set up and run the MESH modeling system in any of the Canadian basins are now in place and functional. These include; Pre-processor to extract land cover, soil and digital elevation data from the Canadian GeoBase data source, Programs to process forcing data from reanalysis products such as the Canadian Precipitation Analysis (CaPA), the North American Regional Reanalysis (NARR) and from the Global Environmental Multiscale (GEM) model, a connector program for auto calibration runs using the Dynamically Dimensioned Search (DDS) Algorithm (and many other calibration algorithms on the way), and Batch files and scripts to run the MESH model either in personal computers or at any node in the halsasgrid cluster system of the Hydrometeorology and Arctic Lab. The current version of MESH also allows to produce model outputs in a format that can be visualized using the Canadian Hydraulics Centre's GreenKenue software (advanced data preparation, visualization and analysis tool for hydrological models).
5. Improved model development practices continue to be incorporated into the development of MESH. In addition to the testing procedures already described, these practices include regular code reviews, software configuration management, and better developer and user documentation.

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

Large scale modelling – soil moisture and storage

As described in previous reports 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.

This modelling effort was undertaken by PDF Saul Marin. It was possible to make improvements to the hydrological model and make long-term simulations with WATFLOOD, focusing on storage terms and comparing the results with the deep-well lysimeter work being carried out by Garth van der Kamp. A recent publication has been completed and is being accepted by the Journal of Hydrology. 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. Details are outlined in last year's reports. Current efforts this year are to now do similar analysis with the MESH modelling system (using CLASS 3.5) and to also examine the data collected at Kenaston in the same manner to provide another validation point in the model.

The ongoing SSRB modeling approach can be briefly summarized as follows. Forcing data from GEM with CaPA for the year 2004 to 2009 is being used to calibrate the parameters based on the head water basins that have natural streamflows. With the contributing area of SSRB being represented based on the PFRA map, and NARR forcing data that extend to 1980, the calibrated model will be validated against the naturalized stream flows and soil moisture data in the downstream parts of the basin.

Glacier Contribution

Estimates of glacier contribution to flow within the South Saskatchewan basin have been completed. A paper for the HP issue from MASc student L. Comeau resulting from presentations at the CGU in 2008 has been submitted and reviewed. It has been accepted for publication. Summary of the work can be found in last year's report.

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.

This research formulates a conceptual framework developed from field observations that describes the influence of surface depressions or potholes on runoff generation in the prairie pothole region of the North American prairies. The fill-and-spill of potholes results in intermittent surface water connectivity between potholes within the basin. The extent of connectivity between potholes is dependent on antecedent water levels. Connected areas may be found throughout the basin. However, only when these connected areas ultimately

runoff to the outlet of the basin will they be classified as basin contributing area (CA_B) Figure 1).

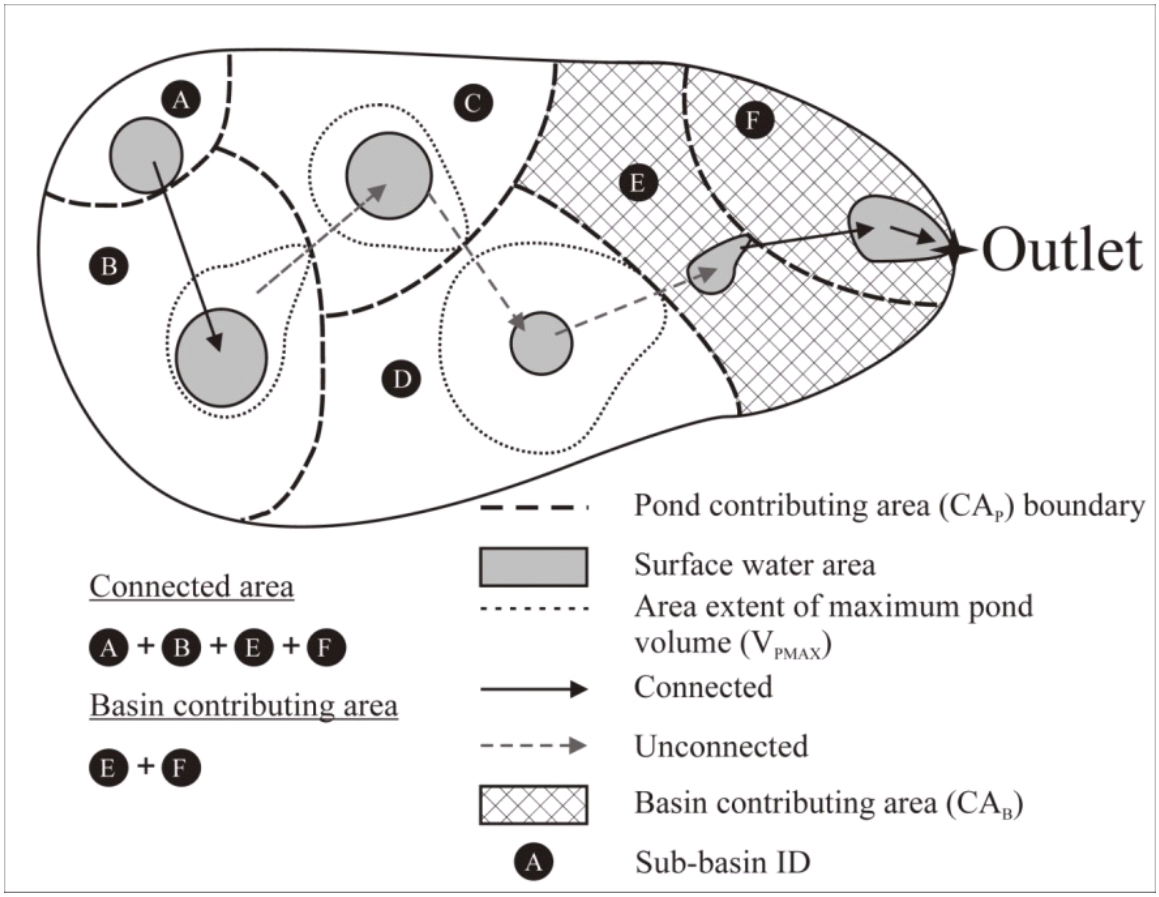

Figure 1. Illustrates terminology used to describe the response of a prairie pothole region basin to a runoff event.

The concept of connectivity is manifested in the conceptual curves (Figure 2). These conceptual curves model the response of runoff events for landscape types found in the prairie pothole region, and capture the influence of the spatial distribution and extent of surface storage on contributing area. The conceptual curves differ due to variations in the spatial distribution and extent of surface storage volume.

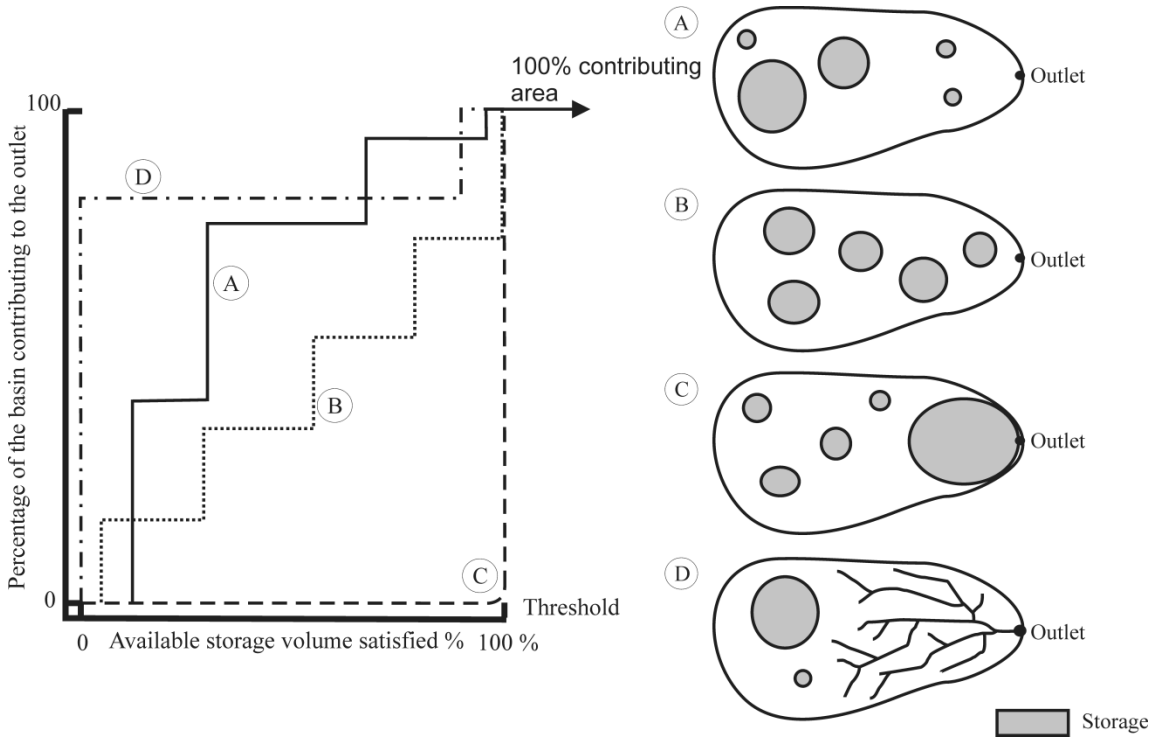

Figure 2. Conceptual curves expressing the relationship between basin storage and contributing area in a prairie pothole landscape.

An algorithm based on the conceptual framework proposed was developed. The algorithm, which uses the D-8 drainage direction method, automates a methodology for identifying and quantifying runoff contributing area. The algorithm is applied in prairie pothole basins both to demonstrate its efficacy and to test the potential for using conceptual curves to describe the relationship between decreasing potential surface storage in the landscape and contributing area.

Results indicate that the proposed conceptual curves represent the non-linear relationship between potential surface storage volume and contributing area generated by the algorithm in test basins (Figure 3).

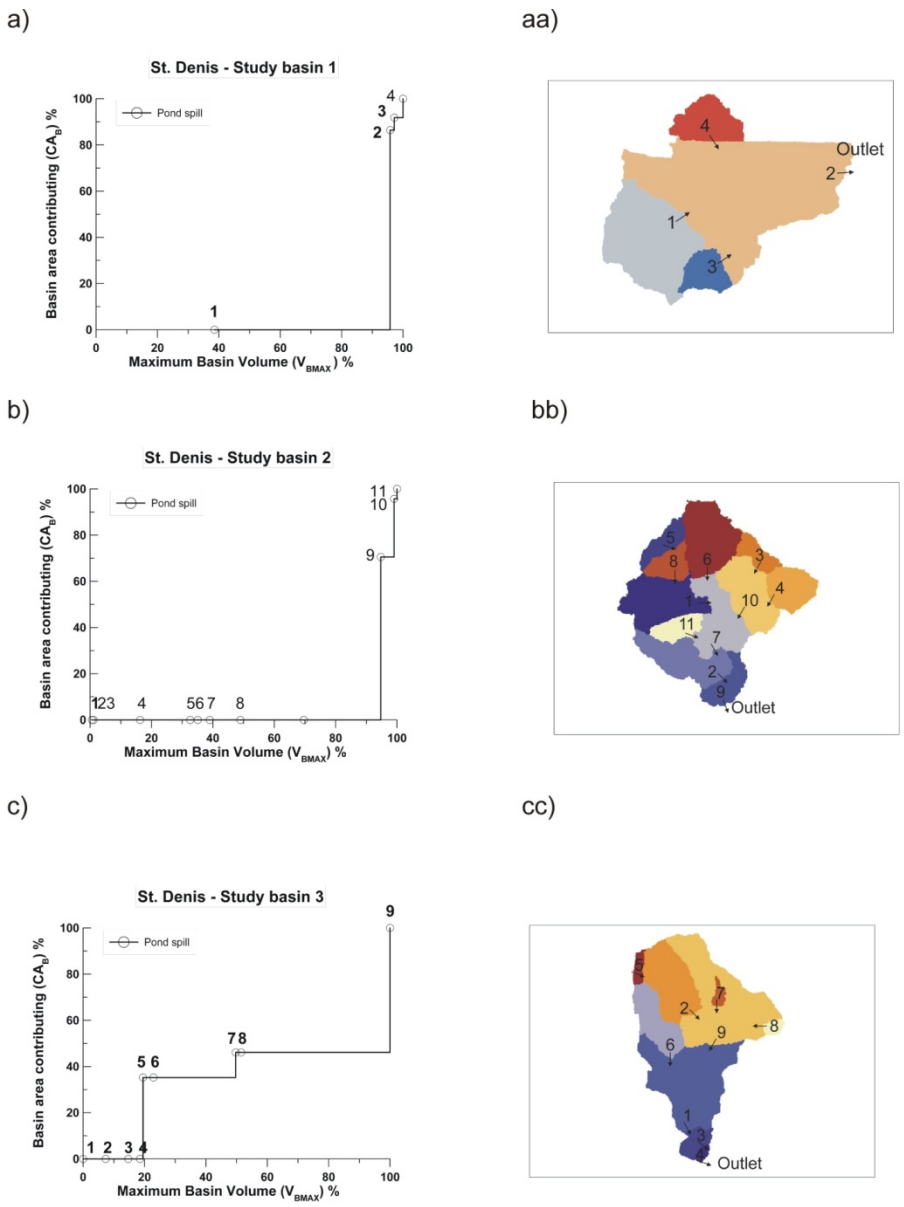

Figure 3. The resulting relationship between contributing area (CA_B) and threshold storage volume (V_{BMAX}) as calculated by the SPILL algorithm for sub-basins within the SDNWA watershed.

Results from this work are being summarized in a series of 2 papers and are detailed in a thesis. Thesis was successfully defended in November, 2009. Mr. Shaw is now employed with AAFC and is working on contributing area and unit runoff estimates for AAFC efforts in the Canadian Hydrological Atlas.

Shaw, D. (2010). The influence of contributing area on the hydrology of the prairie pothole region of North America. Department of Geography. Saskatoon, University of Saskatchewan: 167.

Shaw, D., Martz, L.W., Pietroniro, A. Topographic Analysis for the Prairie Pothole Region. In review.

Shaw, D., Martz, L.W., Pietroniro, A. Topographic Analysis for the Prairie Pothole Region. In review. The influence of surface water connectivity on runoff volume in the prairie pothole region. In review.

Modelling soil moisture and evaporation using field data and atmospheric model output: Hydrometeorological prediction often requires calibration of parameters. Furthermore, the sparse distribution of meteorological stations requires extrapolation of station data or other techniques. An alternative to extrapolating meteorological station data is to use of output from numerical weather prediction (NWP) models. For cases where meteorological station data and NWP model output may be used interchangeably as model forcing, it is important to know if the same hydrological parameter values can be used for both sets of forcing or if unique values should be established for each set of forcing data. Matthew MacDonald is undertaking a study examining this issue. The Canadian Land Surface Scheme version 3.5 (CLASS) is used to model evaporation and soil moisture at Kenaston, as well as snowcover and soil moisture at Marmot Creek Basin. Parameters are calibrated using both field data and GEM/CaPA as meteorological forcing. The transferability of parameter sets derived from using observed meteorological forcing data and from using NWP output is examined. In addition, the efficacy of an equation to estimate snowmelt infiltration into frozen soils is being evaluated.

1.4 **Describe how the work of co-investigators was integrated or coordinated.**

Collaborator, Brenda Toth of HAL in Saskatoon is integrated with the DRI project through her direction of the NAESI field study. Also, continued collaboration with Dr. John Pomeroy fro CHRM model development along with the MESH/CHRM courses for public outreach occurred this past year. Lawrence Martz and I completed supervision of Dr. Dean Shaw to the completion of his thesis and 2 upcoming publications.

Collaborator, Bruce Davison and Anthony Liu of the HAL in Saskatoon has a significant role to play in code refinement for CLASS, and the MESH prototype and the development of the MEC/MESH system.

1.5 **Describe the participation of government (federal, provincial or municipal), university, industry, foreign or private sector researchers (and/or other staff) involved in the project.**

There has been significant involvement by two federal agencies within Environment Canada, the National Water Research Institute (NWRI) and the Hydrometeorology and Arctic Laboratory (HAL), both in Saskatoon. Matching resources, expertise, and outside facilities are involved and specified in Sections 3.2, 3.3 and 3.5.

2.0 <u>Impact</u>

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
- Continued improvements and validation of the MESH modelling system

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.
- Continued reporting on data collection activities

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 process 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.

- Testing and validating of MESH for the SSRB against observations and new data sources. This work is nearing completion.

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. Collins with the University of Calgary, remote sensing and satellite verification links to the NAESI and DRI field study.
  - Potential collaboration with Manitoba Hydro

- **Whether and how it has improved the reliability of predictive methods;**
  - CLASS and MEC/MESH code review and improvements, links to NWP through RPN. Validation of hydrology models now includes other parameters including soil moisture, lysimeter data (van der Kamp) and flux estimates.

- **The impact of the project on your own institution;**
  - Synergy of activity in arid region research (i.e. DRI and NAESI) and contributes directly to the mandate of the HAL lab. MESH testing under DRI will form the basis for improved operational land-surface modelling within the context of both the EC NWP model and the CRCM. It would not have been possible to make the advancements in validation and modelling with the collaboration of DRI investigators and the funding for the university research projects.

- **Whether and how the project has helped increase funding from other agencies, or led to new partnerships;**
  - New partnerships with University of Calgary, increased involvement with RPN in Dorval and now interest form other outside agencies such as Manitoba Hydro.

- **Any current (or potential) commercial or social applications, which the results may have;**
- **Links with international initiatives and the potential impact of these;**
  - This work was highlighted at GEO meetings and the MESH and Kenaston data are being highlighted as potential contributions to GEO initiatives.

- **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
  - Interest form Hydro and other water management entities such as Manitoba water stewardship.

4.0 Dissemination

4.1 Provide information on dissemination of the research results during 2008 (publications, including journal names and whether refereed), conference contributions, seminars, workshops or videos, websites or other methods of transferring the results.

Refereed journal articles:

Use of Observation Well Records for Confined Aquifers to Evaluate Modelling of Areal Evapotranspiration, Saul Marin, Garth van der Kamp , Alain Pietroniro, Bruce Davison and Brenda Toth. Accepted – Journal of Hydrology.

Topographic Analysis for the Prairie Pothole Region, Dean Shaw, L.W. Martz and Alain Pietroniro, Accept with revision – Hydrological Processes

The influence of surface water connectivity on runoff in a prairie pothole region, Dean Shaw, L.W. Martz and Alain Pietroniro, under review – Journal of Hydrology

The influence of contributing area on the hydrology of the prairie pothole region of North America. Shaw, D. (2010), Department of Geography. Saskatoon, University of Saskatchewan: 167.

Glacier contribution to the North and South Saskatchewan Rivers. E. L. Comeau,A. Pietroniro and M.N. Demuth, Hydrol. Process, 23, 2009

Calibration of land surface parameters using field observations versus atmospheric model output with assimilation precipitation.
M.K. MacDonald, B. Davison, M.A. Mekonnen and A. Pietroniro, in preparation.

Conference presentations:
Numerous conference presentations including CGU, CMOS and CWRA last year/

Others:
Work has been described at many smaller workshops including discussions Environment Canada workshops with NOAA under GEO.

4.2 Describe data management/sharing activities including organization of the metadata. Also is the data being archived, and how will it be made available to other researchers?
All data is being archived and will be part of the HAL lab data collection. Data will be made available upon request.

4.3 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?
Kenaston field site will be part of a larger soil moisture mapping experiment to be conducted this summer with a number of universities and other government branches including RPN and climate research within EC. There will be aircraft mission flown and NASA investigators working on this. Although not directly tied to DRI, the DRI program

will be mentioned in the EC press releases since these sites were supporting (and being supported) for the DRI program.

5.0 Training

5.1 **Quantify student and postdoctoral involvement in the project, indicating the number of: undergraduate, masters, doctoral or PDF's. Also summarize their roles in the project.**

complete
Dean Shaw - Ph.D. candiate –Completion November, 2009

Saul Marin, Ph.D, - Post Doctoral fellow – Employed by private sector in July 2008

Laura Comeau – MASc student – Complete December 2008

ongoing
Habib Mazaheri – Ph.D Candidate – Deprtment of Geomatics Engineering, University of Calgary – Supervised by M. Collins

Dr. Muluneh Admass Mekonnen – PDF – University of Saskachetwan – located at HAL lab facility under supervision of A. Pietroniro