BOREAS

Boreal Forest Hydrological Research Study

Hydrology Group 9:
From Micro-Scale to Meso-Scale Snowmelt, Soil Moisture and Evapotranspiration from Distributed Hydrologic Models

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August, 1997

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INTRODUCTION

The Boreal Ecosystem-Atmosphere Study (BOREAS) was initiated during the late 1980's to increase understanding of the boreal forest biome and the atmosphere. This international project is supported by scientific research agencies from Canada, the United States as well as other countries. The core supporters were responsible for the early planning of BOREAS, including the proposal solicitation, peer review and investigation selections.

There were several scientific issues which led to BOREAS. Each of these issues deals with the response of the boreal forest to changing climatic conditions. The first of these issues deals with the sensitivity of the boreal forest biome to changes in the physical climate system. Studies have shown that increasing atmospheric CO_2 will have its most marked effects on the area covered by the boreal forest. Another issue is the carbon cycle and biogeochemistry in the boreal forest. Tans et al. (1990) suggest a large terrestrial sink for fossil fuel carbon in the boreal forest. Changes in surface temperature, or moisture could affect this cycle, and cause the release of CH_4 and CO_2. The third scientific issue is the possibility of biophysical feedback on the physical climate system. Changes in temperature or moisture could change the boreal forest biome, and cause changes in the biophysical characteristics of the surface. These changes could in turn cause further changes to the boreal forest biome or to the climatology. These scientific issues highlight how little is known of the processes in the boreal forest, and the need for a comprehensive study of the forest was made apparent.

The data collection and scientific research was performed by six *Science Groups*, dividing up the BOREAS work load into distinct fields of science (Table 1). The Science Groups were then further subdivided into *Teams*, each of which were charged with performing certain tasks integral to the success of the group. This report provides a cursory background to the BOREAS project and summarises the work of Team 9 of the Hydrology Science Group (HYD-9). More details about the BOREAS project and the other Science Groups and Teams can be found on the BOREAS web page (http://boris.gsfc.nasa.gov/).

The HYD-9 project sought to identify, through field measurements and computer modelling, the space-time distribution of meltwater supply to the soil during the spring melt period, and the evolution of soil moisture, evaporation, and runoff from the end of the snowmelt period through freeze-up. The snow modelling activity consists of two components. The first was to make use of existing, "off-the-shelf" models to forecast the onset and spatial extent of snowmelt and meltwater supply to the soil column prior to the 1994 IFCs. The second phase extended, implemented, and verified a physically based energy balance snowmelt model of the two sites, and evaluated

Table 1 - BOREAS Science Groups

Acronym	Boreas Science Team
AFM	Airborne Flux and Meteorology
TF	Tower Fluxes
TE	Terrestrial Ecology
HYD	Hydrology
TGB	Trace Gas Biogeochemistry
RSS	Remote Sensing Science

approaches to aggregating snowmelt predictions and measurements based on the model to large scales, up to the size of a rectangle of several hundred km containing the northern and southern sites. The soil moisture modelling will allow characterization of soil moisture, evaporation, and runoff for the entire northern and southern sites. The primary external data requirements of the project are for 1) winter period surface meteorological and energy flux data, 2) high quality DEM data, 3) vegetation characterization, at the scale of the DEM, 4) supplemental snow-free period precipitation data at the local scale, perhaps along selected transects.*

STUDY AREA

There are two main study sites in the BOREAS project (see Figure 1), one for each controlling factor: temperature and moisture. The Southern Study Area (SSA) is near Candle Lake, Saskatchewan and was picked for its sensitivity to moisture. Temperature is the major controlling factor in the Northern Study Area (NSA), near Thompson, Manitoba. Each study area covers a domain large enough to allow the acquisition of useful airborne flux measurements and satellite observations but small enough to conserve a reasonable density of surface instrumentation. The distance between the two study areas is large enough to resolve the ecological gradient but small enough to permit the ferrying of research aircraft and specialized equipment and the transfer of personnel on a frequent basis. Two research watersheds were selected within the south and north study areas respectively.

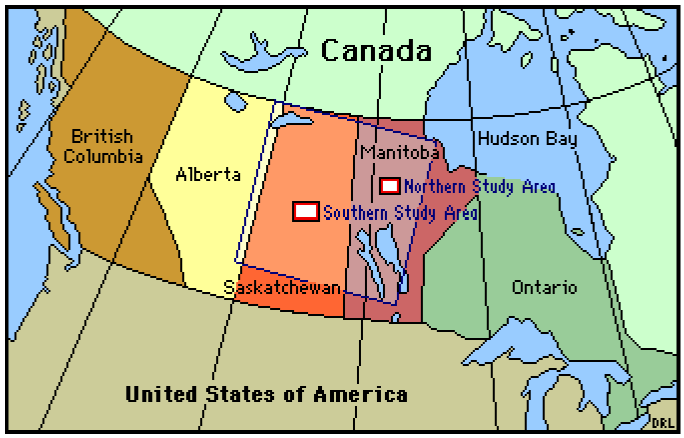

Figure 1 - BOREAS Study Areas

Southern Study Area

The Southern Study Area is 130 km wide by 90 km (see Figure 2). The hydrological study is focused on the White Gull Creek basin. The basin is an area of approximately 595 km^2 centred on a latitude of 54°58’ north and a longitude of 105°55’ west.

The water in the basin flows in a southeasterly direction. There are numerous small water storage areas, the largest of which is White Gull Lake. The streams originate only in wetland locations; very little overland drainage occurs. The White Gull watershed was divided into 4-subwatershed areas by placing stream flow gauges at readily accessible locations (Table 2).

* BOREAS Experiment Plan, p 4-129

Table 2 - SSA Streamflow Stations

Station	Latitude	Longitude	Drainage area	Description
SW1	53 51 46N	104 37 02W	595 km^2	Hwy 106 (05KE010)
SW2	53 53 37N	104 40 56W	81	Harding Road
SW3	53 55 36N	104 47 28W	470	Hwy 120
SW4	53 55 35N	104 49 12W	204	Lorenz Lake
SW5	53 55 48N	104 49 18W	22	Harding Tributary

The region has a very gentle relief, with elevations ranging from 400 to 700 metres. The surface soils consist of glacial till, glaciolacustrine, and glaciofluvial material. The soils range from grey wooded to degraded black with brunisolic, gleysolic, chernozemic, luvisolic and organic soil.[*]

There are two main vegetation groups in the Southern Study Area: Boreal Forest and aspen groves. The western part is located in the Prince Albert National Park boundary, and is characterized by aspen and spruce uplands, black spruce and tamarack bogs, jack pine ridges, sedge meadows and fescue grassland outliers. The ages range between 50 and 100 years, with heights ranging between 15 and 22 metres. Small holes occur in the canopy due to local wet sites. The eastern portion of the SSA is classified as mixed boreal forest. Well drained sites consist mainly of jack pine (sandy soil) or mixed stands of aspen and white spruce (glacial deposits). Poorly drained areas support black spruce. The study watershed is located in the eastern part of the SSA.

The Southern Study Area has a mid-continental climate. The average annual precipitation is between 410 and 500 mm, the majority of which (about 2/3) falls between April and September. In the summer, the temperatures range from about 7 °C to 24 °C. For the winter, the temperatures range from about -21 °C to -4 °C. There are approximately 110 frost-free days each year.[†]

There were fires in 1940-1949 in the central region of the Prince Albert National Park's southern half. In 1969, a fire occurred west of Bittern Lake, while another in 1989 occurred to the south. In the northeast section, a burn occurred in 1977-1978. In 1995, severe fires occurred in the SSA, however, there was no infrastructure damage. A comprehensive forest fire suppression program has limited recent fires in extent and frequency.

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[*] BOREAS Experiment Plan, p 2-18

[†] Department of Energy, Mines and Resources and Information Canada, The National Atlas of Canada, 4th Edition, Revised, Macmillan Company of Canada Limited: Toronto, 1974.

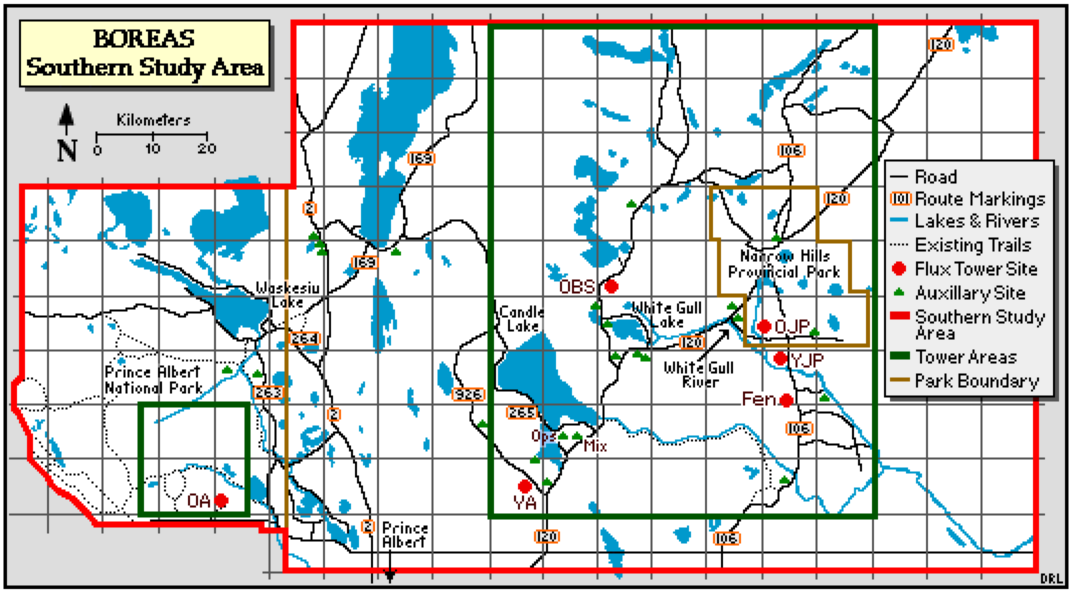

Figure 2 - BOREAS Southern Study Area

Northern Study Area

The Northern Study Area is an area 100 km wide by 80 km (see Figure 3). Detailed hydrologic activities are focused within two small watersheds which are tributary to the Sapochi River. The entire basin of the Sapochi River (an area of 433 sq km) is not suitable for study due to its inaccessibility. However, the Sapochi is gauged at the Highway 391 bridge (streamflow and precipitation are recorded) and there is one precipitation gauge in the southern part of the Sapochi watershed.

Table 3 - NSA Streamflow Stations

Station	Latitude	Longitude	Drainage Area	Description
NW1	55 54 26N	98 29 40W	433 km^2	Sapochi (05TF005)
NW2	55 54 55N	98 31 39W	35	West Basin
NW3	55 55 01N	98 22 32W	31	East Basin

The East Basin has a drainage area of roughly 31 sq km. It is drained mainly by a series of interconnected fens. The West Basin has a drainage area of about 35 sq km. It has steeper creeks and fewer bogs than the East Basin. The water is flowing in the northerly direction in both sub-basins, and in the Sapochi River basin. The East, West and Sapochi basins are separate watersheds, having their outlets at Highway 391 crossings.

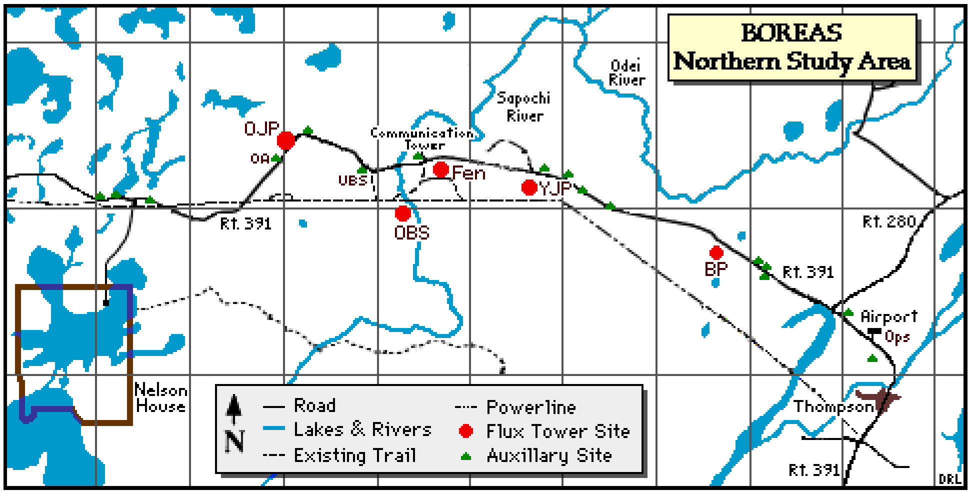

Figure 3 - BOREAS Northern Study Area

The Northern Study Area lies within the Canadian Shield. It has been glacially smoothed, with relief of less than 15 metres. Several narrow stream valleys have a relief of 25 metres, and there are two kame deposits which have 60 metres reliefs. The soils are derived from sediments and consist of clay, organics and some sandy deposits. Soil depths vary from bare bedrock outcrops to sediment basins up to 17 metres thick. There are areas of discontinuous permafrost.

The vegetation consists predominantly of black spruce, in stands of varying density. Some jack pine stands are located in the south and west portions of the region. Forest stands are generally mature, some being over 100 years old, and heights range up to 15 metres. Some of the coniferous stands contain scattered white birch and trembling aspen, but pure stands of these are rare and small. The forest cover is broken in areas of varying density, moisture conditions, and open treed bogs.

The Northern Study Area has a mid-continental climate. The average annual precipitation is between 410 and 500 mm, the majority of which (about 2/3) falls between April and September. In the summer, the temperatures range from about 5 °C to 21 °C. For the winter, the temperatures range from about -26 °C to -8 °C. There are approximately 90 frost-free days each year.

There have been three large burns in the NSA. In 1981, a burn occurred in the southern part of the area, and in 1964, a burn with jack pine regeneration occurred in the east. Large burns in 1989 occurred in the northern and western sections.

OBJECTIVES

The main goal of BOREAS is to "improve our understanding of the interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change."* However, the experimental phase is only designed to last for three years, which

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* BOREAS Experimnet Plan, p 1-2

is not long enough to observe global change. Instead, measurements were taken at representative sites to improve process models. These process models will be used with remote sensing and integrative modelling techniques to apply them over large areas and determine how well the current situation is described. If the current situation can be well described, the models can be used predictively to determine global change.

Therefore, the objectives of BOREAS are to:

- Improve the process models which describe the exchanges of energy, water, heat, carbon and trace constituents between the boreal forest and the atmosphere; and
- Develop and test methods for applying the process models over large spatial scales using remote sensing and integrative modelling techniques.

For the hydrology component of the project, the objectives are to "characterize the storage of moisture at and near the land surface, in both solid and liquid states, and the fluxes of moisture to and from the land surface."[*] The investigations were to measure and allow the prediction of moisture storage at various scales from meters to kilometres. Also, the investigations were to measure and simulate the interactions between subsurface, surface, and canopy hydrologic and ecological processes over the same range of scales.

RESEARCH ACTIVITIES

1993

This first year was used to prepare and organize the BOREAS experimental phase. The major accomplishments of 1993 were:

- Completion of the details of the BOREAS experiment design, and the production of a prototype version of the experiment plan;
- The installation of nine flux towers in the southern and northern study areas along with power, access trails, boardwalks, and investigator huts;
- The installation of a mesoscale meteorological network, complete with nine new meteorological towers located in the 1000 x 1000 km grid and an enhanced radiosonde network to feed real-time data onto the global operational weather network;
- The installation of regional radio networks to provide real-time communications among BOREAS mission management, principal investigators and aircraft;
- The location and marking of some 70 auxiliary sites throughout the study region to conduct carbon flux and remote sensing studies;
- The installation of seven streamflow stations (five seasonal, two all-year) and 24 precipitation gauges; and

[*] BOREAS Experiment Plan, p 4-125

- In August, a "shake-down" intensive field campaign, IFC-93, occurred. This 21-day IFC was used to test the experiment infrastructure and investigators' instruments as well as to refine coordination and communication procedures.*

1994

There were five field campaigns in 1994:

FFC-W	Focused Field Campaign - Winter (February 1994)
FFC-T	Focused Field Campaign - Thaw (April 1994)
IFC-1	First Intensive Field Campaign (24 May through 16 June 1994)
IFC-2	Second Intensive Field Campaign (19 July 1994 through 10 August 1994)
IFC-3	Third Intensive Field Campaign (30 August through 19 September 1994)

The ground teams worked continuously from the IFC-1 through to the end of IFC-3 (or beyond). Certain ground teams have data for FFC-W and FFC-T. For the hydrological part of BOREAS, a field crew was split between the SSA and the NSA from April 5 until October 15, 1994. All seasonal stream gauge equipment was installed between April 1 and April 30 and removed in mid-October. These results will be described below.

1995 - 1996

The field campains for the HYD-9 team in 1995 and 1996 involved the following:

- the installation in April and removal in October the instrumentation for 5 streamflow stations in 1995 and for 6 stations in 1996
- the measurement of streamflow at the gauge locations to form the basis for the stage-discharge curves;
- the installation in April and removal in October of approximately 22 precipitation gauges;
- the completion of regular checks of the precipitation stations; and
- the collection of accumulated data from the data loggers connected to the stream level recorders and precipitation gauges.

* BOREAS Web Page (http://boris/gsfc.nasa.gov/)

Streamflow Monitoring

Figure 4 - Streamflow Monitoring Station at SW2

In 1994 and 1995 seven streams were monitored; four in the south and three in the north. In 1996 that number was increased to eight as an additional streamflow monitoring station was added to the Southern Study Area (SW5). The water height was monitored continously, and an average produced every 15 minutes. Periodic stream flow measurements were taken to provide a stage-discharge relationship. With this relationship established, the countinuous water level measurements are converted into continuous flow measurements. Figure 4 contains a photograph of one of the streamflow monitoring stations in the Southern Study Area. Here the float tube is visible, supported by a log.

Float tubes were used to monitor water heights. Flow measurements were determined by taking velocity measurements across a stream cross section near the location of the float tube and integrating the results over the cross sectional area. A propeller meter and an electromagnetic meter were used for the velocity measurements. Figure 5 illustrates graphically the calibration process of a particular gauge. Shown in this figure are the original voltages from the float tube datalogger, the voltage-stage and voltage-flow relationships, the Observed vs. Calculated flow plot and the final hydrograph plotted with the observed flow points. When calculating the hydrographs, a polynomial function was typically fitted to the voltage-flow relationship. The function was then applied to the voltages from the datalogger, providing continuous flow measurements.

The details of each streamflow measurement station over the three year observation period are included in Appendix B.

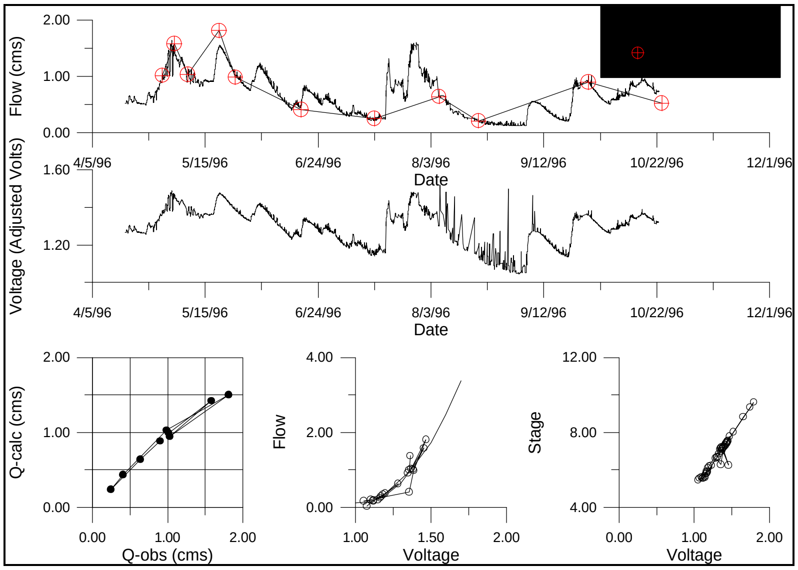

Figure 5 - Stremflow Gauge Calibration (SW2 1996)

Precipitation Monitoring

In the SSA, approximately 12 seasonal precipitation gauges were installed. In the NSA, approximately 10 seasonal gauges were used, and one permanent gauge was used. The number of stations varied from year to year.

Two kinds of precipitation instruments were used: belfort and tipping bucket gauges. The belforts retain precipitation in a bucket and record the weight using a datalogger. This is converted to precipitation with the use of a calibration coefficient. The tipping buckets contain buckets which, when filled with water, tip over. The number of tips is recorded using a datalogger. The tipping buckets used would register a tip at approximately 0.1 mm or 0.2 mm of precipitation. Figure 6 is a photograph illustrating a typical tipping bucket rain gauge in the process of having its logger data downloaded.

Figure 6 - Tipping Bucket Rain Gauge at SSA - OBS

The details of each precipitation measurement station over the three year observation period are included in Appendix A.

Other Meterological Data Acquisition

Meterological data was obtained from several of the Tower Flux sites included in the BOREAS project. These data were used to augment the precipitation data acquired by the Hyd-9 group as well as to provide radiation fluxed for evaporation modeling. There are also several other meteorological stations operated by the Saskatchewan Research Council (AFM-07) which are not located in the watersheds, but which can used for transect modelling.

Ground Cover Data Acquisistion

Ground cover information was acquired from the Remote Sensing Sciences (RSS) group in the form of classified LandSat imagery. For the purposed of modeling in Watflood each class was grouped into one of 7 GRU classes:

- Wet Conifer;
- Dry Conifer;
- Mixed and Deciduous;
- Disturbed and Young;
- Recent Burn and Regenerating;
- Wetlands; and
- Water

Hydrologic Modeling

One of the principal tasks of the HYD-9 team was to properly simulate the space-time distribution of the snow and subsequent meltwater within the study areas; in short, a complete hydrologic model of the selected watersheds. The WATFLOOD forecasting model, developed at the University of Waterloo, was chosen for this task for it's abilities to model snow accumulation and ablation, evapotranspiration, soil moisture and runoff. It was also considered favourable for its specific sensitivity to land class information. The model consists of an integrated set of computer programs to forecast flood flows for watersheds having response times ranging from one hour to several weeks. The emphasis of the WATFLOOD system is on making optimal use of remotely sensed data and to partition the landcover into hydrologically similar groups called Grouped Response Units (GRU).

It is well known that the hydrological response from such land covers as, for instance, forests and alpine tundra, differ greatly but it can be expected that for example, two or more similarly forested areas that experience the same meteorological conditions would have the same response. The same logic applies to other land covers. In the GRU method, all similarly vegetated areas (not necessarily contiguous) within a sub-watershed or element are grouped as one response unit and called a GRU. The GRU is the basic computational unit in the model. An element has one GRU for each hydrologically significant land cover type. The hydrological response from all GRUs in an element are summed to give its total response.

Very good hydrograph fits were observed once the full 3 years of data was obtained and the hydrologic parameters were calibrated to this data set. The importance of continuous data in hydrologic modeling cannot be overstressed. Usually, the initial conditions are interpreted from antecedent meterological data, snow course data, snow cover extent from remote sensing and, indirectly, from streamflow. However, when hydrological models are applied, the effect of initial errors in estimating initial storages are reduced over time.

Figure 7, below, illustrates the modeling results of the White Gull Watershed in the form of runoff hydrograph comparisons. In this watershed the hydrologic parameters were calibrated to the first year (1994) and validated over the following 2 years. It can be seen that the volumes of water are generally conserved and the timing of the snowmelts are quite reasonable. The excessive peaking of the estimated hydrographs is believed to be a result of wetland retention not currently modeled in WATFLOOD.

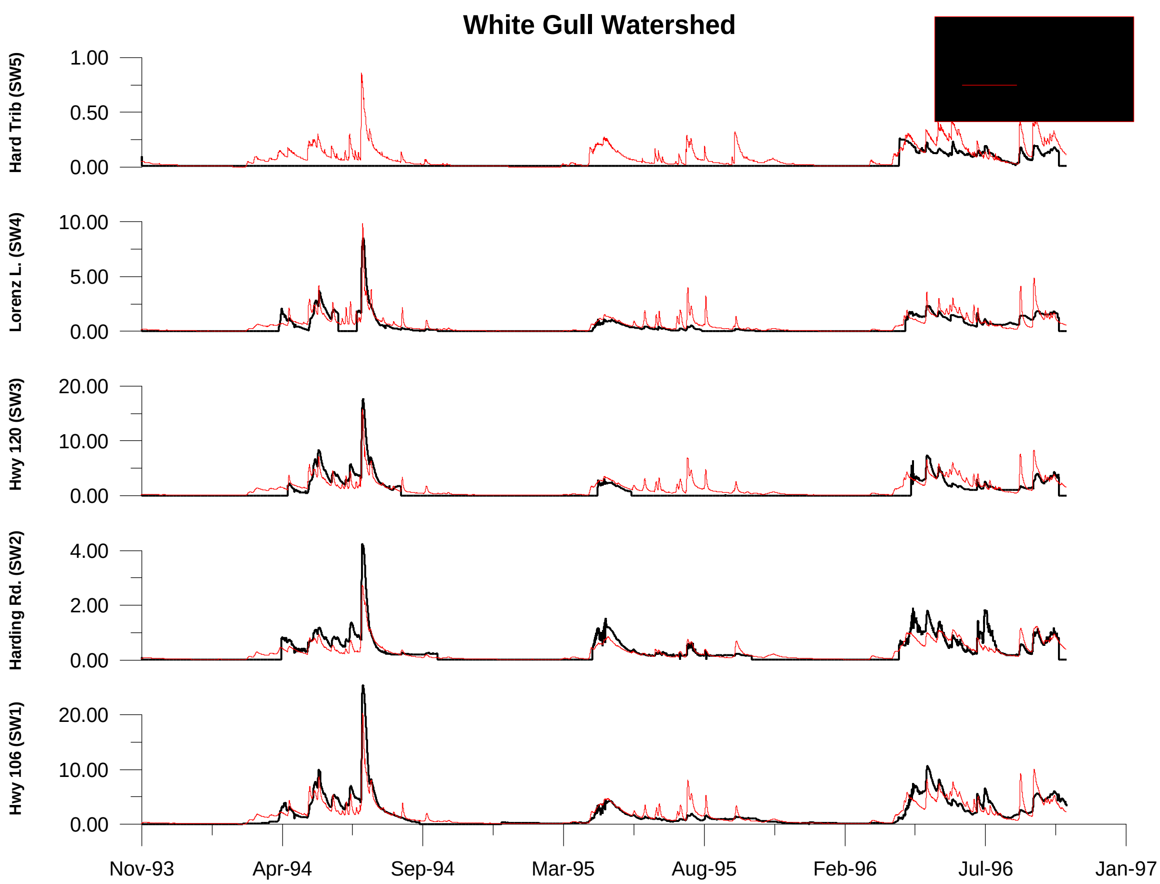

Figure 7 - Observed and Calculated Hydrographs in White Gull Watershed

* size of the watershed advantageous - closed system
* incorporation of our data

Figure 8, below, illustrates some snow modeling results on the White Gull watershed. These three plots show the snow water equivalent on the ground across the watershed at three different times in the 1995 winter season. Here the accumulation of the amount of snow on the ground can be seen to occur between the January 1 and March 1. Conversely, the amount of snow can be seen to drop from March 1 to May 1 and almost disappear completely. Snow ablation rates are land class specific in WATFLOOD. Consequently, different land classes in the same grid element could have different snow pack levels. What is shown in Figure 8 is a weighted average of the snow pack based on land class area in each grid element.

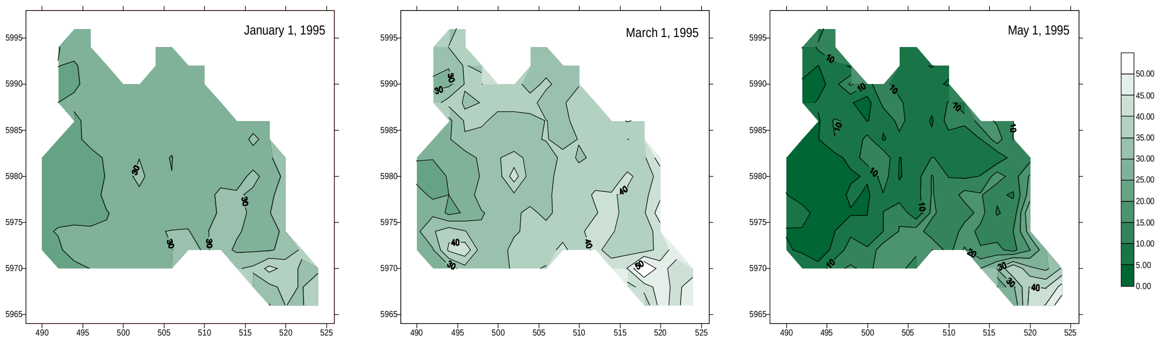

Figure 8 - Snow Cover Modeling on the White Gull Watershed

When evaluating the performance of a watershed model it is critical to examine the hydrologic processes at all levels throughout the simulation. For this purpose WATFLOOD generates process plots like the one shown in Figure 9. An individual process plot can be generated for every GRU within every grid of the watershed basin, allowing the user to examine the variation in hydrological responce by land cover class and by location. In Figure 9 one can see the fluctuation of a complete array of hydrologic parameters:

Groundwater in the upper and lower zones (UZS and LZS);
Snow cover (SNOWC);
Snow covered area as a percentage of the grid area (SCA);
Heat deficit in the snowpack (DEF);

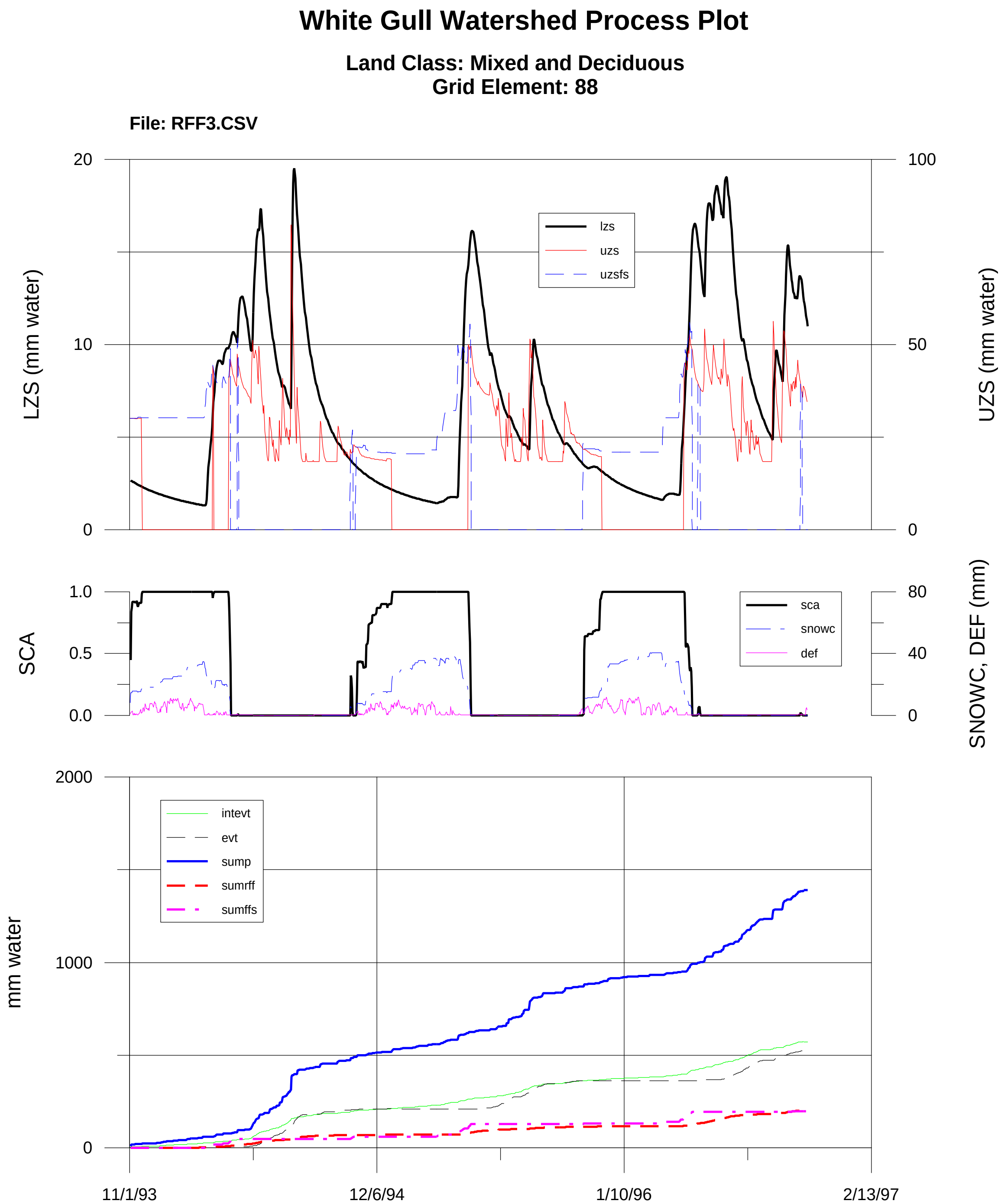

Figure 9 - Process Plot for White Gull Watershed Simulation

ACKNOWLEDGEMENTS

For further information about the data, please contact:

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COOPERATING AGENCIES

Appendix A - Precipitation Gauges

Belfort 21 (Bel 21) - Tipping Bucket 26 (TB26)
Belfort 22 (Bel 22) - Tipping Bucket 28 (TB 28)
Belfort 23 (Bel 23) - Tipping Bucket 27 (TB 27)
Belfort at NW3 (Bel NW3)
Belfort at NW2 (Bel NW2)
Tipping Bucket 21 (TB 21) - Belfort 24 (Bel 24)
Tipping Bucket 22 (TB22)
Tipping Bucket 23 (TB 23)
Tipping Bucket 24 (TB 24) - Belfort 25 (Bel 25)
Belfort 1 (Bel 1)
Belfort 2 (Bel 2)
Belfort 3 (Bel 3)
Belfort 4 (Bel 4) - Tipping Bucket 9 (TB 9)
Belfort 5 (Bel 5)
Tipping Bucket 1 (TB 1) - Tipping Bucket 10 (TB 10)
Tipping Bucket 2 (TB 2)
Tipping Bucket 3 (TB 3)
Tipping Bucket 4 (TB 4)
Tipping Bucket 5 (TB 5)
Tipping Bucket 6 (TB 6) - Tipping Bucket 6A (TB 6A)
Tipping Bucket 7 (TB 7)
Tipping Bucket 8 (TB 8)

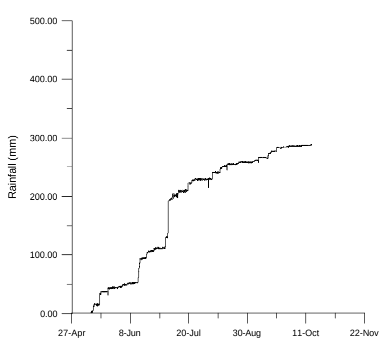
Precipitation - Northern Study Area

Belfort 21 (Bel 21) - Tipping Bucket 26 (TB26)

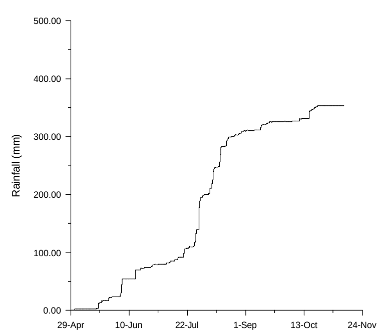
Latitude:	55 53 18.4 N
Longitude:	98 24 43.2 W
Logger No.:	25 (1994), 27 (1995), 26 (1996)
Description:	East Basin / Power line, mid-point
Notes:	Bel 21 replaced with TB 26 at start of 1995 season

Year	**Date**	**Event**
1994		
	05/11	Bel 21 gauge installed
	05/12	Logger changed to double precision
	07/11 - 07/12	Gauge knocked over, repaired and reset; missing data
	10/04	Bel 21 gauge removed
1995		
	04/29	TB 26 gauge installed (55 53 18.8 N, 98 24 43.2 W)
	08/24	Gauge levelled, logger restarted
	11/10	TB 26 gauge removed
1996		
	Entire Season	No reliable rainfall data

Bel 21 1994



TB 26 1995



1996

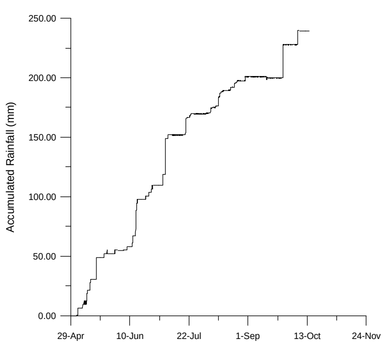
NO DATA

Belfort 22 (Bel 22) - Tipping Bucket 28 (TB 28)

Latitude: 55 46 35.5 N
Longitude: 98 29 56.1 W
Logger No.: 28 & 30 (1994), 12 (1995), 29(1996)
Description: Sapochi Basin / Interior
Notes: Bel 22 replaced with TB 28 at start of 1995 season

Year	Date	Event
1994		
	04/29	Bel 22 installed (logger 28)
	07/09	Changed logger number to 30
	10/13	Bel 22 removed
1995		
	All Season	No reliable rainfall data*
1996		
	All Season	No reliable rainfall data*

Bel 22 1994



1995

NO DATA

1996

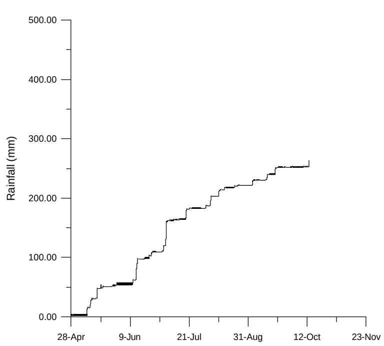
NO DATA

Belfort 23 (Bel 23) - Tipping Bucket 27 (TB 27)

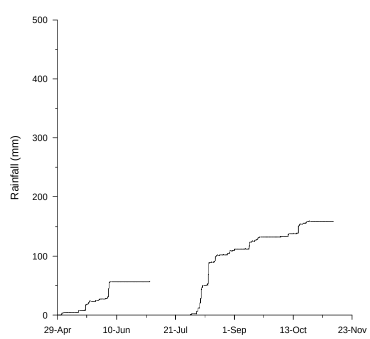
Latitude: 55 53 29.3 N
Longitude: 98 33 29.6 W
Logger No.: 29 (1994 & 1995), 27 (1996)
Description: West Basin / Power line
Notes: Bel 23 replaced with TB 27 at start of 1995 season

Year	Date	Event
1994		
	04/28	Bel 23 installed
	07/30	Gauge knocked over
	08/02	Gauge repaired
	10/13	Bel 23 removed
1995		
	04/29	TB 27 installed
	07/04 - 08/01	Missing data
	11/10	TB 27 removed
1996		
	04/14	TB 27 installed
	06/10	Gauge found knocked over and damaged - replaced and reset
	10/25	TB 27 removed

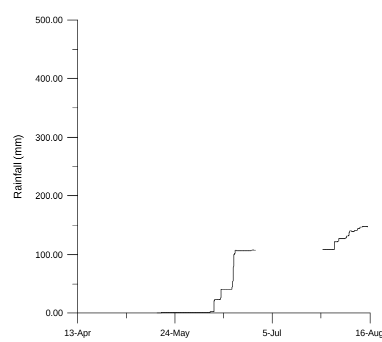
Bel 23 1994



TB 27 1995



TB 27 1996

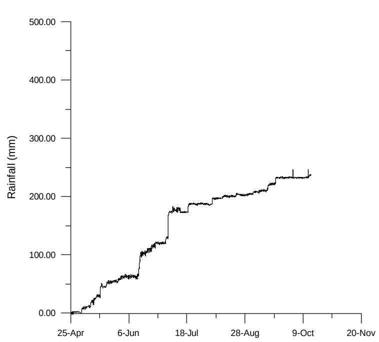


Belfort at NW3 (Bel NW3)

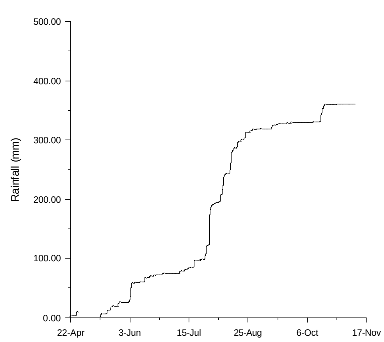
Latitude: 55 55 00.6N
Longitude: 98 22 32.3W
Logger No.: 22
Description: East Basin @ 391
Notes:

Year	Date	Event
1994		
	04/25	Bel NW3 installed
	10/14	Bel NW3 removed
1995		
	04/23	Bel NW3 installed
	11/09	Bel NW3 removed
1996		
	04/13	Bel NW3 installed
	06/09	Bel NW3 moved downstream*NW3A
	10/24	Bel NW3 removed

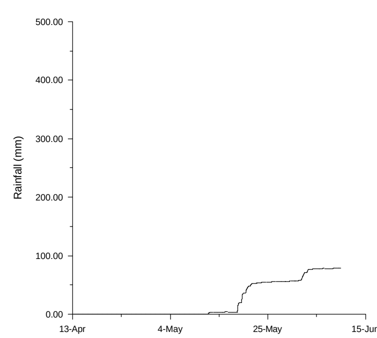
Bel NW3 1994



Bel NW3 1995



Bel NW3 1996

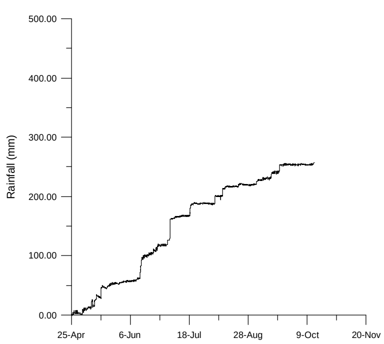


Belfort at NW2 (Bel NW2)

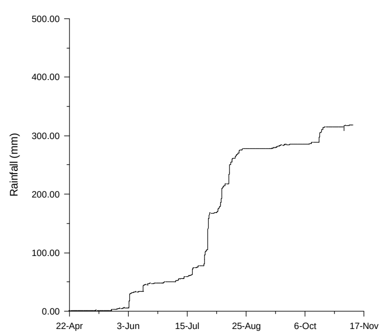
Latitude: 55 54 55N
Longitude: 98 31 41W
Logger No.: 21
Description: West Basin @ 391
Notes:

Year	Date	Event
1994		
	04/25	Bel NW2 installed
	10/14	Bel NW2 removed
1995		
	04/22	Bel NW2 installed
	11/03	Missing data
	11/09	Bel NW2 removed
1996		
	04/13	Bel NW2 installed
	10/23	Bel NW2 removed

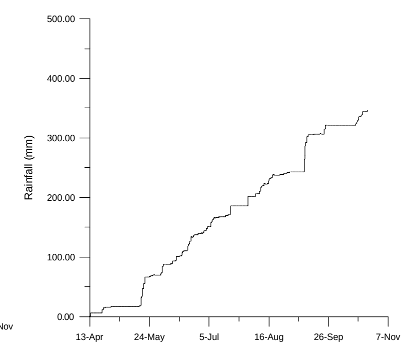
Bel NW2 1994



Bel NW2 1995



Bel NW2 1996

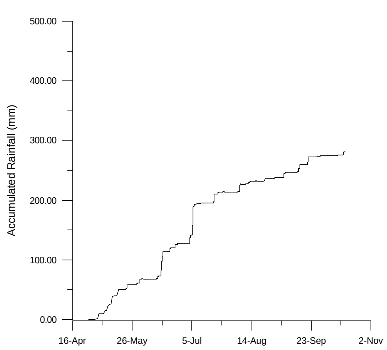


Tipping Bucket 21 (TB 21) - Belfort 24 (Bel 24)

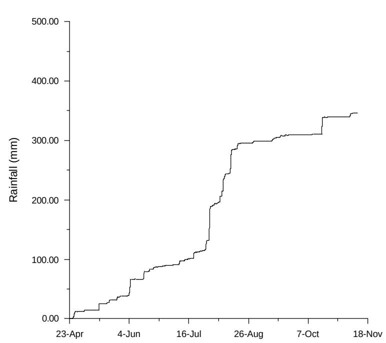
Latitude:	55 54 44.25N
Longitude:	98 20 32.75W
Logger No.:	21 (1994), 29 (1995), 23 (1996)
Description:	East Basin @ 391, east side
Notes:	TB 21 replaced with Bel 24 at start of 1995 season

Year	Date	Event
1994		
	04/27	TB 21 installed
	04/27 - 05/18	Missing data
	10/14	TB 21 removed
1995		
	04/23	Bel 24 installed (55 54 44.5N, 98 20 33.9W)
	11/10	Bel 24 removed
1996		
	04/13	Bel 24 installed
	07/04 - 08/02	Missing data
	11/06	Bel 24 removed

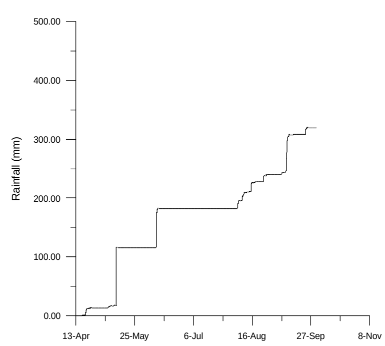
TB 21 1994



Bel 24 1995



Bel 24 1996

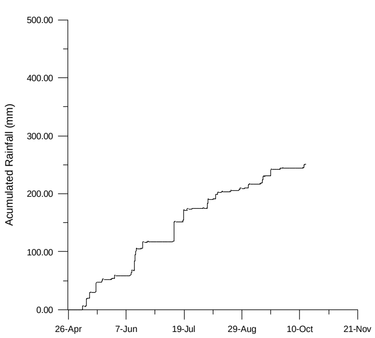


Tipping Bucket 22 (TB22)

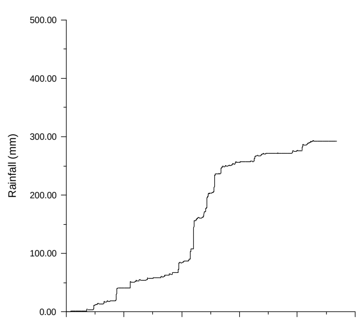
Latitude: 55 53 20N
Longitude: 98 26 11W
Logger No.: 24 (1994 & 1995), 12 (1996)
Description: East Basin / power line, west side
Notes:

Year	Date	Event
1994		
	04/26	TB 22 installed
	05/18	Missing data
	07/12	Spider's nest found in tipping bucket. Water stored in nest released and recorded as precipitation. Evaporation losses likely.
	07/22 - 07/23	Missing data
	10/14	TB 22 removed
1995		
	04/29	TB 22 installed
	11/10	TB 22 removed
1996		
	Entire Season	No reasonable data

TB 22 1994



TB 22 1995



1996

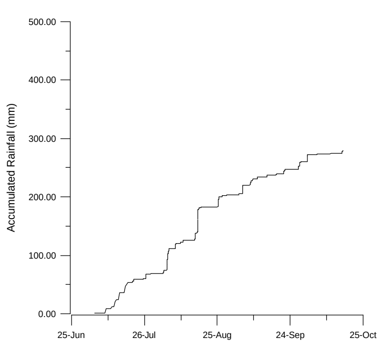
NO DATA

Tipping Bucket 23 (TB 23)

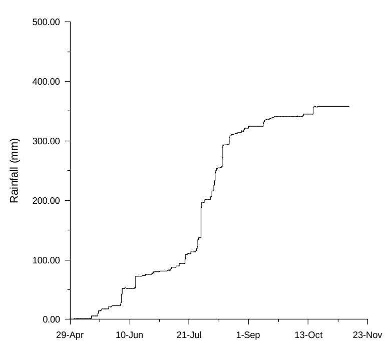
Latitude: 55 53 20W
Longitude: 98 20 40N
Logger No.: 26 (1994 & 1995), 25 (1996)
Description: East Basin / Power line, east side
Notes:

Year	Date	Event
1994		
	04/27	TB 23 installed
	10/14	TB 23 removed
1995		
	04/29	TB 23 installed
	11/10	TB 23 removed
1996		
	04/15	TB 23 installed
	*	problem (graph terminates early)
	11/06	TB 23 removed

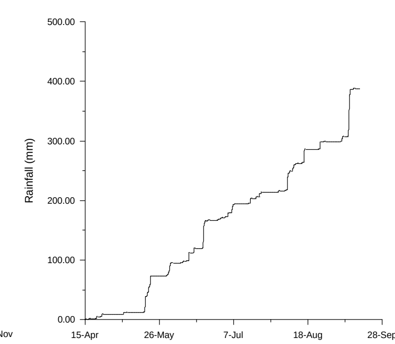
TB 23 1994



TB 23 1995



TB 23 1996

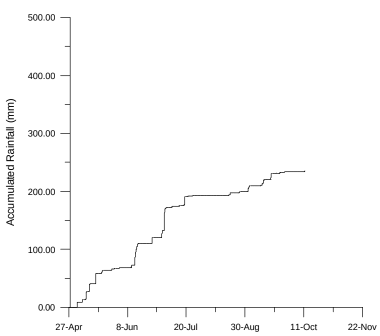


Tipping Bucket 24 (TB 24) - Belfort 25 (Bel 25)

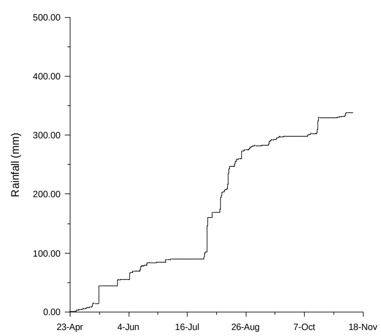
Latitude: 55 55 37.5W
Longitude: 98 33 58.2N
Logger No.: 27 (1994), 30 (1995), 24 (1996)
Description: West Basin @ 391 at rock cut
Notes: TB24 replaced with Bel 25 at start of 1995 season

Year	Date	Event
1994		
	04/27	TB 24 installed
	10/14	TB 24 removed
1995		
	04/23	Bel 25 installed (55 55 35.8W, 98 53 37.6N)
	11/10	Bel 25 removed
1996		
	04/13	Bel 25 installed
	11/06	Bel 25 removed

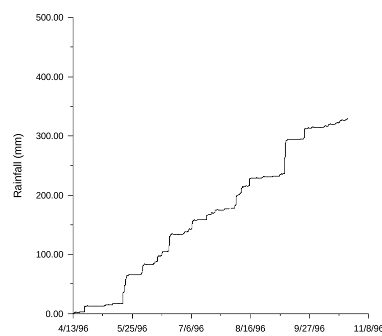
TB 24 1994



Bel 25 1995



Bel 25 1996



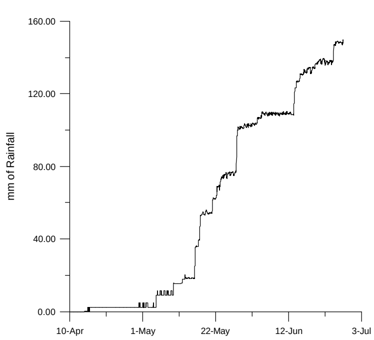
Precipitation - Southern Study Area

Belfort 1 (Bel 1)

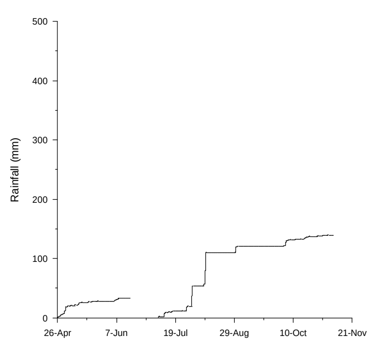
Latitude: 53 51 39W
Longitude: 105 56 27N
Logger No.: 4 (1994), *(1995), 11 (1996)
Description: White Gull Drain
Notes:

Year	Date	Event
1994		
	04/10	Bel 1 installed at Hwy 913 & 120
	05/05	Bel 1 moved to White Gull Drain (53 53 30.4N, 105 00 47.8W)
	05/11	Gauge reset at 11:00
	07/21	Gauge knocked over
	07/24	Lid knocked off
	10/16	Bel 1 removed
1995		
	04/26	Bel 1 installed (53 53 29.6N, 105 00 41.4W)
	06/17 - 07/06	Missing data - mechanical problems
	11/07	Bel 1 removed
1996		
	06/05	Bel 1 installed (53 53 23.6N, 105 00 43.2W)
	11/06	Bel 1 removed

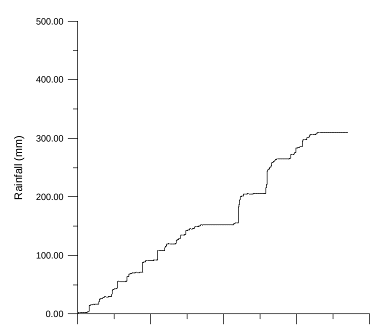
Bel 1 1994



Bel 1 1995



Bel 1 1996

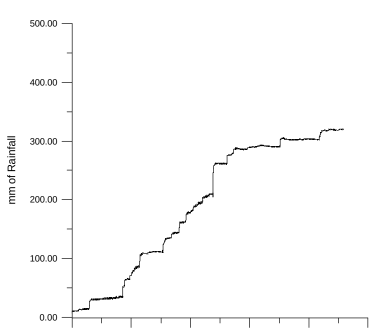


Belfort 2 (Bel 2)

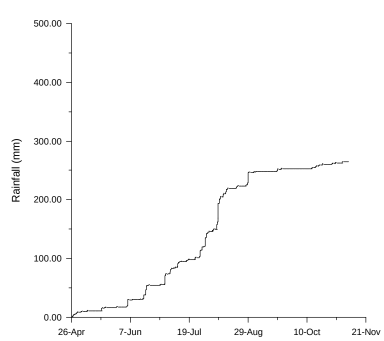
Latitude: 54 05 06.2W
Longitude: 105 02 15.9N
Logger No.: 6
Description: Lorenz Lake Rd. & 913
Notes:

Year	Date	Event
1994		
	04/10	Bel 2 installed
	06/01	Gauge knocked over
	06/13	Lid knocked off affecting all subsequent readings. Readings adjusted by using the ratio of the diameter of the gauge opening to the diameter of the bucket.
	10/17	Bel 2 removed
1995		
	04/12	Bel 2 installed
	04/12 - 04/26	Precip recordings by TB 5
	08/30	Water level lowered - Belfort gauge hit maximum water level
	11/08	Bel 2 removed
1996		
	04/15	Bel 2 installed
	11/06	Bel 2 removed

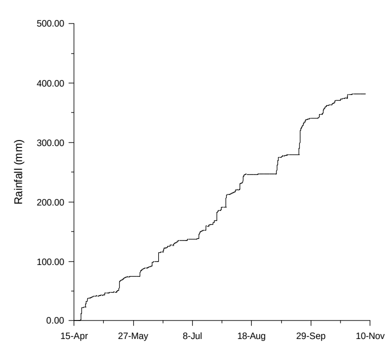
Bel 2 1994



Bel 2 1995



Bel 2 1996

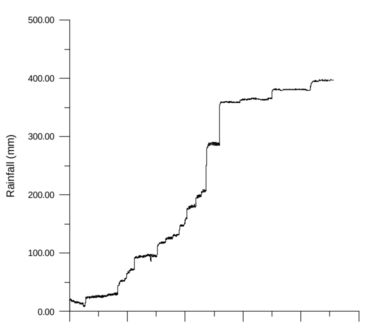


Belfort 3 (Bel 3)

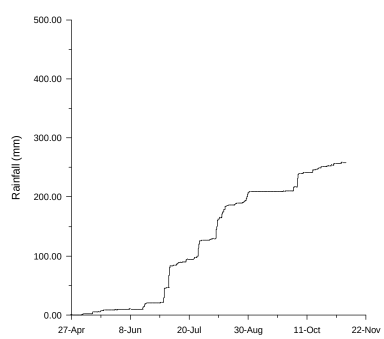
Latitude: 54 05 05N
Longitude: 105 45 44W
Logger No.: 9 (1994 & 1995), 84 (1996)
Description: Fairy Glen Lake
Notes:

Year	Date	Event
1994		
	04/11	Bel 3 installed
	06/28	Lid knocked off gauge
	07/21 - 07/28	Missing data
	10/14	Gauge damaged by bear
	10/17	Bel 3 removed
1995		
	04/27	Bel 3 installed
	11/07	Bel 3 removed
1996		
	06/05	Bel 3 installed
	07/24 - 09/11	Missing data
	11/05	Bel 3 removed

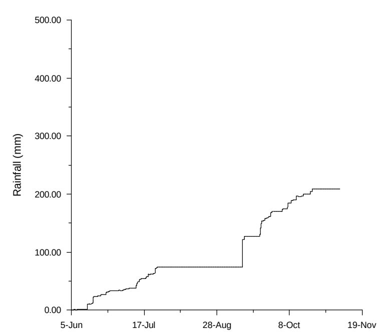
Bel 3 1994



Bel 3 1995



Bel 3 1996

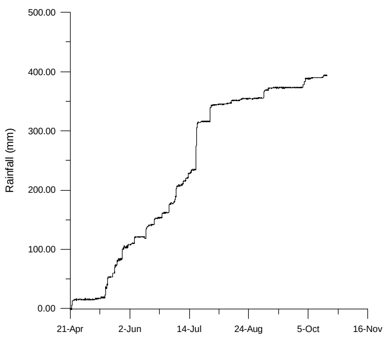


Belfort 4 (Bel 4) - Tipping Bucket 9 (TB 9)

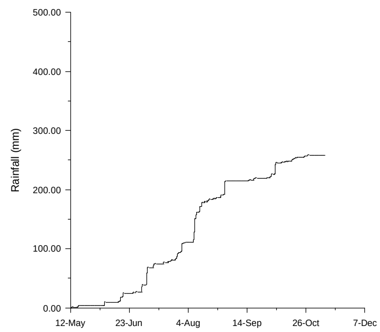
Latitude:	54 00 16N
Longitude:	104 53 44W
Logger No.:	12 (1994), 11(1995), 93 (1996)
Description:	Lorenz Lake Rd., Interior
Notes:	Bel 4 replaced with TB 9 at start of 1995 season

Year	Date	Event
1994		
	04/21	Bel 4 installed
	06/13	Lid knocked off
	10/17	Bel 4 removed
1995		
	05/12	TB 9 installed (54 03 08.9W, 104 56 12.5W)
	11/08	TB 9 removed
1996		
	08/23	TB 9 installed
	11/06	TB 9 removed

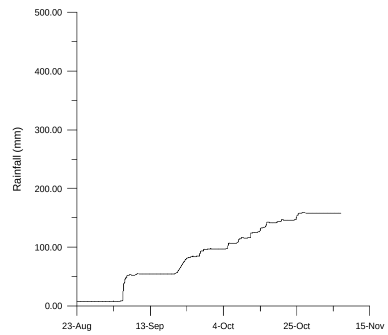
Bel 4 1994



TB 9 1995



TB 9 1996

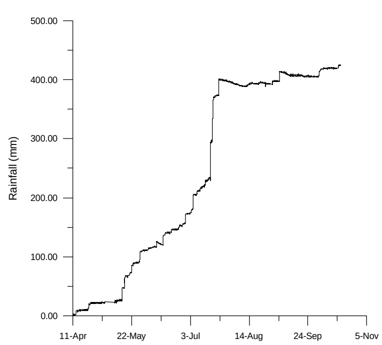


Belfort 5 (Bel 5)

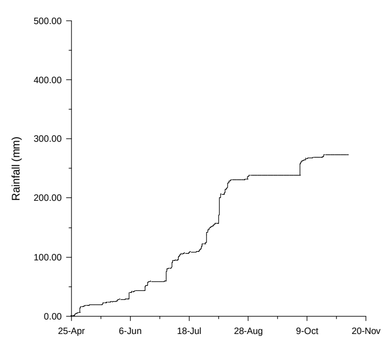
Latitude: 53 55 35N
Longitude: 104 49 13W
Logger No.: 3
Description: White Gull Creek at Lorenz Lake Rd. (SW4)
Notes:

Year	Date	Event
1994		
	04/12	Bel 5 installed
	05/04 - 05/09	Gauge knocked over during this period, data unreliable
	05/16	Gauge knocked over during windstorm
	05/17	Gauge reset
	10/16	Bel 5 removed
1995		
	04/11	Bel 5 installed
	11/07	Bel 5 removed
1996		
	08/23	Bel 5 installed
	11/06	Bel 5 removed

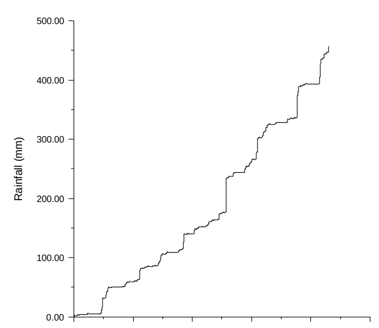
Bel 5 1994



Bel 5 1995



Bel 5 1996

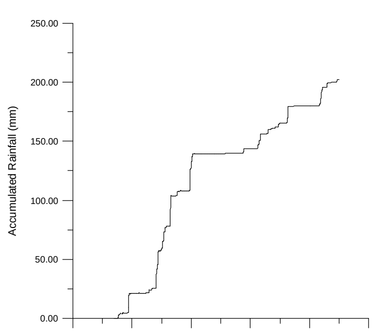


Tipping Bucket 1 (TB 1) - Tipping Bucket 10 (TB 10)

Latitude: 53 55 93N
Longitude: 105 08 05W
Logger No.: 5
Description: 913 Cut block (1994), 1km south, Heratage L. Rd. @ 913 & SP9 (1995,1996)
Notes: TB 1 was moved May 31, 1995 and renamed TB 10 at this time

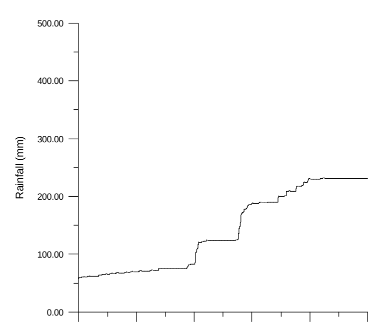
Year	Date	Event
1994		
	04/10	TB 1 installed
	10/16	TB 1 removed
1995		
	04/11	TB 1 installed
	04/18 - 04/26	Missing data - mechanical problems
	05/06 - 05/31	Missing data - mechanical problems
	05/31	TB 1 removed
	06/01	TB 10 installed (53 55 07.8N, 105 08 38.0W)
	06/01 - 07/06	Missing data - mechanical problems
	11/07	TB 10 removed
	*	*2 plots required for this area!!!
1996		
	04/15	TB 10 installed
		* Where is the initial data from s05jan01??
	07/26	Battery flat - logger recharged and started with 226 tips
	11/06	TB 10 removed

TB 1 1994



1995

TB 10 1996

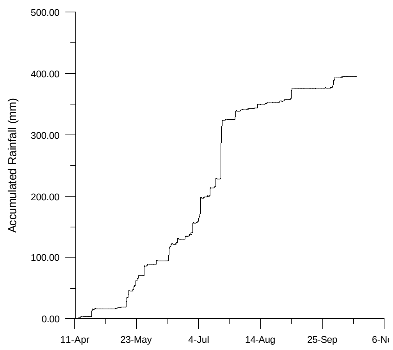


Tipping Bucket 2 (TB 2)

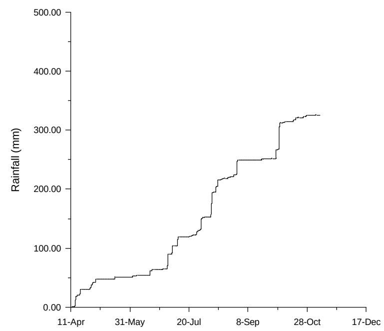
Latitude: 53 59 02N
Longitude: 104 41 12W
Logger No.: 7(1994 & 1995), 8 (1996)
Description: Hwy 120, Site #263
Notes:

Year	Date	Event
1994		
	04/11	TB 2 installed
	10/17	TB 2 removed
1995		
	04/11	TB 2 installed
	11/07	TB 2 removed
1996		
	04/01	TB 2 installed
	07/25 - 08/19	Missing data
	11/06	TB 2 removed

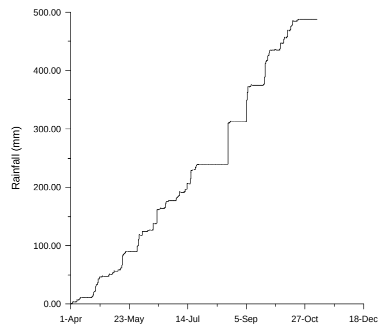
TB 2 1994



TB 2 1995



TB 2 1996

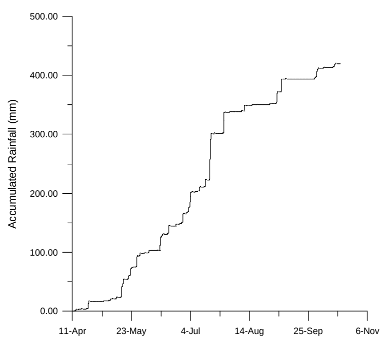


Tipping Bucket 3 (TB 3)

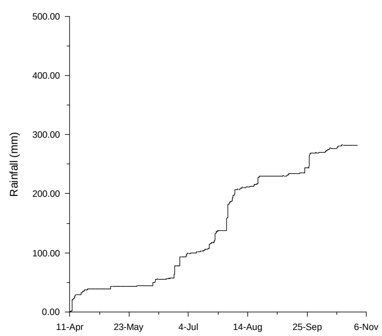
Latitude: 54 02 35N
Longitude: 104 42 12W
Logger No.: 8(1994 & 1995), 9 (1996)
Description: Int. 106 and old 120 (Top OJP Cr.)
Notes:

Year	Date	Event
1994		
	04/11	TB 3 installed
	05/25	Missing data
	10/18	TB 3 removed
1995		
	04/11	TB 3 installed
	11/07	TB 3 removed
1996		
	04/16	TB 3 installed
	05/27 - 06/05	Missing data
	11/06	TB 3 removed

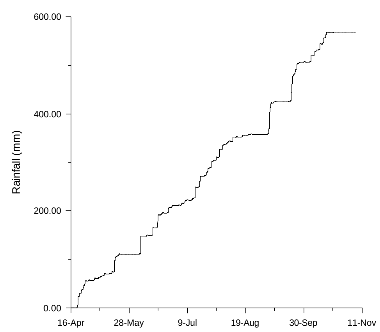
TB 3 1994



TB 3 1995



TB 3 1996

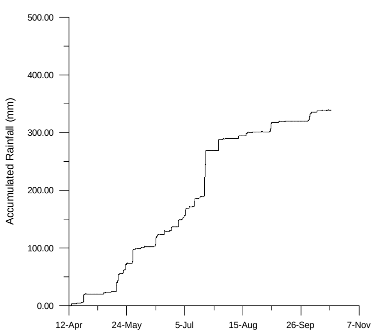


Tipping Bucket 4 (TB 4)

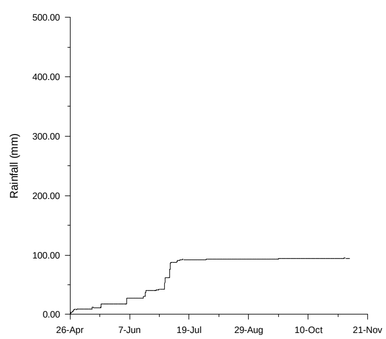
Latitude: 54 09 29N
Longitude: 104 52 26W
Logger No.: 10
Description: Int. 913 and old 120 (Regen. site)
Notes:

Year	Date	Event
1994		
	04/12	TB 4 installed
	10/17	TB 4 removed
1995		
	04/26	TB 4 installed
	07/15-11/08	Missing data
	11/08	TB 4 removed
1996		
	04/01	TB 4 installed
	11/06	TB 4 removed

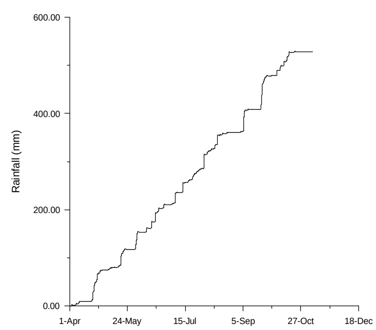
TB 4 1994



TB 4 1995



TB 4 1996

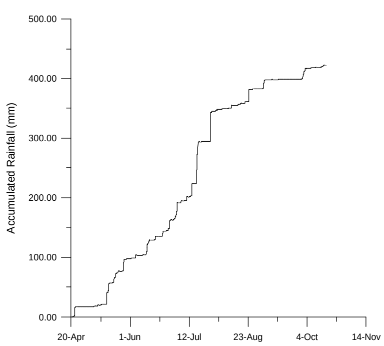


Tipping Bucket 5 (TB 5)

Latitude: 54 03 06.5N
Longitude: 104 56 14.1W
Logger No.: 11
Description:
Notes:

Year	Date	Event
1994		
	04/20	TB 5 installed
	10/17	TB 5 removed
1995		
		Not Installed
1996		
		Not Installed

TB 5 1994



1995

NO DATA

1996

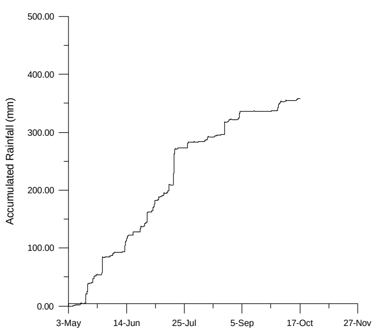
NO DATA

Tipping Bucket 6 (TB 6) - Tipping Bucket 6A (TB 6A)

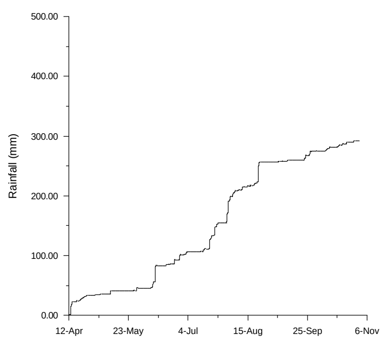
Latitude: 53 59 55N
Longitude: 105 06 48W
Logger No.: 13
Description: Old Black Spruce Site
Notes: ***something happens with TB6A, but when?

Year	Date	Event
1994		
	05/04	TB 6 installed
	10/17	TB 6 removed
1995		
	04/12	TB 6 installed
	11/08	TB 6 removed
1996		
	04/16	TB 6 installed
	07/15	Moved to Tower site approx. 76 m from OBS Tower - renamed TB 6A
	11/06	TB 6 removed

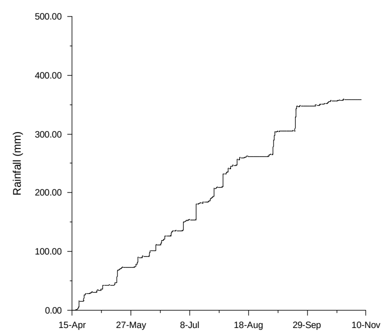
TB 6 1994



TB 6 1995



TB 6 & TB 6A 1996

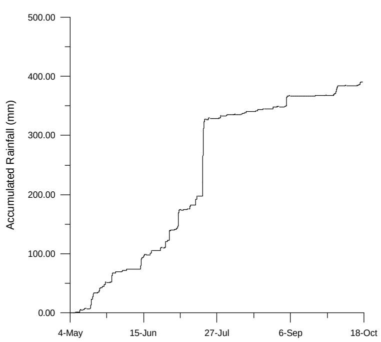


Tipping Bucket 7 (TB 7)

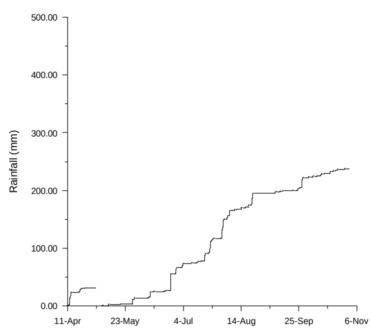
Latitude: 53 53 36.5N
Longitude: 104 40 55.7W
Logger No.: 1
Description: Harding Road (SW2)
Notes: TB 7 is part of the SW2 installation

Year	Date	Event
1994		
	05/04	TB 7 installed
	10/16	TB 7 removed
1995		
	04/11	TB 7 installed
	05/09 - 05/12	Missing data
	11/07	TB 7 removed
1996		
	04/16	TB 7 installed
	11/06	TB 7 removed

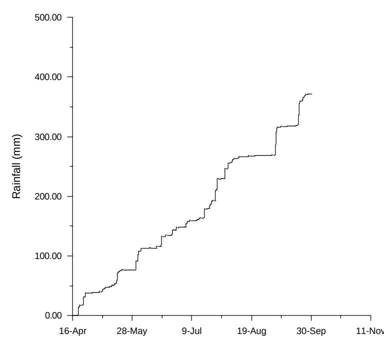
TB 7 1994



TB 7 1995



TB 7 1996



Tipping Bucket 8 (TB 8)

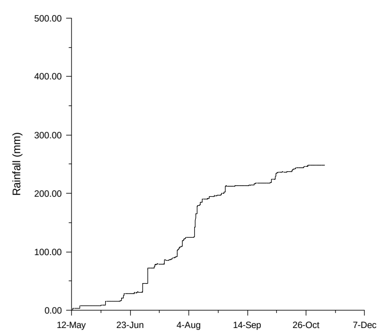
Latitude:	54 00 16.9N
Longitude:	104 53 46.2W
Logger No.:	28 (1995), 92 (1996)
Description:	Lorenz Lake Rd. - Middle
Notes:	

Year	Date	Event
1994		
	All Season	No data available - not installed
1995		
	05/12	TB 8 installed
	11/08	TB 8 removed
1996		
	07/27	TB 8 installed
	10/21	TB 8 removed

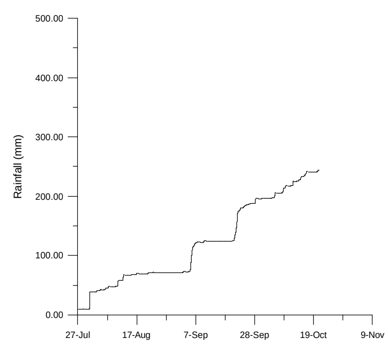
1994

NO DATA

TB 8 1995



TB 8 1996



Appendix B - Streamflow Stations

SW2
SW3
SW4
SW5
NW2
NW3

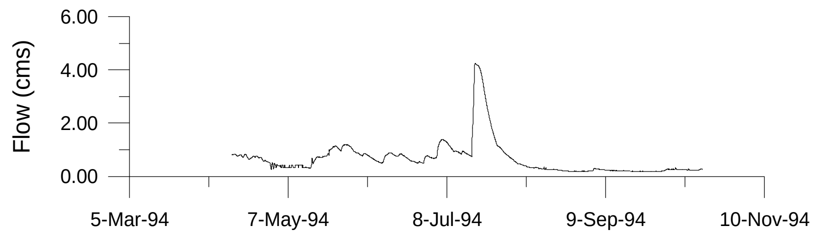
Streamflow - Southern Study Area

SW2

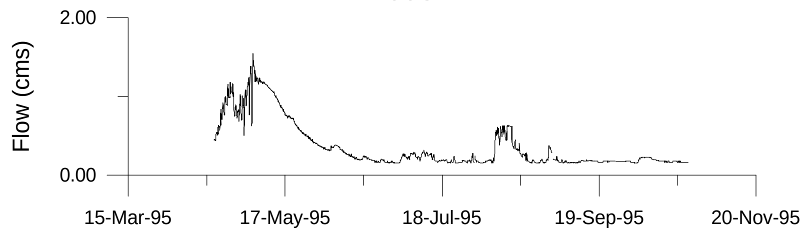
Latitude: 53 53 37N
Longitude: 104 40 56W
Logger No.: 1
Description: Harding Road
Notes:

Year	Date	Event
1994		
1995		
1996		

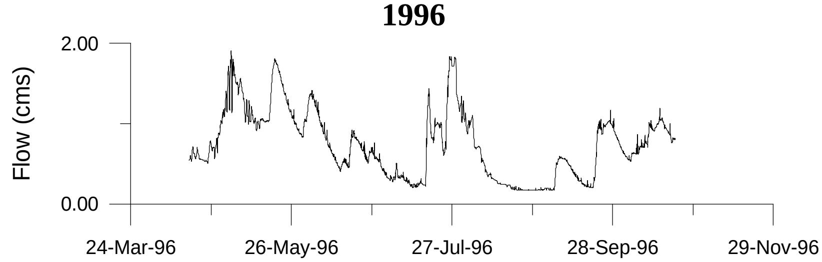
1994



1995



1996



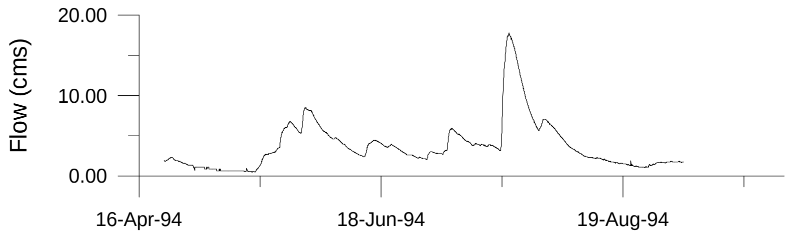
SW2, July 1996

SW3

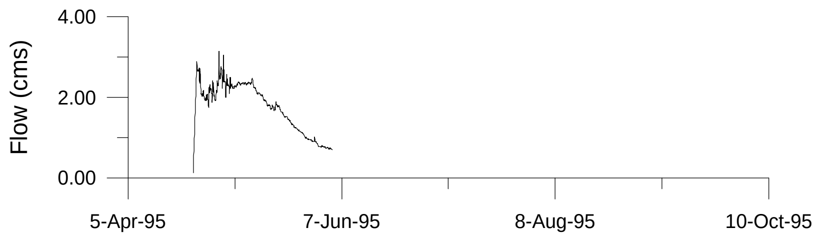
Latitude: 53 55 36N
Longitude: 104 47 28W
Logger No.: 22
Description: Hwy 120
Notes:

Year	Date	Event
1994	Oct.	No data due to beaver problems
1995	06/1-10/31	No data due to beaver problems
1996		

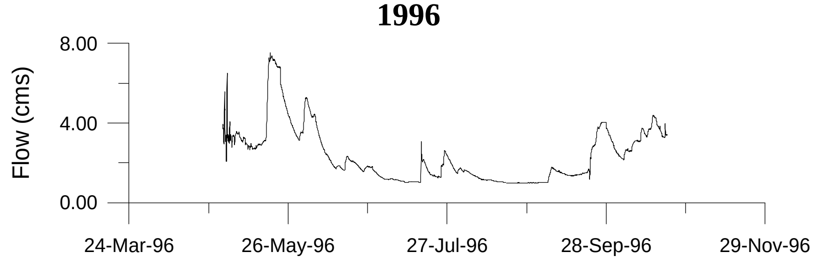
1994



1995



1996



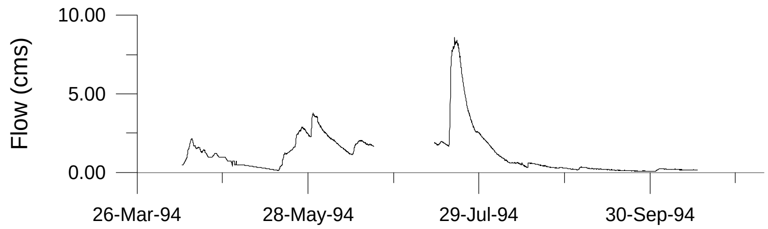
SW3, July 1996

SW4

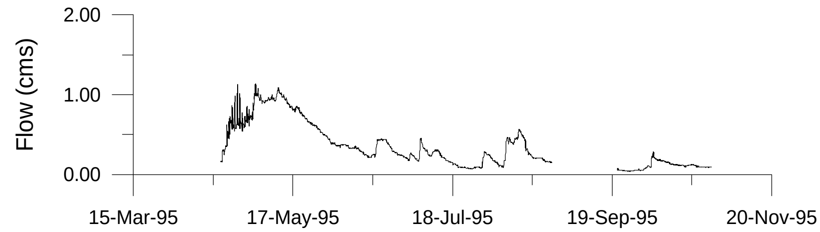
Latitude: 53 55 35N
Longitude: 104 49 12W
Logger No.: 3
Description: Lorenz Lake
Notes:

Year	Date	Event
1994		
1995		
1996		

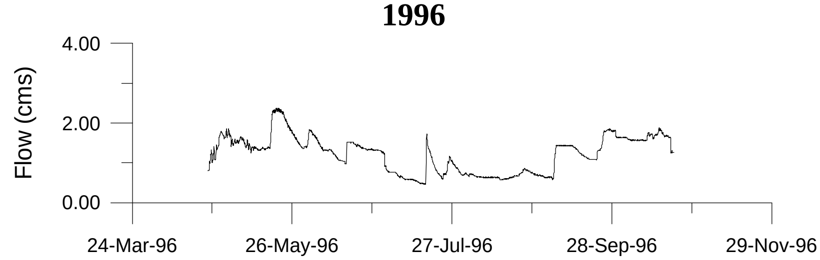
1994



1995



1996



SW4, July 1996

SW5

Latitude: 53 55 48N
Longitude: 104 49 18W
Logger No.: 28
Description: Harding Tributary
Notes:

Year	Date	Event
1994		
1995		
1996		

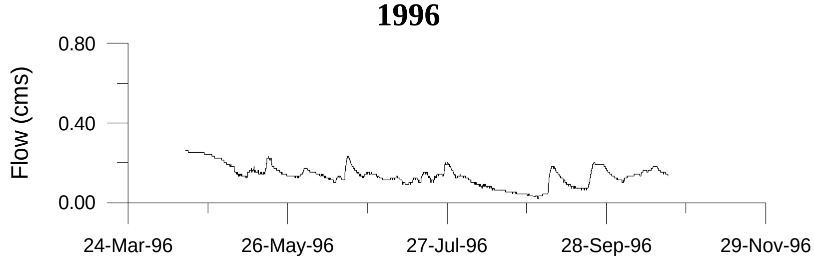
1994

NO DATA

1995

NO DATA

1996



SW5, July 1996

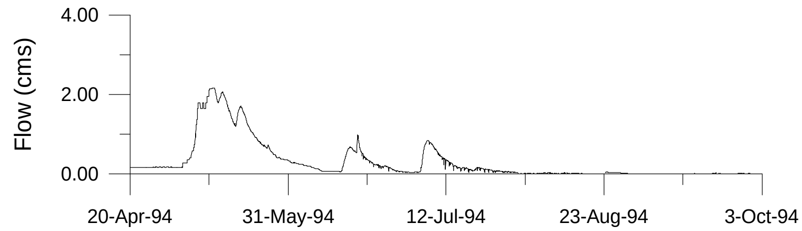
Streamflow - Northern Study Area

NW2

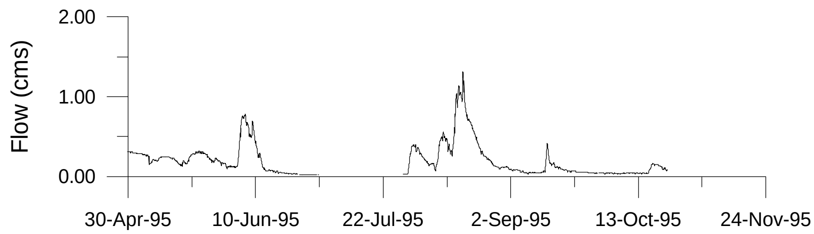
Latitude: 55 54 55N
Longitude: 98 31 39W
Logger No.: 21
Description: West Basin
Notes:

Year	Date	Event
1994		
1995		
1996		

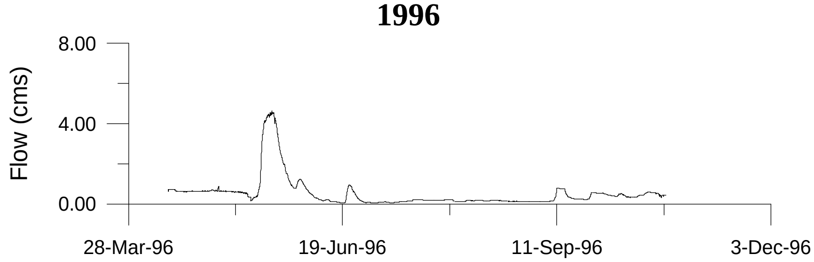
1994



1995



1996



NW2 & Hwy 913, May 1994

NW2 West Side of 913, June 1994

NW2 West Side of 913, May 1994

NW2 East Side of 913, June 1994

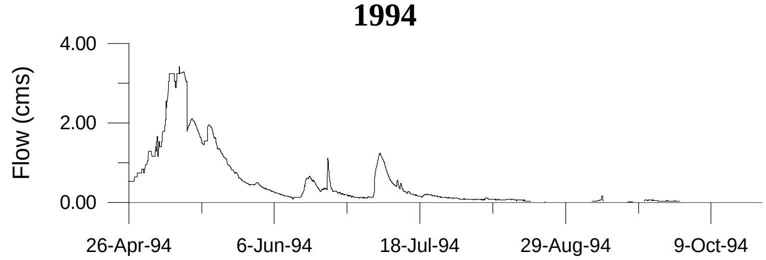
NW2 North Side, May 1994

NW3

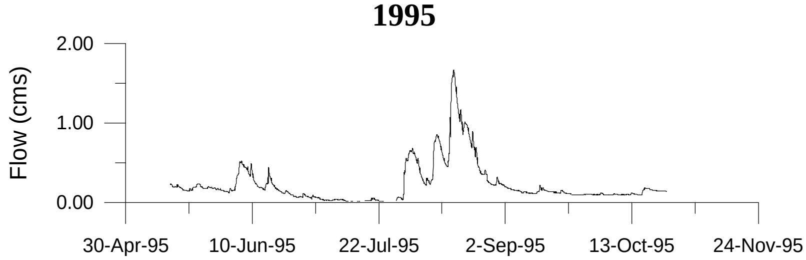
Latitude: 55 55 01N
Longitude: 98 22 32W
Logger No.: 22
Description: East Basin
Notes:

Year	Date	Event
1994	06/22	Plugged curvert removed 3 km east of NW3 on tributary causing sudden increase and decrease in flow
1995		
1996	04/13 - 05/15	Data estimated

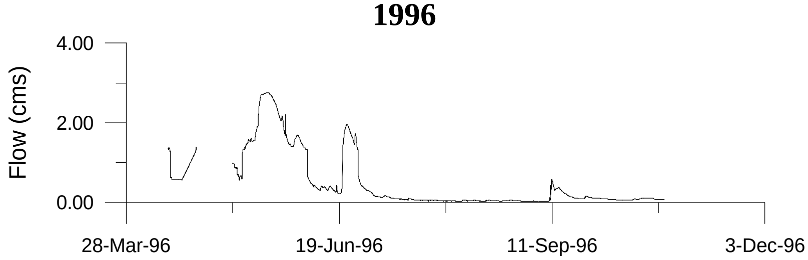
1994



1995



1996



NW3 May 1994

Please note:
Data for SW1 and NW1 are on the Environment Canada HYDAT CD-ROM