CANADIAN GEWEX PROGRAM

SCIENCE AND IMPLEMENTATION PLAN

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TABLE OF CONTENTS

Appendix 1: GEWEX Research Basins

Appendix 2: Canadian GEWEX Participants

1. INTRODUCTION

1.1 Objectives

The Global Energy and Water Cycle Experiment (GEWEX) was developed by the World Climate Research Programme as an internationally coordinated group of activities aimed at improving our understanding and prediction of the role that the water cycle plays in the climate system. Such improvements are crucial if we are to determine the sensitivity of the climate system to anthropogenic increases in the concentration of greenhouse gases and thereby to reduce the uncertainties in our predictions of climate change. Canada'a vast fresh water reserves coupled with the predicted sensitivity of the high latitude Northern Hemisphere to climate change suggests that any resultant modifications to the water cycle will have a profound impact on Canada'a ecosystems and socioeconomic activities.

It is therefore only natural that the Canadian scientific community has developed its own component to the international GEWEX program. The overall objectives of this Canadian effort are to:

. understand and model the high latitude water and energy cycles that play roles in the climate system, and

. improve our ability to assess the changes to Canada's water resources that arise from climate variability and anthropogenic climate change.

It was decided that the focus of the Canadian GEWEX program would be the water cycle of the Mackenzie River basin (Figure 1). The need to focus on a particular region was felt to be critical to achieving a reasonable degree of progress. Selecting this northern basin also allows Canada to build upon its natural focus on cold region processes and to nicely complement the Mississippi River initiative of the GEWEX Continental-Scale International Project (GCIP).

As our program has evolved, it has become apparent that the Mackenzie GEWEX Study (MAGS) has the potential to make a singularly important contribution not only to GEWEX but to the entire World Climate Research Programme. This arises from the important role that the fresh water outflow from the Arctic Ocean plays in regulating the thermohaline circulation of the world's oceans (Aagard and Carmack, 1989). The discharge from the north flowing rivers of North America and Siberia is a major source of fresh water for the Arctic Ocean (Woods, 1984), as shown in Figure 2. The meteorological and hydrological processes that transport water into and through these basins is therefore of great importance to the climate research community. It follows that, through MAGS, the Canadian program with its emphasis on the high latitude water and energy cycle has the potential for improving our understanding of some of the important couplings that exist between the various components of the global climate system.

The outcome of MAGS will be validated numerical simulations with coupled atmospheric-hydrological-land surface models that, on monthly or longer time scales, will replicate the transport of moisture into and through the Mackenzie River basin and into the Arctic Ocean.

In this document, a plan for achieving this outcome is briefly described. It is envisioned that a great deal of use be made of operational weather prediction models to develop atmospheric forcing fields over the basin and that hydrological models be eventually fully coupled to these. Model validation over the data-sparse region of interest will rely to a large extent on remote sensing, but there will be basin-wide efforts to improve model initialization and validation datasets, and there will be a number of specific process studies conducted within the overall effort.

1.2 Linkages

This Canadian effort also represents an appropriate focus in light of other GEWEX initiatives. Under the umbrella of the GEWEX Hydrometeorological Experiment Panel (GHP), other regional focal points are being studied that are characterized by quite different conditions. This includes the southerly flowing Mississippi River (GCIP), the Amazon River (LBA), the Baltic Sea water discharge area (BALTEX), and the Asian Monsoon region (GAME). One can see that the focus on a northern river at high latitudes nicely complements these other efforts and that natural interactions should develop with GCIP, BALTEX and GAME, for example.

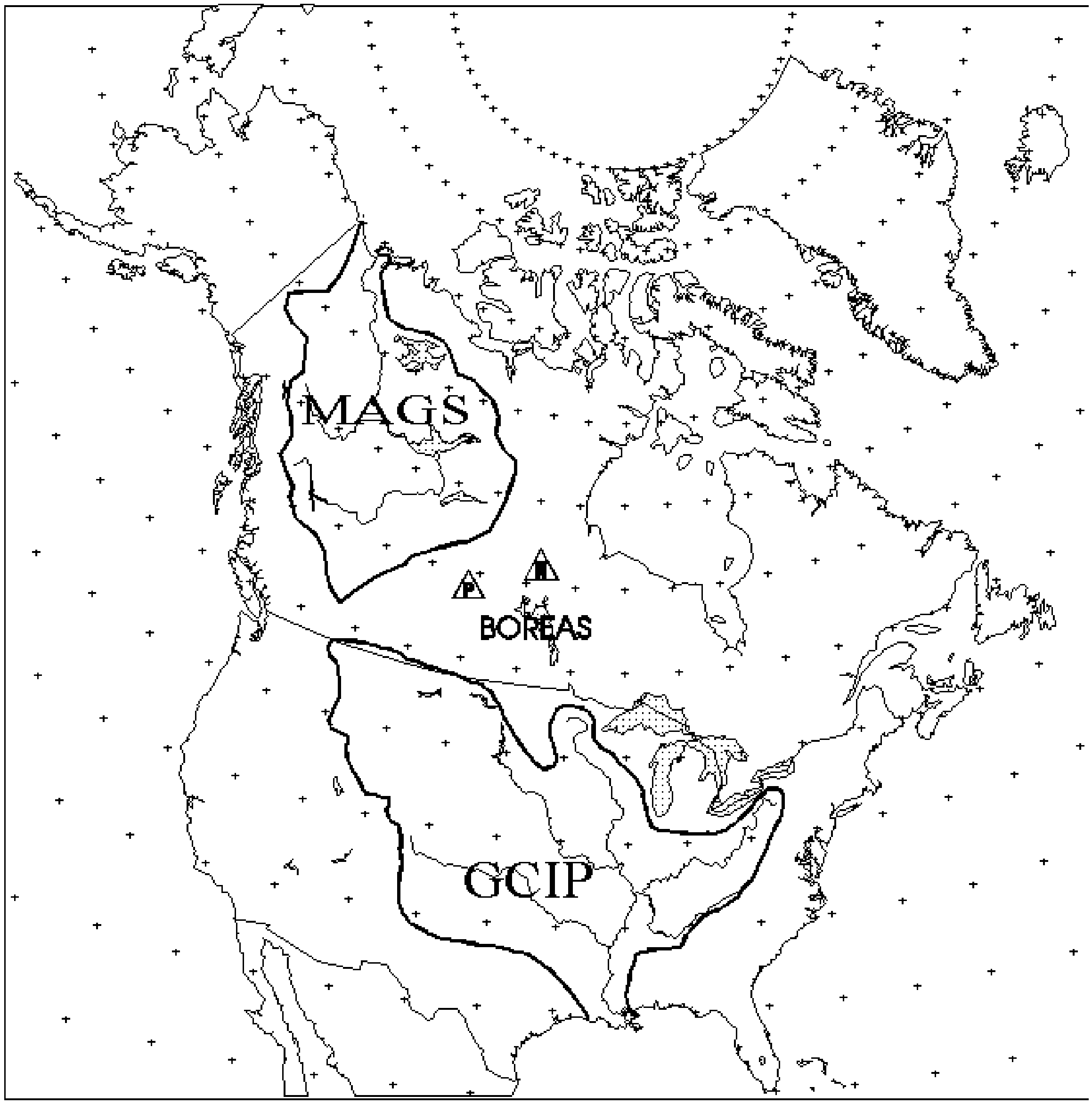


Figure 1: A map of North America showing the location of the Mackenzie Basin as well as the Mississippi River basin.

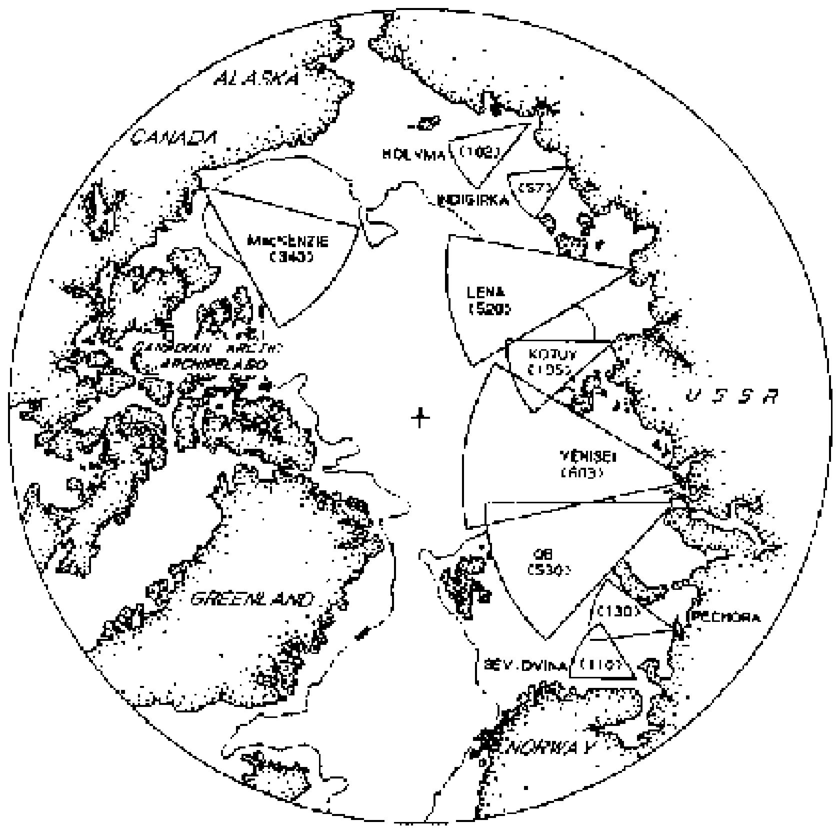


Figure 2: The fresh water input to the Arctic Ocean in units of $km^3\ y^{-1}$. Adapted from Aagaard and Carmack (1989).

It should be noted that our Canadian GEWEX program actually addresses issues important to two major WCRP initiatives, GEWEX and the Arctic Climate System Study (ACSYS). Both of these major initiatives are interested in the fresh water flux into the Arctic. Because of this rather obvious overlap, it is then expected that some of the linkages between these two WCRP programs will be established through our Canadian one.

It is apparent that strong linkages must be maintained with the BOREAS program which is focussing on boreal forest issues. Approximately 80% of the MAGS area is covered by forest.

In addition, the Surface Heat Budget of the Arctic Ocean (SHEBA) is planning an extensive set of measurements over the southern Beaufort Sea during the 1997-98 period. This may be coupled with the potential FIRE III experiment (First ISCCP Regional Experiment III) examining low level clouds and their relation to the sea ice. Both these efforts may lead to possibilities for advancing the objectives of our Mackenzie Basin study.

It is also quite possible that as the Canadian GEWEX program proceeds, it will develop closer ties with complementary initiatives such as the Mackenzie Basin Impacts Study (MBIS). This natural, if not now mature, interaction will inevitably develop.

2. BACKGROUND PERSPECTIVE

The Mackenzie River is one of the great rivers of the world, ranking tenth by drainage area. This large drainage basin stretches over 15 degrees of latitude and covers about 1.8 million km2 or about 20% of the total Canadian land mass.

The Mackenzie Basin is composed of 6 main sub-basins, 3 great lakes, and 3 major deltas. Of the sub-basins, only the Peace River is regulated to a significant degree. The hydrological regime of the basins is influenced by 4 major physiographic regions (Western Cordillera, Interior Plain, Precambrian Shield and Arctic Coastal Plain), permafrost which covers a significant portion of the basin, and vegetation which varies from boreal forest to alpine tundra.

Important features of the river basin are described in a separate Canadian GEWEX document (Krauss, 1995a). The qualitative features of many of the critical water and energy cycle fields are known in general but quantitative aspects and the couplings between them are not (Figure 3). For example, it is estimated that the mean annual precipitation over the basin is about 410 mm/y but there is considerable uncertainty with this as a result of inadequate sampling and errors with gauge measurement in winter conditions. Likewise, it is estimated that the annual discharge from the Mackenzie is about 310 km3/y but difficulties in measurement during the spring melt period undoubtedly lead to large uncertainties (Figure 4). It is nevertheless clear from this figure that the spring melt represents a very dramatic feature of the annual discharge pattern.

3. SCIENTIFIC ISSUES

3.1 Introductory Comments

For a goal-oriented initiative like the Canadian GEWEX program, it is very important that the critical scientific issues be carefully elucidated. The determination and resolution of the scientific issues is critical to the success of the entire program, and, even though the issues will of course evolve, there are some fundamental ones that can be highlighted. Some of these critical issues are therefore briefly discussed in the following two sections.

3.2 Water Budget Updates

The ultimate goal of the MAGS initiative is to elucidate and to properly account for all the critical elements of the basin water cycle. As an initiative to drive the sub-components and to assign priorities to them, the most up-to-date assessment of the water budget of the basin must be developed over an annual cycle with allowance for longer term variations as well as budgets occurring on seasonal or shorter time scales.

An article by Walsh (1994) was recently completed on this issue. This study used rawinsonde information from the operational network in the high latitudes to show some of overall features of the Mackenzie River

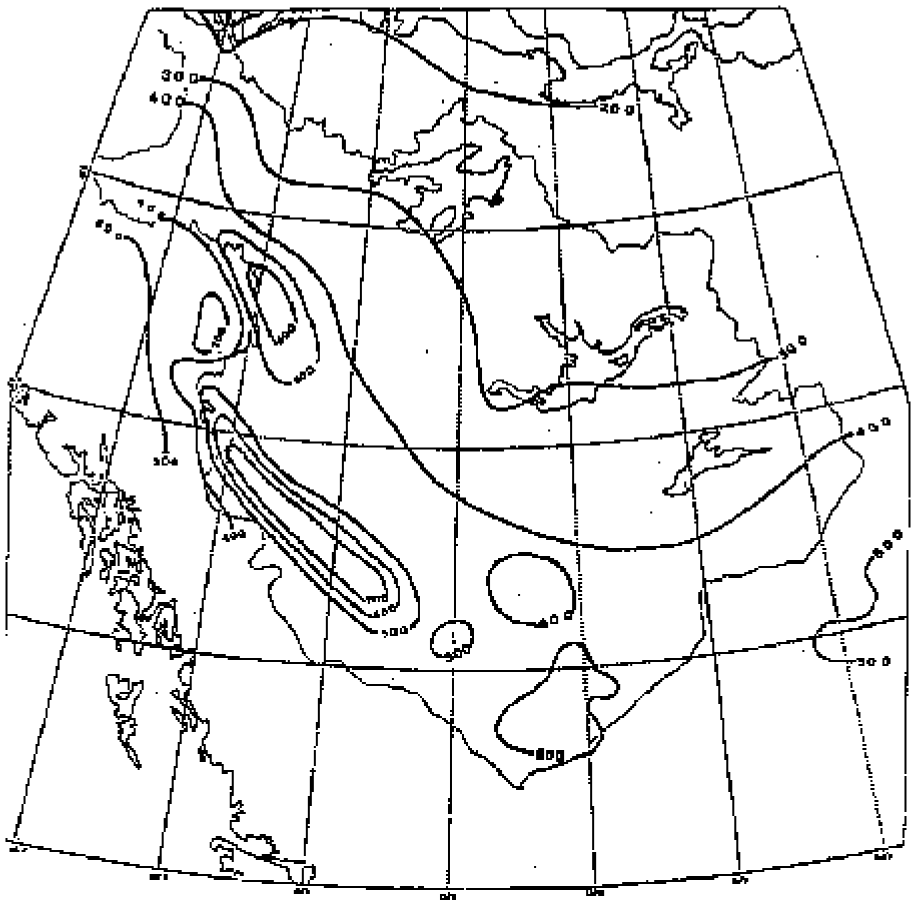


Figure 3: Illustrative diagram of the annual estimated precipitation distribution over the Mackenzie River basin.

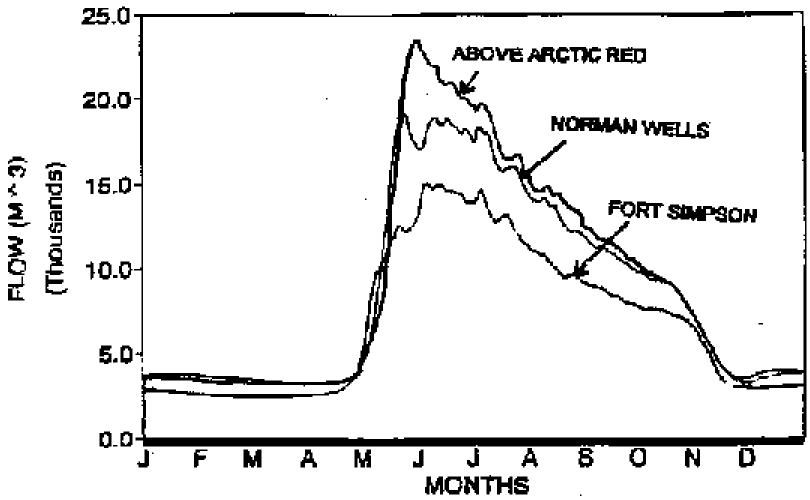


Figure 4: Average hydrographs for the 1973-1990 period for hydrometric stations along the Mackenzie River. The upper curve represents the measuring site closest to the mouth of the river.

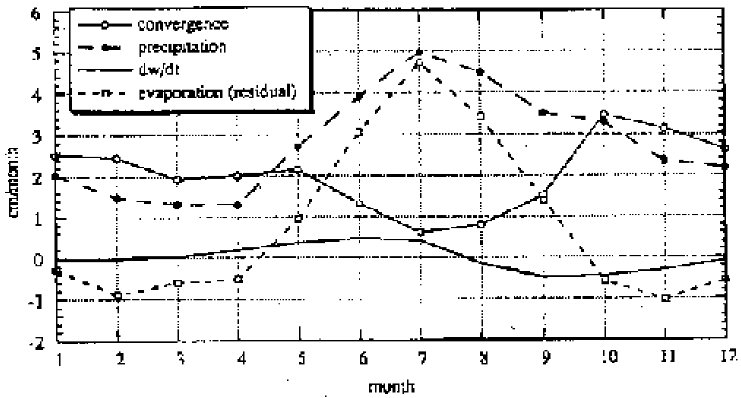


Figure 5: Annual cycle of monthly water vapour flux convergence (cm month^{-1}, areal equivalent) and area-averaged precipitation, monthly change of precipitable water, and evaporation (estimated as a residual) over an area encomopassing the Mackenize River basin. All values are 18-year means. Adapted from Walsh et al. (1994).

basin budgets (Figure 5). The net moisture flux was found to be positive, except for some occasions during the summer. As well, there is a very large inter-annual variation of flux convergence.

Future water budget efforts will largely be accomplished through the use of models that have assimilated all the observational data. This is especially true given the data sparse nature of the area. The efforts described under the Data Management Section 7 will go a long way towards achieving this requirement.

3.3 Specific Scientific Issues

There are many scientific issues that need to be addressed in order to realize the objectives of the program. A brief summary of these is presented below; establishing a reasonable approach to address the most critical of these in an efficient manner is crucial.

3.3.1 Meteorology

. Large scale circulation patterns: What large scale patterns are linked with typical and anomalous precipitation and stream flow events within the basin? To what degree is the inter-annual variability in these fields linked to the observed inter-annual variability in the large scale circulation pattern?

. Moisture sources: Where does the moisture that enters the basin come from? Is the Gulf of Alaska the main supply region in both typical and anomalous periods? What are the consequences of the basin water budget of varying Arctic ice pack coverage?

. Weather Systems: Precipitation is produced within cloud systems with spatial coverage generally smaller than the basin itself. What are the critical components of these systems that impact the basin water budget. How do the characteristics and impacts vary during typical and anomalous periods?

. Basin weather system evolution: Many weather systems undergo pronounced changes as they cross the basin and their impact on the water budget consequently changes as well. How do the systems evolve? How critical are phenomena such as lee cyclogenesis, frontal decay, topographic forcing, and cold air outbreaks to the water budget?

. Topographic influences: The mountains to the west of the basin impart a major impact on the basin water budget by greatly reducing the amount of moisture flowing into the area from the Pacific, by inducing major modifications to the character of the storms, and by enhancing precipitation over its high terrain. How critical is the barrier and how well do we need to know its impact?

. Surface-moisture sources and sinks: During the summer period, much of the moisture over the region appears to be due to local moisture supply, but in the winter much comes from the sublimation of snow for example. How well do we have to account for local moisture supplies for the basin water budget?

. Precipitation amount, distribution, production: A fundamental issue for the initiative is the amount of precipitation that occurs over the basin and its spatial and temporal distribution during typical and anomalous periods. How is precipitation produced over the basin during the different seasons and for the various cloud systems? How does its production vary across the basin? Since a significant amount of the precipitation arises from very light precipitation rate events, how critical is the simulation of such events to subtle microphysical changes?

. Precipitation type: Surface precipitation over the Mackenzie River basin is in general either rain or snow. In the autumn and spring periods in particular, it is very common for both forms to occur. Because of their major impact on hydrological processes, how well are the forms of precipitation predicted and how well do they need to be?

. Basin and smaller scale energy considerations: For the understanding of critical processes occurring at the surface such as snow melt, it is critical that the perturbations to solar radiation, as well as the infrared production and alteration, by the atmosphere be well-handled and, in the first instance, be well-observed in relation to spatial and temporal scales of importance to the effort. What factors govern such energy processes and how are these related to larger scale forcing?

. Clouds and radiation: What is the role of clouds on the critical energy budgets of the region? How well do the cloud fields need to be handled within prediction models to produce acceptable results for the snow melt period in particular?

3.3.2 Hydrology

. Snowpack evolution: The accumulation of snow is controlled by the snowfall rate, by blowing snow and by snowfall interception by the boreal forest canopy. How does the snow accumulation vary over the winter period and how does it change with vegetation type? What impact does it have on ground temperatures, permafrost conditions and soil heat flux during the spring and summer periods?

. Snowfall interception: During the winter period, interception of snow by the boreal forest canopy is large; this limits the ground snowcover and increases the surface albedo and sublimation. Over what period of time is snow stored in the boreal forest canopy?

. Blowing snow: Blowing snow is an important process controlling snowcover distribution and sublimation with the Arctic and alpine tundra areas of the basin. This sublimation can significantly reduce the amount of snow available for runoff and can be a substantial source of moisture to the atmosphere during the winter, but the magnitude of this sublimation needs to be established.

. Snowmelt: One of the most critical periods of the year is the spring runoff when 35-60% of the annual precipitation melts and runs off during a brief 1-3 week period. What basin weather systems govern the timing of this runoff? What role does snow and ground temperature play in delaying runoff? What portion of the winter precipitation actually contributes to stream flow?

. Sub-basin and complete basin energy budgets: To properly predict critical hydrological events such as snowmelt, lake ice melt, and runoff, the energy budgets of the basin at various scales and for various landcover types are required.

. Mackenzie River runoff: Spring breakup of the Mackenzie River is controlled both by snowmelt runoff from more southerly portions of the basin and by ice breakup as the melt wave moves downstream. Why is the timing of the peak discharge in the Mackenzie Delta so consistent from year to year with the peak water level in the Mackenzie delta, for example, occurring over an 8 day period in early June?

. Glacial runoff: Although glaciers cover only a small portion of the Mackenzie Basin, they store large volumes of water during cold wet periods and release melt water during warm dry periods. How important is glacial runoff to the Mackenzie River discharge and under what conditions does their role increase or decrease?

. Evapotranspiration/Evaporation: Current estimates suggest that evapotranspiration/evaporation is a major component of the water basin water balance, returning a significant portion of annual precipitation back to the atmosphere during a brief 3-4 month period. How large is this factor and what is its spatial and temporal variation?

. Lakes: The Mackenzie Basin has 3 great lakes and myriad small ones. How much water is stored in these lakes, how large are the seasonal and annual changes in lake storage, and how important are the lakes in controlling evaporation and generating precipitation over nearby areas of the Basin?

. Permafrost: Through much of the northern portion of the Mackenzie Basin, permafrost occurs at a depth of 0.3 to 1.0 m, and can be as much as 300 m in depth. This permafrost is virtually impermeable and limits short term water storage to the thin active layer that occurs between the surface and the permafrost table. How important is this active layer in controlling water storage and what is the role of the permafrost in controlling ground heat flux and therefore the surface energy balance as well as surface moisture?

. Sub-surface issues: Although deep underground storage of water is generally neglected for annual water budget estimates, considerable attention needs to be placed on the seasonal changes in near-surface groundwater and/or soil moisture. How variable are seasonal changes in the storage component in areas with seasonal frost or in permafrost areas?

3.3.3 Land-surface

. Actual surface conditions: Although the present assessment of land surface topography and vegetation cover is satisfactory, it is critical that assessments be conducted of the impacts of this land surface cover on the critical budget issues.

. Variations in land surfaces over seasons: Due to snow cover and leaf area changes, the land surface changes over the year and the full appreciation of the consequences of this need to be assessed and eventually, for the important implications, accounted for within prediction models.

. Variations in water surfaces over seasons: Lakes and rivers within the basin freeze in the autumn and melt in the spring. How these changes affect the regional water and energy budgets need to be clearly assessed, and significant ones will need to be well-handled within prediction models.

3.3.4 Interactions

. Atmosphere-hydrology-land surface interactions: Almost all of the issues linked with the regional water budget require ultimately a strong coupling between all the components. It has to be recognized of course that for making significant progress it is sometimes necessary to deal with only some of the critical aspects at a time. The use of models to integrate the individual findings into a cohesive numerically-based system is then a requirement to achieve our ultimate objectives.

4. THE PLAN FOR MAGS

4.1 Large Scale Weather and Hydrological Models

For realizing the objectives of MAGS, use must be made of the numerical weather prediction models and large scale hydrological models. In general, these models will be Canadian but in order to satisfy GEWEX's global perspective and to ensure transferability of results, use will also be made of other models.

Several Canadian weather prediction models will be used. These will be the Mesoscale Community Model (MC2) that can consider scales down to < 1 km, the Regional Finite Element Model (RFE) that operationally operates at scales down to about 40 km and 1-2 days, and the Global Spectral Model (SEF) that operates on scales of about 100 km and out to a week or so. In addition, RPN is in the process of developing a new 'unified' model.

Several other weather prediction models will be used as well. It is obvious that the ETA model developed at NMC is the most obvious candidate for this purpose since it is the main model being used by the complementary GCIP program. Because of the need for transferability, consideration should also be given to using, for example, the ECMWF model as well as the main models being used by BALTEX and GAME in particular.

Large scale hydrological modelling is being done with the Canadian WATFLOOD and SLURP models, developed at the University of Waterloo and NHRI respectively. Both are state-of-the-art simulation models that use the Grouped Response Unit approach to deal with landcover heterogeneity but have different parameterizations of, for example, evapotranspiration and streamflow routing.

Surface features will largely be incorporated by implementing the Canadian Land Surface Scheme (CLASS) into WATFLOOD. This will provide a direct link to the atmospheric models, which also use CLASS. This will also allow the hydrological application of new developments in surface parameterizations developed for CLASS both through MAGS as well as other projects such as BOREAS or the Canadian Research Network Land-Air Node.

A critical goal of the GEWEX program is to merge the atmospheric and hydrological models. From experience in the use of hydrological models such as WATFLOOD and SLURP, some researchers feel that runoff simulations require scales of about 10 km and 1 h to capture most of the critical hydrological phenomena. As these spatial scales are considerably smaller than the resolution at which global numerical weather prediction and global climate models are run, there is obviously a need to develop techniques that allow one to scale up the hydrological models to coarser resolution.

4.2 Model Strategy

To achieve the goal of eventually coupling the atmospheric and hydrological models, the following strategy has been developed:

Phase 1: Uncoupled hydrological/land surface models that use conventional numerical weather prediction model output as forcing fields and that will run for extended periods of one month or more. For this work, use will be made of the data stored in conventional and special archives. The aim of this work will be to validate the coupling of the land surface and hydrological models and to document that, given "realistic" atmospheric forcing fields, the hydrological models can in a qualitative sense reproduce basin scale observed runoff/streamflow. It is anticipated that the output from the Regional Finite Element Model will be the primary source of the forcing fields for both WATFLOOD and SLURP.

Phase 2: Coupled hydrological/land surface/mesoscale atmospheric models that will be run for short periods of time (1-2 days). The aim of this task will be to show that for specific events, the coupled models can reproduce the runoff/streamflow in small sub-basins. Studies will be conducted to understand the importance of various physical processes and their representation in the evolution of the rain or snow producing mesoscale systems. In particular, sensitivity tests will be used to document the role that feedbacks from the hydrological/land surface component play in modifying the atmospheric flow and moisture. This work will be performed with the MC2 mesoscale forecast model coupled to WATFLOOD.

Phase 3: Coupled hydrological/land surface/large scale atmospheric models that will be run for periods extending from one month to one season for the entire Mackenzie Basin. In this work, we hope to be able to show that the coupled model (with all the new physical parameterizations that it will include) is stable for extended integrations. This work will need to be done with the global spectral model or its successor. It will be coupled to either WATFLOOD or SLURP. One issue that will be highlighted in this work is the importance of the "horizontal flux" of water. That is, with a fully interactive land surface/hydrological model it should be able for precipitation that falls in one area (grid point) to be transported laterally to another area (grid point) by the hydrological model where it would be available for, say, evaporation. If such a model is run over the snow melt period, then it should be able to simulate the observed discharge pattern of the Mackenzie and its tributaries. The ability to run such a coupled model would then give one confidence that including a similar physics package and land surface/hydrological model in a GCM has some hope of being able to predict the variability (natural and anthropogenic) in the high latitude water cycle.

4.3 Climate Prediction Models

The initial development of the Canadian GEWEX program is largely utilizing operational weather prediction models rather than through the use of climate models. This strategy follows from the need for the relatively straightforward examination of smaller scales than presently achievable with climate models.

A plan for directly testing the capabilities of the Canadian climate model has been developed as well. This activity will largely be accomplished through the use of the Regional Climate Model (RCM) with its GCM physics package. The RCM will be initialized with the large scale forcing generated from the large scale weather prediction models. The RCM will run in either uncoupled or coupled mode to assess the ability of the GCM physics package to replicate critical elements of the basin water and energy cycles. This process can be extended up to periods of a month or season by continually updating the large scale forcing.

Experiments with a freely-running GCM will be initiated once it has been demonstrated that its physics package is suitable.

4.4 Model Grids

It should be added that the gridded information developed by these modelling efforts over the basin will be a critical benchmark for other studies. Operational RFE products at spatial scales of the order of a few 10s of kilometers will be archived and a special effort within the Data Management Plan will be directed towards seeing that this information is readily available to all the researchers (see Section 7). The present RFE grid including the Mackenzie basin is shown in Figure 6.

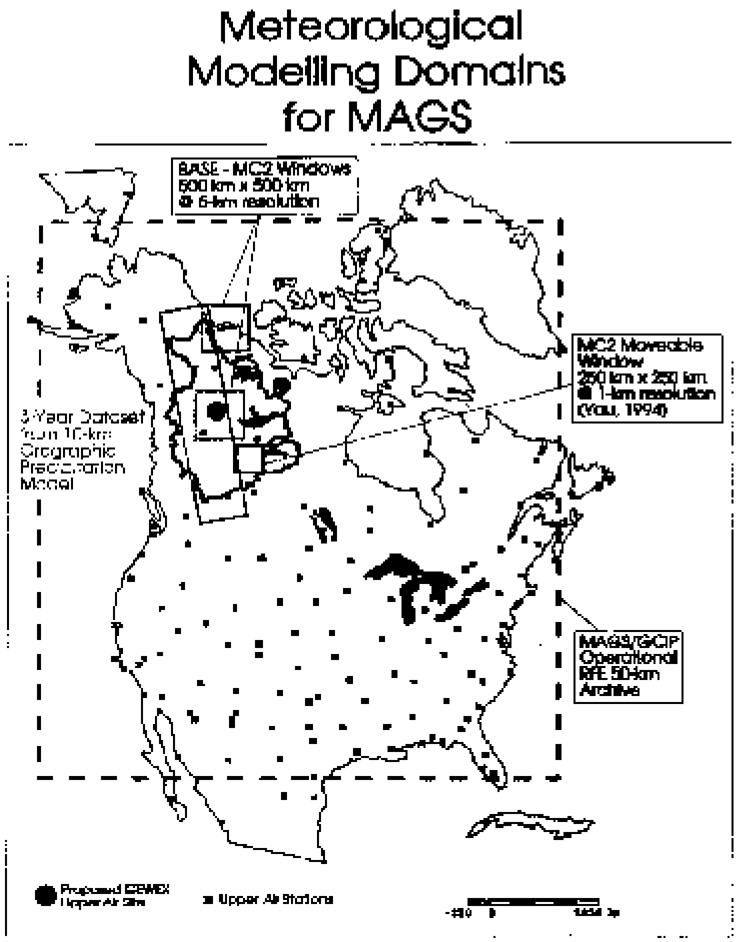


Figure 6: The present RFE model grid over the Mackenzie River basin and neighbouring regions.

Having an estimate of critical fields from the models at the crucial scales of importance will allow, for example, remote sensing and ground-based measurements to directly compare their estimates against model performance. In this manner, deficiencies in model performance can be continually assessed, the delineation of key deficiencies highlighted, and as appropriate special efforts mounted to overcome the problems.

It should be noted that a special effort will undoubtedly be required to actually arrive at a definitive grid that will be required for all the needed efforts within the overall program. In regards to properly accounting for the effects of topography for example, the gridding will have to be significantly finer than the current operational RFE one.

5. OBSERVATIONAL CAPABILITY

Proper observations are needed for climatological studies, for model initialization and validation, and for process studies. In this Section, some of the available or needed tools to realize these objectives are described.

5.1 Ground-Based Facilities

The costs associated with deploying instruments into the basin are large. As a result, as much as possible of the measurement program has to take advantage of operational sites and remote sensing. There are already a number of observing sites over the area (Figure 7).

The number of observing sites is certainly unsatisfactory however. For the study of basin-scale atmospheric water budget studies, the number and location of sounding sites is certainly insufficient. As well, the number and location of surface observing sites for parameters such as precipitation and radiation is also far from satisfactory (Figure 7).

In terms of hydrological measurements, the current networks are reasonably capable of measuring the river runoff (Figure 8). However, there are uncertainties in interpreting the actual measurements at some crucial periods. This is especially true during ice-covered periods in general and it is exacerbated during ice break up in the spring. In addition, budget cuts are forcing the closure of observing sites and the impacts of these closures needs to be assessed.

In support of GEWEX, special research sites have also been established in four areas, as reported by Krauss (1995a) and as summarized in Appendix 1. These sites provide ongoing information on a variety of parameters within regions that typify conditions found across the Mackenzie basin as a whole. It is critical to utilize these basins in the most efficient manner; the establishment of new sites and/or the completion of observations at present sites will be decided later.

5.2 Satellite Remote Sensing

Extensive use must be made of satellite remote sensing systems for the determination of critical elements of the basin water budget. Table 1 lists some of the satellite sensing systems of importance to MAGS and some of the derived products. A number of critical atmospheric and surface parameters, including the cryosphere, are being inferred from satellite measurements down to very small scales.

The MAGS area is not well-observed by geostationary satellites, so extensive use is being made by a number of investigators of the data from the polar orbiting NOAA satellites. This information is being used, for example, to identify cloud features associated with storm systems, to develop algorithms to infer the precipitation field, and to infer surface vegetation and fluxes. Future polar orbiting satellites will also carry a H2O-channel.

The new generation of geostationary satellites now becoming operational have improved radiometers that have a channel that is sensitive to atmospheric water vapour. This new channel is in the 6.5-7.0 micron wavelength range and at present such a channel is also not available on polar orbiting satellites. Geostationary satellites also have the advantage of providing one with data at a sufficiently high frequency, at least once per hour, to allow one to effectively study the embedded mesoscale circulations within large scale cloud systems that are responsible for producing much of the highly variable water vapour spatial

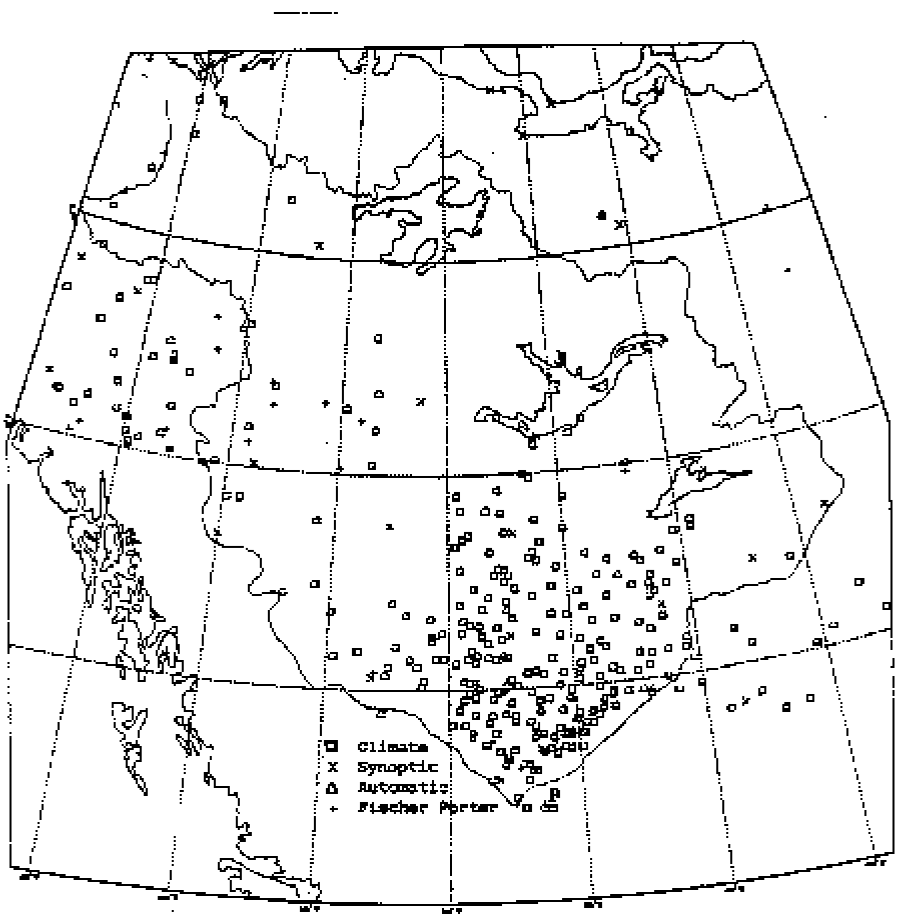


Figure 7: Operational surface observing sites over the Mackenzie River basin and neighbouring regions. Some of these sites are being closed.

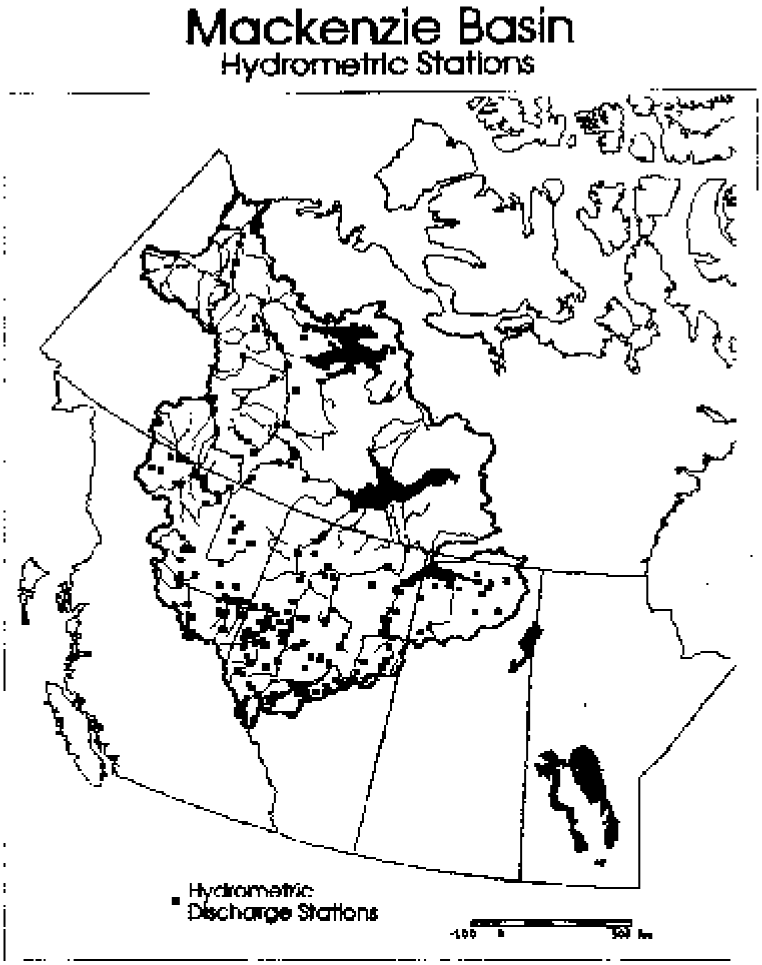


Figure 8: Ongoing hydrological observing sites over the Mackenzie River basin and neighbouring regions. Some of these sites are being closed.

TABLE 1: Satellite remote sensing for MAGS

Satellite Remote Sensing Data	researchers	parameter	resolution
NOAA AVHRR	Agnew et al. Benoit et al. Bussières Granger; Garand et al.; Gyakum & Moore Stewart Welsh et al. Yau & Zhang Zawadzki	cloud temp., sea surface temp., land temp., vegetation index evapotranspirat.	1.1 km
NOAA TOVS	Benoit et al. Garand et al.	temp. and moisture profiles (exp.)	20 km
GOES VISSR	Gyakum & Moore Stewart Zawadzki	imaging cloud cover sounding - temp. and water content	1-4 km
DMSP (SSM/I)	Walker et al.	ice snow water equiv.	12.5-25 km
Landsat (multi-spectral, seasonal images), SPOT	Soulis & Kouwen Kite Pietroniro	mapping land cover	20-80 m
SAR (ERS-1, ERS-2, JERS1, RADARSAT)	Agnew et al.; Brugman et al. Maxfield et al.	snow cover area snow melt area ice cover soil moisture (exp)	30m

variability. Improvements in the resolution of the radiometer also allow one to use geostationary data in high latitude regions such as the Mackenzie Basin.

It should be added that MAGS is going to be the beneficiary of products from the International Satellite Cloud Climatology Project (ISCCP). It was recently agreed that ISCCP will provide enhanced 30 km spatial and 1.5-3 h temporal resolution products for all the regional water budget experiments, starting with September 1, 1994 in the case of MAGS. This date coincides with the commencement of the BASE experiment. The available products will be the actual pixel information with calibrated radiances and viewing geometry along with products such as cloud/no-cloud, clear sky radiances, and a range of cloud and surface derived properties. MAGS will also contribute to ISCCP through its validation efforts and algorithm developments for high latitude cold systems.

It should be added that the GEWEX Precipitation Climatology Project (GPCP) efforts will also be a big boost to MAGS. Estimates of precipitation have been generated through this program but there is some uncertainty with the applicability of their techniques in some instances. One apparent area in which MAGS can help is in connection with snow: the GPCP techniques assume all the precipitation is rain. To what extent do their techniques work with snow? In this sense, results from MAGS will provide critical information to assist GPCP.

5.3. Extra Observational Capabilities and Requirements

The ongoing measurements being made within the Mackenzie Basin are marginal for the success of the effort. At least during special observing periods, additional measurement capability is needed. Some of the needed measurements for this are discussed briefly below.

Access to portable radar facilities is crucial to the success of MAGS. The remote locations of the hydrologically important sub-basins and the need to document precipitation dictate this requirement.

It is fortunate that the McMaster University radar has been upgraded to be able to satisfy the requirements of MAGS for intensive measurement campaigns. This radar, with its X-band fully polarized and Doppler capabilities, will be able to document snowfall quite well, a critical concern of MAGS.

One should not overlook the portable X-band radar at the University of Toronto. It has a much wider beam width than the McMaster University radar and so cannot detect precipitation over large distances, but its usefulness has been well illustrated through the BASE experiment.

There is certainly a need for good near-surface flux measurements across the highly variable terrain of the Basin during snow melt in particular. The National Research Council of Canada Twin Otter has aptly demonstrated its capability for such activities through efforts such as BOREAS. In addition, this aircraft can be fitted with the microphysical and radiational instruments needed to monitor the clouds affecting the surface radiation fields during the snow melt period.

A portable wind profiler has just been acquired by Environment Canada. This ground-based system will be able to continually measure low level (less than a few kilometers) winds and hopefully temperature as well.

In addition, two portable sounding systems have been acquired for deployment at remote sites in order to support water vapour flux studies.

To provide relatively inexpensive measurements in the lower troposphere of a number of critical parameters, consideration may also need to be given to balloons and/or kite flying technology (Balsley et al., 1992). Within the next 2 years, it is expected that such kites will be able to stay aloft for periods ranging from a few hours to a few days. They will be able to measure and transmit to a ground receiving station parameters such as temperature, moisture, winds, and radiation.

To provide more continuous determination of integrated water vapour and perhaps temperature information over the Basin, consideration must also be given to the rapidly developing capabilities of the Global Positioning System (GPS). The signals from GPS satellites are delayed (refracted) in almost direct proportion to the quantity of water vapour along the signal path to the surface (Bevis et al., 1994). In addition, phase alterations of the signals are correlated with vertical temperature profiles (Yaun et al., 1993).

It would also be desirable to acquire an enhanced portable satellite receiving capability. During intensive field campaigns, this would allow investigators ready access to critical information such as water vapour in order to improve observational strategies.

There is a deficiency of surface radiation measurements over the basin. To assess the critical role of solar and infrared fluxes on many key issues, there is a need to supplement the existing network. The exact locations for this expansion will have to be carefully considered to provide the maximum benefit. Suggestions for areas to cover with representative measurements include mountains, forest, tundra, and lakes. Specifically, this suggests the need for measurements at locations such as Inuvik, Yellowknife, Contwoyto Lakes, Ft. Simpson, Ft. Smith, Whitehorse, Norman Wells, and in the Peel River Basin. Such measurements will contribute to the global Surface Radiation Budget (SRB) initiative.

To properly measure near-surface heat, moisture and momentum fluxes under harsh winter conditions, there is also a critical need to acquire new 3-axis eddy correlation systems. New technology has led to the development of a system with low battery requirements that will allow for much better and longer duration measurements under cold conditions in remote locations.

Enhanced stream discharge measurements are required during the spring breakup period at critical locations, including the main channel of the Mackenzie River as well as rivers within research sub-basins. For the main channel, the primary need is on the Mackenzie River at Arctic Red River. At this site, a combination of intensive observations of water level and ice jam thickness along a jam section, in conjunction with, for example, a portable acoustic Doppler velocity profiling meter and hydraulic modelling are required to produce greatly improved discharge measurements during ice jam situations. If possible, such techniques would also be applied to tributaries such as the Athabasca, Peace, Liard and Peel Rivers. Because snow melt is initiated in the southern portion of the basin first, it should be possible to use the same equipment and move it northward through the basin to measure the discharge over the entire basin during a single snowmelt period.

In general, observations must be increased to overcome the inherent problems with measuring discharge in channels choked with snow and ice. Traditional methods of velocity/area techniques using current meters from boats are possible but are very manpower intensive, normally requiring 2-3 persons taking 3-5 measurements/day over a 1-3 week period. Such full-time commitment is impossible. As a result, new techniques must be developed, tested, and used. These techniques include automated continuous tracer dilutions, air bubble technology, or electro-magnetic means for example.

It is obvious that MAGS alone cannot acquire all the special observing systems that are needed to be able to conduct the necessary top notch science. Through the GHP, it is possible to approach other regional experiments for access to their facilities if such situations arise. MAGS can in fact assist these other experiments through the loaning of its equipment such as the McMaster University radar for snow measurement (of importance to BALTEX, GCIP and GAME), portable sounding systems and other facilities.

6. INITIATIVES TO ADVANCE THE MODELLING PLAN

6.1 Introduction

Given that there is a clear objective of the Canadian GEWEX program, there must be a strong plan that moves towards the achievement of this objective in the most rapid manner possible.

It is also recognized that there are only limited resources. Given this reality, the strategy is to examine some aspects of the overall problem first. The initial emphasis will be on cold season issues rather than summer ones, although it is recognized that year-long information is needed. For the atmospheric side, this means that weather systems are not in general convective and the precipitation is snow rather than rain. For the hydrological side, this means that snowpack evolution and cold season and spring discharge are critical rather than summer direct runoff.

It should be pointed out that from the meteorological point of view, there are four distinct periods of the year, whereas from the hydrological Mackenzie river flow point of view there are three. Meteorologically, much of the winter snowpack falls in the autumn (September-November) when cyclonic storms affect the area, in the winter (December-March) relatively light snow is more common, in the spring (April-June) warming and rain storms enhance runoff, and in the summer (July-August) convective activity dominates. From the river runoff point of view, summer (July-October) is when there is no issue of ice or snow, winter (November-March) is when ice and snow hinder flow, and spring (April-June) is when melt occurs.

There will be four main focal areas that feed directly into the MAGS modelling strategy described in Section 4 above:

1. The use of process and small scale models for developing parameterizations for the large scale models.

2. The development of critical climatologies and the continual assessment of the water budget.

3. The determination of basin scale and sub-scale critical features and budgets under special basin-wide enhanced observing periods.

4. The conduct of focussed observational studies directed at critical phenomena that can be conducted on smaller levels of activity.

These focal points are certainly related of course. They will move forward in tandem and there will be a great deal of interaction between them.

6.2 Process and Small Scale Modelling

Many processes occur in the atmosphere and at the surface that affect critical aspects of the water budget. Since many of these are not well understood or their implications not appreciated, they need to be studied thoroughly with small scale models. Some of these are briefly presented here.

The cloud features that produce the precipitation over the basin generally occur over scales (down to 1 km) that must now be simulated with high resolution cloud resolving models. Examples of such models include MC2. Only through the use of such models can one really appreciate the degree of sophistication that is needed within larger models to adequately address the water budgets and to understand the impact of individual systems properly.

Two and/or three dimensional models using idealized or actual conditions are also extremely useful for assessing the impacts of a wide range of parameters on key considerations. One such model is being used to simulate baroclinic wave development and its impact on water vapour transport. Another such model is being used to assess the precipitation efficiency of weather systems that occur over the Mackenzie region as a function of larger scale conditions. The information deduced from such models normally leads to improved parameterizations within larger scale models of water cycling in particular.

Another example from the atmospheric side is the determination of the sublimational loss of precipitation on the regional water budget. This model determines, given input of observed or simulated fields or radar vertical reflectivity profiles, a measure of the loss of precipitation given the common occurrence of very dry conditions below cloud base or between layers in the atmosphere. The high degree of sophistication of this model is needed to determine the minimum microphysical requirements of larger scale models for realistically simulating precipitation at the surface.

For hydrological studies as well, many processes occur that have an impact on the basin water balance. Again there is a need to utilize small scale models to completely understand the large scale implications of these processes. For example, the impact of blowing snow can only be assessed by modelling the blowing snow processes to determine the redistribution of the snowcover and the sublimational loss from the surface when provided with boundary layer conditions. Similarly, the importance of snow stored in tree canopies can be assessed by applying appropriate models to determine sublimation rates, rates of dropping to the ground, and retention times in the canopy, thereby assessing albedo variations.

Another example is the application of surface energy balance models for the determination of snow melt rates for patchy snowcovers. During this period, the advection of energy from bare ground to the snow patches greatly enhances surface melt rates. Only through modelling studies can the impact of these processes be established. The routing of the meltwater through the snowcover and the lag time between the melt and runoff must also be determined through small scale modelling studies.

Regardless of whether the modelling is aimed at atmospheric or surface issues, the last step is to include the models or a parameterization of their results into basin scale models to assist in the simulation of the full annual hydrological cycle.

6.3 Climatology and Ongoing Water Budget Calculations

There is a need to establish clearly the climatology of the pertinent parameters affecting or depicting the energy and water budgets of the basin. Of course, the emphasis on such studies will be decreased as the efforts are completed so that more of the modelling and process studies can be carried out to build upon the climatology. To properly assess the situation, there will be a special section of the autumn 1995 MAGS meeting at which the climatology of relevant parameters to MAGS will be reviewed and priorities set on potential future efforts.

A special effort will also be mounted to directly calculate basin and sub-basin water budgets from the output of operational models. As summarized in the Data Management Section 7, arrangements have been made for ongoing budget estimation with the operational ETA and ECWMF models and it is anticipated that a similar effort can be carried out with the RFE model. These operational results are critical in order to develop an ongoing appreciation of the general budgets of the region that will assist in the pinpointing of key uncertainties.

6.4 Basin Scale Enhanced Observing Periods: CAGES

The Mackenzie basin is poorly observed on an operational basis. There have to be periods of enhanced observations that allow for greater confidence in the initialization and validation fields for modelling efforts and remote sensing studies. In order to accomplish this, it is envisioned that 2 year-long efforts with enhanced observing periods be undertaken.

This effort is tentatively being referred to as CAGES (Canadian GEWEX Enhanced Study). The first such year will be the year of "1997-98" and the second will be "1999-00". Plans for the first special year are summarized below; plans for the second will be developed later.

It should be noted that the SHEBA year-long measurement program is planned for the 1997-98 period as well. This effort, based on the Arctic ice pack of the southern Beaufort Sea with a range of measurements to monitor critical atmospheric, cryospheric and possibly oceanographic parameters, will complement some of our efforts. In addition, the proposed FIRE III effort to specifically examine the role of clouds on radiational balances over the sea ice will be quite important as well. Specific interaction plans are being developed between our program and these two efforts. Our focus on Mackenzie Basin (over land) issues is very complementary role to these programs (with their over sea ice and over open water emphases).

6.4.1 1997-98 Special Year: CAGES 1

There must be a year-long study which provides a higher degree of confidence in the water and energy budget parameters than available with routine measurements. Waiting till 1997/98 will allow sufficient time for preliminary studies to be completed and their results incorporated into an improved experimental design.

It is expected that some special observations will be made over the entire year (such as ground-based radiation measurements and enhanced surface precipitation observations, especially in higher terrain), but this effort is expected to be boosted during up to four periods within the year when other enhancements are made.

Some of the initial considerations for these phases are discussed below.

6.4.1.1 Autumn Phase

In the initial phase of CAGES 1, the current consideration is that this study should build-upon the experience being gained on Mackenzie region cloud systems being first of all established through an analysis of BASE information. In that experiment, additional sondes were released during storm periods from a few sites over the area for periods up to 2 days. While this approach is sufficient for some storm-scale studies, it is inadequate for regional water budget estimates.

It is therefore proposed that an enhanced period (1-2 months) of continuous 6-hourly soundings be planned. This will take advantage of regular and special portable sites across the area to provide critical information not available through the operational sounding program. It is quite likely that a portable wind profiler will also be deployed.

Within this overall period of enhanced soundings, the McMaster University radar will be located over an area of critical importance to the hydrological component of the experiment. The radar will assist in providing information on precipitation and its variations down to scales of a few hundred meters out to about 150 km, even in snow.

It is further proposed that, as appropriate several additional surface-based weather stations be placed over the basins covered by radar information and to provide crucial input data for the hydrological component that will be already in a position to measure runoff features.

It is expected that other components will be added to this initiative to address related issues. Stationing of a portable satellite system will allow for observing the cloud systems in real-time for moisture assessment. Balloon-borne sondes in a few cases to validate radar inferences of particle properties can be envisioned so that remote-sensing estimates of precipitation can be compared with measurements as well. To provide greater information on orographic barrier precipitation, a small number of sites will also be established in critical areas.

A major initiative within this concept is the real-time measurement calculation of the regional water budget, carried out with the use of the data assimilated by weather prediction models. Algorithms for calculating the basin flux have already been developed and it is envisioned that this water budget "product" will be made available to researchers in real-time, along with an ongoing assessment of prediction capability.

6.4.1.2 Winter Phase

During the very cold period of the year, the water budget is dominated by meteorological forcing that is different from that experienced in the autumn. Much of the precipitation that arises over the lower (northern) regions of the basin in particular is produced from low boundary layer clouds and precipitation rates are very low but they can be sustained for long periods at a time.

This period represents an extremely important portion of the annual energy and water cycle. Critical questions are concerned with the manner in which water substance is made available from the surface through, for example, periods of blowing snow as well as from tree canopies and to what extent this water substance plays a critical role in the formation of new clouds and hence the production of snow at other locations through some "leap frog" technique that occurs well below 0C.

In order to consider a definitive study of this period, a special measurement program is needed. This will rely upon a special 6-hourly sounding program similar to that of the autumn period but perhaps at few sites. As well, detailed measurements of the precipitation will be determined with the McMaster University radar and it will require detailed measurements of the near-surface flux of moisture, heat and momentum as derived from a network of surface-based systems. Since the main emphasis is quite close to the ground, there will be limited need for large numbers of high ascending balloon sensors but there will need to be detailed measurement of the precipitation characteristics as well as the near-surface temperature and humidity profiles. It is not clear to what extent available remote sensing systems onboard satellites will be able to discern the presence of these light precipitating clouds but this issue needs to be clarified well before the measurement program.

This measurement program will mainly be carried out in the Inuvik areas (although some activities may also be conducted in Prince Albert National Park). Inuvik provides both tundra and forested sites which are representative of the vast boreal forest/tundra regions of the basin. In addition, this location will allow direct use of the hydrological research basin ongoing measurements.

It should be added that the conduct of this initiative will occur under extremely difficult conditions with complete or partial darkness and extremely low surface temperatures. Ongoing advances in technology however should allow for a successful measurement campaign.

6.4.1.3 Spring Phase

The 1998 spring discharge period must be studied so as to take advantage of the enhanced observations of snowpack formation and evolution made during the autumn and winter of 1997-98. The period of this spring phase would be, for example, April-June.

Enhanced soundings over this phase will again be needed and there must be substantial hydrological measurements. It is critical in particular to properly measure the river discharge from various sites. As previously mentioned, it may be possible to use the same discharge measuring systems at different sites as the main discharge event moves northward.

It will also be critical to observe snowmelt behaviour and its interactions with surface radiational heating. The main centre for activities should again be Inuvik in order to take advantage of the winter program measurements. It will be critical to observe the low level (typically < 1-2 km) cloud field over this site in order to understand the surface radiation. The Twin Otter aircraft would fly at low levels over the surrounding terrain to place the specific sites measurements into a larger scale perspective and to monitor cloud characteristics affecting surface radiation. This is where suggestions such as tethered balloons or maybe even a new generation kite could be useful; they may be able to provide relatively inexpensive monitoring of critical atmospheric and cloud characteristics in the lower troposphere. If feasible, this is again an opportunity for the utilization of the McMaster radar with its advanced cloud sensing capabilities.

6.4.1.4 Summer Phase

To complete an annual cycle, measurements of basin water and energy budgets are needed in the summer as well. Over much of the basin, precipitation is a maximum during this season.

Here, it will be critical to determine the surface evaporation effects thought to be largely responsible for the available vapour. A small network of sites for assessing this process will need to be established. An enhanced sounding program will of course also have to be conducted in order to quantify the large scale features affecting the basin.

6.5 Special Focal Points

6.5.1 Blowing Snow and Snow Interception Impacts

As justified by the ongoing process studies of blowing snow and forest canopy interception in conjunction with small basin water balance studies, a larger effort is warranted to study this feature. The purpose of such a study would be to determine the regional impact of blowing snow and snow interception on the basin water budget. However, there are few local residents of the mainly-affected tundra areas to document occurrences of blowing snow; consideration will have to be given to satellite detection. In addition, a few sites embedded within the basin will need to be established to directly measure the sublimational loss during these episodes. Basin-scale impacts will need to be derived from large scale model predictions of blowing snow occurrence, validated with these measurements.

The first attempt to carry out this study will be carried out under the umbrella of the atmospheric water vapour study that will begin in the autumn of 1997, as outlined above.

6.5.2 Tundra and Barren Lands and their Role

The Canadian portion of the international GEWEX initiative has the largest amount of tundra and barren lands of any of the other projects and we therefore have a special obligation to consider the complete implications of this form of surface on energy and water cycles. GAME is also planning a future focus on tundra and linkages with that initiative will be developed.

A special focus on the complex interactions between the atmosphere, surface and snow-cover will be undertaken within specific initiatives in the Inuvik area as outlined above. In addition to these small scale studies, there must be an effort addressing their larger regional impacts.

6.5.3 The Orographic Barrier and its Role

It is very apparent that the substantial orographic barrier on the western edge of the basin produces a major impact directly and indirectly on the energy and water budgets of the Mackenzie River. From the meteorological point of view, the cloud systems are typically greatly altered by the orography and in general precipitation accumulations are greatest over this region. The production of this precipitation and the implications of the melt timing and volume are dominant considerations for runoff issues.

Much work has been conducted on the impacts of orographic barriers in other regions of the world but, with latitudes up to 70 and coupled with low moisture levels in general, this dictates that the adequate simulation of orographic effects will be very difficult to achieve. The analysis of model data from the water budget studies will highlight key missing issues and, as necessary, specific initiatives will need to be established to address the key questions that arise.

6.5.4 Freshwater at the surface and its Role

Much of the Mackenzie basin is covered by surface water in the form of rivers, lakes of many sizes, melt water, and the Mackenzie delta itself.

There are many impacts of this open water on the regional water and energy cycles. For example, their altered albedo as a result of freeze-over may play a significant role in the regional energy budget. As well, evaporation from its surfaces is crucial during the summer to precipitation production and this effect is probably even greater in the autumn when the lakes are warm and the atmosphere can be cold.

It is critical that specific issues related to these open water regions be established so, as appropriate, specific initiatives be established to rectify the uncertainties. A first step is to establish an accurate map of lake coverage using the same grids used in vegetation characterization.

7. DATA MANAGEMENT

7.1 Overview

Accomplishment of the major scientific objectives of MAGS involves the development of a comprehensive and accessible observational database for the Mackenzie River Basin and the establishment of a model development program that will permit observations and analyses to be extended spatially or applied globally with new observations within the context of the International GEWEX program.

This portion of the Implementation Plan summarizes the strategies needed to achieve the overall data management objectives. A more detailed MAGS Data Management Report is currently being prepared (Krauss, 1995b).

Progress in addressing data management has included:

i. Creation of a GEWEX Secretariat whose responsibilities include coordination and communication services in support of data management

ii. Adoption of a Data Policy (see Krauss, 1995b), reflecting the functional requirements for support to Canadian researchers and a requirement for international liaison

iii. Creation of a Data Management Subcommittee to provide direction for Canadian GEWEX data management

iv. Adoption of a decentralized approach for data management which will enable the Data Policy to be implemented in support of both Government and University researchers, and intended to use minimal central support resources

v. Provision of interim support to get data management activities underway.

The strategic plan for data management for MAGS must build upon the data management activities and infrastructure which Environment Canada has established in the National Hydrology Research Centre, the Canadian Meteorological Centre, and the Climate Information Branch to support Government GEWEX research. Some additional resources will be required to accommodate the needs of the university scientists in collaborative GEWEX research. These resources will support the central infrastructure in a manner complementary to the central support provided by Government, and also will support infrastructure at each participating university.

New technology (particularly near-real time electronic communications such as the World Wide Web (WWW) and tools such as MOSAIC, NETSCAPE, and CELLO on the Internet, and more sophisticated relational data base management software which can be linked across such communications channels) allows the opportunity for Canadian GEWEX to meet the needs of MAGS researchers both individually and as a group with a decentralized database management system.

As a first step in this approach, information on the Canadian GEWEX program is now available on WWW at: http://www.dow.on.doe.c a/GEWEX/gewex_homepage.html.

The second step to be pursued is the posting of summary data on all available projects on the WWW. It is expected that this will be accomplished by the autumn of 1995.

Discussions have been held with the developers of the CODIAC system who are handling the GCIP data management. CODIAC provides another level of sophistication to allow easy access to a wide variety of data sets resident on different systems. It is not clear that CODIAC would also be useful to the Canadian program, but a decision on this will be made by the autumn of 1995 as well.

7.2 Key Elements of Data Management System

Key elements of the proposed C-GEWEX data management system include:

i. a set of standardized data formats for the melange of necessary data (numeric, descriptive, gridded, and images)

ii. a centrally maintained software infrastructure, resident on collaborating institutions' workstations

iii. assembly and availability of "universal" data sets which might be used in MAGS such as surface climatological data (station and gridded), model output data (e.g. from the Regional Finite Element (RFE) model), and certain remotely-sensed imagery (e.g. GOES, NOAA, LANDSAT, and ERS1)

iv. decentralized archiving (including quality control, control of access in a manner consistent with the Data Policy and updates) for special field data sets; responsibility would lie with the researcher collecting the data to archive and make it available, while the actual access infrastructure would be a central responsibility

v. centralized responsibility for compatibility with international standards for exchange within international GEWEX

vi. data access procedures for participating researchers which do not rely on personal intervention of a collaborating researcher, but rather are presented in a decentralized data base management system as options with data transfer procedures which are invisible

vii. maintenance of unique source copies of data, particularly for the specially collected data sets which would reside on UNIX workstations at the responsible researcher's institution, for which changes/updates would be more readily effected within MAGS

viii. access to MAGS participants not at a node, and later to non-GEWEX participants

ix. security of the MAGS data would be maintained through occasional central backup procedures

x. provision of data to relevant national archives.

7.3 Distributed System

Each Canadian GEWEX participating university and Government site will have a UNIX workstation with an Internet connection. Certain functions (e.g. archive formats, catalogues) would be centrally controlled, installed and updated as necessary over Environment Canada's Wide Area Network, or over Internet for the university installations.

Some datasets for general use would be made available centrally (e.g. climatological data sets, numerical weather prediction model-output, NOAA/AVHRR imagery and some of the BASE field observations), while any data set for which access is authorized by the collecting researcher would also be available as part of the system, but resident on the decentralized university or government installations. A summary of the MAGS data and data providers will be posted on the Canadian GEWEX home page.

Standard meteorological and hydrometric observations from the regular observing network of stations will be archived and available through the National Climate Information Branch of Environment Canada in Downsview.

At least three MAGS data centres will be established:

i. Canadian weather prediction model output (SEF, RFE, MC2) will be archived at the Canadian Meteorological Centre in Dorval, Quebec

ii. Special observations from Enhanced Observing Periods and some long-term remote sensing information will be archived at AES Headquarters in Downsview, Ontario

iii. Special hydrological data sets associated with the research watershed studies will be archived at the National Hydrology Research Centre in Saskatoon, Saskatchewan

Government will provide resources to support its own installations and largely fund the assembly and archiving of the centralized data sets. Investigator Research grants would directly support university participation in the data management system, and the acquisition of selected central data sets (e.g. LANDSAT imagery for the Mackenzie Basin, or Digital Elevation Model (DEM) data).

7.4 International Connections

The European Centre for Medium-Range Weather Forecasting (ECMWF) produces output from a global model (T213L31) and archives the output data. The ECMWF archive data will be made accessible through the GCIP data management system at NCAR. In addition to the routine global analyses, special arrangements have been made to archive areal-averaged, water budget variables for six sub-basins within the Mackenzie Basin (Figure 9). The sub-basin water-budget variables will also be part of the ECMWF, 10-yr reanalysis project, thereby, producing a valuable model data set which can be used to strategic planning of the Enhanced Observing Periods during MAGS.

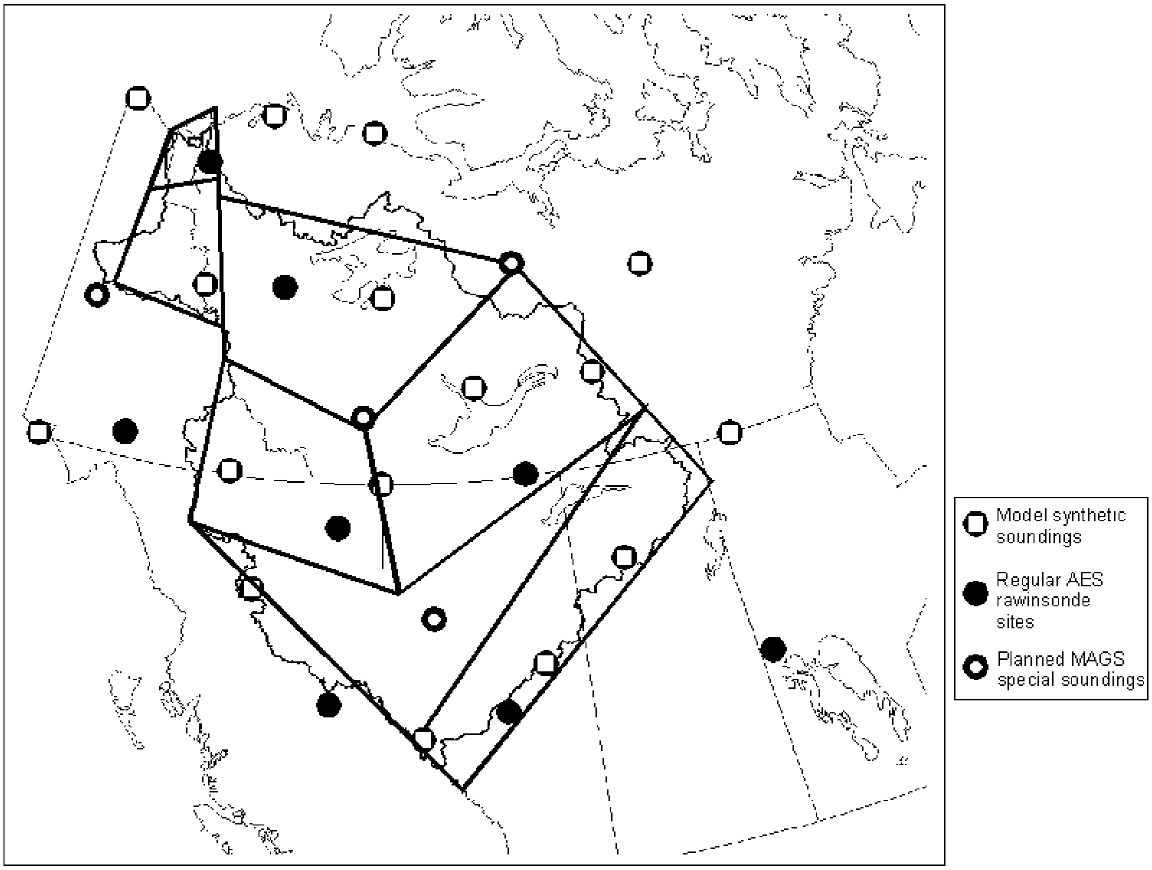
Special arrangements have been made with the U.S. National Meteorological Center to archive the output from the regional Eta model (48 km resolution). For 28 selected locations within the Mackenzie Basin (Figure 9), vertical profile time series of instantaneous values of the 3-dimensional atmospheric fields, cloud, and radiation fields at hourly intervals will be archived by the GCIP data management system at NCAR. Special arrangements have also been made with the University of Maryland, Dept. of Meteorology to conduct basin-scale atmospheric moisture budgets using the full Eta model grid.

It is possible that special data management interactions between the different regional experiments can be facilitated through the GEWEX Hydrometeorological Experiment Panel (GHP). All the regional experiments face similar data management issues and it is quite possible that efficiencies can be gained through some degree of coordination of efforts in this regard. This will be one of the topics to be discussed at the first GHP meeting in August, 1995.

8. ORGANIZATION OF CANADIAN GEWEX PROGRAM

A number of institutes and researchers are involved with the Canadian GEWEX program. The organizational structure appears in other documents available through the Canadian GEWEX but this is also summarized in Table 2. A list of the participating researchers is given in Appendix 2.

Leading the scientific aspects of the program is the responsibility of Prof. Kent Moore of the University of Toronto and Dr. Ronald Stewart of AES with special assistance from Dr. Phil Marsh from NHRI. The responsibility for carrying out the logistical support for the effort is with the GEWEX Secretariat, Dr. Terry Krauss. Sub-committees and working groups will be developed to tackle specific tasks as appropriate.


Model synthetic soundings
Regular AES rawinsonde sites
Planned MAGS special soundings

9. SCHEDULE

9.1 Annual Meetings

An annual meeting of MAGS investigators will be established with the first of these being in the autumn of 1995. The agenda for the first meeting will be as follows:

1. There will be a presentation on the purpose of the initiative, along with a brief summary of recent developments and other international implications.

2. This will be followed by a specific section concerned with the climatology efforts that collectively seek to answer the question: "what are the values of key parameters?". Some of these studies have now reached the end of their efforts.

3. The next section is concerned with basin scale simulations from a large scale modelling perspective. The emphasis here is to assess the strengths and more importantly the weaknesses of the models to realistically simulate key parameters.

4. The next section will be concerned with process studies that are leading to improved understanding and parameterizations within the needed numerical simulations.

5. There will be a special section devoted to our current assessment of our ability to predict on a physical basis the discharge of the Mackenzie River. A special statement on our current status will be produced.

6. The last section of the workshop will improve the implementation plan for the next year and for the longer term, and this includes specific updates on the enhanced observational effort planned for 1997-98 as well as the data management initiative. All this needs to be carefully documented for later reference and as a measure of our progress.

9.2 Timeline

A timeline of actions is shown below. This will be updated as decisions and progress are made.

1995
Jan Establishment of MAGS Management Structure
March 23-24 Science Committee meeting
March 28 Advisory Panel meeting
May 22-26 GEWEX Cold Region Workshop, Banff
June First version of basin conditions report
June First version of MAGS Implementation Plan
June First version of data management Plan
June Researchers for ongoing budget analyses chosen
July Submission of NSERC proposal
July Start of ETA model budget calculations
Aug 31 First meeting of GHP (3 day meeting)
Sept Progress report on data management
Sept 12-15 ACSYS solid precipitation workshop
Oct ECMWF reanalysis with MAGS information started
Oct 16-18 GCIP North-Central Area workshop, Minneapolis
Nov 14-15 Analysis workshop, Toronto
Nov 16 Science and Advisory Panel meetings (tentative)
Nov Scientific review article on MAGS started
Nov 1-3 GCSS workshop with BASE cloud system impacts

1996
Jan 15-19 GEWEX SSG meeting
June Special sessions at CMOS Congress, Toronto
Aug GHP meeting, Toronto

Sept Analysis workshop, Saskatoon
Sept GHP meeting in Canada on international linkages
Nov Review article on Mackenzie science published

1997
July GHP Symposium at IAMAS'97
Sept Start of enhanced observing period CAGES 1
Oct-Nov Autumn phase of CAGES 1
October Analysis workshop, Yellowknife

1998
Jan Winter phase of CAGES 1
Apr-June Spring phase of CAGES 1
May Summer school: regional water budgets
Aug Summer phase of CAGES 1
Sept End of CAGES 1
November Analysis workshop

1999
Sept Assessment of CAGES 1 completed
Sept Start of CAGES 2
October Analysis workshop and future plans meeting

2000
Sept End of CAGES 2
October Analysis workshop

2001 Jan-Dec Very focussed studies of key remaining issues
October Analysis workshop

2002
Feb Synthesis workshop on Canadian GEWEX program
July International conference on MAGS
Sept Final report of MAGS completed

9.3 Overall Actions

The multi-faceted and multi-year effort of the Mackenzie initiative is briefly summarized in graphical form in this Section. This material will be updated as appropriate.

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                   1995 1996 1997 1998 1999 2000 2001 2002

Meetings             .    .    .    .    .    .    .  . .
Discharge Update     .    .    .    .    .    .    .  . .
Science Survey Article. ...
Final Report                                        . ...

Historical Datasets.... ..
Bkgrd. Climatology .... .... ....
Remote Sensing     .... .... .... .... .... ..
Process Studies    .... .... .... .... ....

Water Budgets
 RFE                  . .... .... .... .... .... ..
 ETA                 .. .... .... .... .... .... ..
 ECMWF               .. .... .... .... .... .... ..

Modelling Effort
 Process Models      .. .... .... .... .... ....
 Analysis Fields      . .... .... .... .... .... ..
 Short-Term Prediction    .. .... .... .... .... ..
 Monthly Prediction          .... .... .... .... ..
 Coupled Models                   .... .... .... ..
 Regional Climate Model .... .... .... .... .... ..

CAGES 1 and 2
 Soundings                     .. ..      .. ..
 Radar                         .. .       .. .
 Mtn.Precip. Gauges            .. ..      .. ..
 Surface Radiation             .. ..      .. ..
 Discharge                    ... ..    ... ..
 Aircraft                          .

Research Basins
 Inuvik            .... .... .... .... .... ..
 Wolf Creek        .... .... .... ....
 Ft. Simpson       .... .... .... ....
 Prince Albert     .... .... ....
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APPENDIX 1: GEWEX Research Basins

GEWEX hydrological research basins are located in four general areas. These are briefly discussed in this Appendix.

A. Inuvik, NWT

There are two main types of data presently being collected in the Inuvik area. The first is the standard river stage and level measurements collected by the Water Survey of Canada office located in Inuvik. The second includes the research data collected by the National Hydrology Research Institute at two research basins.

Water Survey of Canada (WSC) river discharge data have been collected at a large number of basins in the Inuvik area since the early 1970's when a WSC office was established in Inuvik. Previous to that, streamflow data were not collected on a routine basis in the Inuvik area. Seven streams are currently monitored by WSC. These small drainage basins are all located on the east side of the Mackenzie Delta. They collectively offer a unique sequence of drainage basins along a transect which crosses the Arctic treeline. Four stream basins are located south of the treeline, and the vegetation is dominated by northern Boreal forest. Three others are located north of the treeline and the vegetation is dominated by Arctic tundra. The operational status of these basins is unclear at present due to budget cuts.

In addition, WSC monitors a number of larger basins in the vicinity of Inuvik. These include: Mackenzie River at Arctic Red River (1,660,000 km2), Arctic Red River (18,600 km2), Peel River (70,600 km2), Anderson River (56,300 km2), Babbage River (1,510 km2), and the Firth River (5,710 km2). These rivers drain a variety of topographic and vegetation classes, and all provide a significant input of freshwater to the Beaufort Sea/Arctic Ocean.

NHRI has developed a research program at Havikpak Ck. and Trail Valley Ck. NHRI conducts additional measurements of discharge at these two basins. This additional data greatly enhances the WSC discharge data during breakup when standard techniques for determining discharge are of limited use. NHRI has installed a recording weather station at Havikpak Ck. and Trail Valley Ck. The Trail Valley site is located on rolling upland tundra, while the Havikpak site is located in a broad river valley with stunted black spruce. Each station records: wind speed and direction at 4 levels to a height of 3 m, air temperature, relative humidity, blowing snow at 1 level, snow depth, net radiation, incoming and outgoing solar radiation, air pressure (Trail Valley Ck. only), and soil temperature at 4 depths down to 0.5 m depth.

In addition, a Nipher snow gauge is installed to measure total winter snowfall. At the Havikpak Ck. site, monthly snow surveys are carried out near to the weather station.

In addition, NHRI conducts a variety of research type measurements within the Trail Valley Ck. basin. Some examples include: Bowen ratio measurements for evaporation determination, late winter snow surveys for determining mean

snow storage, energy balance over melting snowcovers, soil moisture determination using twin probe gamma or TDR, measurements of changes in snowpack properties during the melt period, air photography of changes in basin snowcover over the melt period, measurements of water flux through the

snowcover, and ground truth measurements for satellite and aerial remote sensing.

B. Prince Albert National Park, SASK.

NHRI also has installed several instrumented towers in the Bear Trap Creek Basin within Prince Albert National Park. Research sites have been set up in an old clear cut region (about 10 y old), a new clear-cut region (about 2 y old), an aspen forest, and a mature spruce forest.

Data collected include air temperature, humidity, barometric pressure, wind speed and direction, rainfall, snowfall, incoming and outgoing radiation, net radiation, snow depth, blowing snow, soil temperature and soil heat flux.

C. Wolf Creek, Yukon

The Wolf Creek Research Basin project was initiated in 1992 to provide a dedicated site to carry out applied research in a mountainous watershed in the Yukon sub-Arctic. The initiative is funded by the Department of Indian and Northern Affairs Canada (DIAND) Arctic Environmental Strategy Program with support from Environment Canada through NHRI in order to address GEWEX scientific issues. The basin occupies an area of 220 km2 in the southern Yukon headwaters region of the Yukon River.

Three major meteorological stations were established within the study area, one each in the three elevation-vegetation zones which characterize the basin.

1. A Black Spruce Forest research site is located at an elevation of 750 m within a mature black spruce forest stand approximately 1 km upstream from the lower Wolf Creek hydrometric station. The 13 m high instrumented tower extends to within 2 m of the canopy.

2. A Buckbrush Taiga research site is located at an elevation of 1250 m on a gentle slope near the valley bottom. Vegetation consists of 1-2 m high willows and alders with scattered spruce patches. A 5 m high instrumented tower extends above the vegetation.

3. An Alpine Tundra research site is located at an elevation of 1615 m on a wind swept high alpine tundra plateau along a drainage divide at the northern edge of the basin. Vegetation at this site is sparse consisting of mosses and lichens with occasional patches of scrub willow. A 3 m high instrumented tower extends above the vegetation and boulders.

At each research site, instruments record air temperature, rainfall, snowfall, wind speed, humidity, incoming and outgoing shortwave radiation, net radiation, barometric pressure, snow depth, blowing snow transport, soil temperature, and soil heat flux. Precipitation instrumentation includes a tipping bucket rain gauge and a nearby Nipher snow gauge. The instrumentation is controlled by solid state data loggers and powered by solar panels. Twenty-five point snow courses are sampled monthly throughout the winter.

D. Ft. Simpson, NWT

The fourth research "wetlands" basin near Ft. Simpson is being instrumented during 1995. Work to date has concentrated on classification of vegetation-terrain units from LANDSAT-TM for the Ft. Simpson local region and preliminary testing of a distributed runoff model to existing hydrometric data for selected catchments (Martin River, Manners Creek, Jean-Marie River, Birch River, and Blackstone River).

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