WATFLOOD™ – Model Setup for MRBHM Update

Government of the NWT

Contract No. 84

FINAL REPORT

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1 Introduction

The following **bolded** material is reproduced from the EC contract for the initial 2009-2010 setup of the WATFLOOD™ (WF) model to compute inflow from ungauged tributaries to the Mackenzie River system for use by the Mackenzie River Basin Hydraulic Model (MRBHM). The TOR below is on Page 2 of the **MRB_watflood_contract.pdf**, found in the folder **WATFLOOD\MRB22\MRBHM** on the accompanying data set. This report describes the updating of that original work.

1.1 Background

The Mackenzie River Basin covers an area of approximately 1.8 million square kilometers, over one-sixth of Canada's landmass. The governments of Canada, British Columbia, Alberta, Saskatchewan, and the Northwest and Yukon Territories, with jurisdiction to manage water and the environment in the Mackenzie River Basin, have signed the Mackenzie River Basin Transboundary Waters Master Agreement, hereafter, "the Agreement". As noted in the Terms of Reference ("TOR") initiating this phase I report, the Agreement, which came into effect in July 1997, committed the signatories to a number of overarching principles in managing their water resources and made provisions for the development of bilateral water management agreements. The Agreement also established the Mackenzie River Basin Board which, among other responsibilities, implements the master agreement and any related bilateral agreements.

1.2 Problem Statement

The Mackenzie River Basin Board, at its December 12, 2005 meeting, approved work plans submitted by the Technical Committee for the development of a modelling system for the main stem of the Mackenzie River. The proposed hydraulic/hydrologic model would have the capability to reproduce recorded flows, reconstruct natural flows, and assess the flow conditions resulting from the full implementation of potential water management and administrative arrangements considered in the development of bilateral agreements for various locations along the main stems of the Peace, Athabasca, Slave, and Mackenzie Rivers.

Through its reports to the Technical Committee, and within the above context, the Hydrology Sub-Committee functions to provide advice and support to the Board and the bilateral negotiating teams on matters relating to the hydrology of the basin as well as the effects of existing and/or proposed water management works and administrative arrangements on water quantity aspects. At the request of the Hydrology Sub-Committee, a phase I feasibility report examining the establishment of a hydraulic/hydrology modeling framework for the main stem of the Mackenzie River was developed and is presented here. The objectives of Phase I of this project are: i) to describe the design and the implementation of the hydraulic/hydrologic modeling system and its capacity to assess recorded, naturalized, and scenario flows at various locations throughout the basin; and ii) to undertake hydrologic studies and investigations to address water quantity issues.

In March 2006, the Technical Committee proposed the attached two-phase approach to the development of a hydrological and hydraulic model for the Mackenzie River Basin. This work was completed last year, however some final adjustments to the hydrology model need to be considered and implemented.

1.3 Objectives

The objective of this work was to re-calibrate the WF hydrological model for the Mackenzie River Basin (MRB) to reflect enhancements to the model and compute flows for the ungauged tributaries of the Mackenzie River as identified in the Mackenzie River Basin Hydraulic Model (MRBHM). The MRBHM is the University of Alberta's River 1D model as configured for the MRB. During testing and evaluation of the MRBHM, it was identified that refinements to the ungauged flow estimates needed to be made. This report describes how the WF model was calibrated and modified to produce files containing ungauged flows to the Mackenzie River in a MRBHM formatted file, and supplements materials provided at a 2-day modelling workshop in Edmonton, Alberta, on June 7/8, 2016. All workshop materials including model input/output files are available online at civil.uwaterloo.ca/watflood/Studies/current.htm.

1.3.1 Additional Objectives with Contract Extension

At the June 2016 workshop in Edmonton, it became apparent that naturalized flows could be computed by WF by removing Williston Lake from the model. Naturalized flows obtained in this manner can be an alternative approach compared to those derived by B.C. Hydro through carrying out a water balance on Williston Lake[1].

The additional naturalized flows from WF/CHARM are to be added as an additional option in the MRB_WILLISTON_INFLOW.tb0 file for the MRBHM.

Further, the modelled lake levels for Lake Athabasca and Great Slave Lake (GSL) are to be compared for the regulated and natural regimes.

1.4 Deliverables

1. MRBHM input files to AMEC Foster Wheeler, GNWT & MRBB
2. Draft report (1 & 2 to be submitted by March 31, 2016)
3. Final report to be submitted by June 30, 2016, later amended to July 31, 2016
4. Training – 2 day WF workshop in Edmonton (delivered June 7-8, 2016).

[1] BC Hydro. 2011. Technical Report - A Review of Inflow Quality Control Procedures at BC Hydro, by Scott T. Weston, M.Sc., Senior Hydrologist, Hydrology and Technical Services Group, Generation Resource Management Division. March 11, 2011. pp. 25.

2 Mackenzie River Basin Hydraulic Model

2.1 MRBHM setup in WATFLOOD

To provide some context for the WF setup, a brief description of the MRBHM configuration is given first.

Figure 1 is a GreenKenue™ (GK) picture of the Mackenzie River watershed with the reaches as coded for the MRBHM model as delineated and numbered. The MRBHM model was set up with 170 nodes to model 170 separate segments along four rivers contributing flow to the Mackenzie River at Tsiigehtchic (Arctic Red River):

1. The Athabasca River from Windfall to Lake Athabasca (Reach 42 and 41),
2. The Peace River from the Peace Canyon Dam to the Slave River (Reach 32 and 31),
3. the Slave River from Lake Athabasca to GSL (Reach 21), and
4. the Mackenzie River from GSL to Tsiigehtchic (Reach 12).

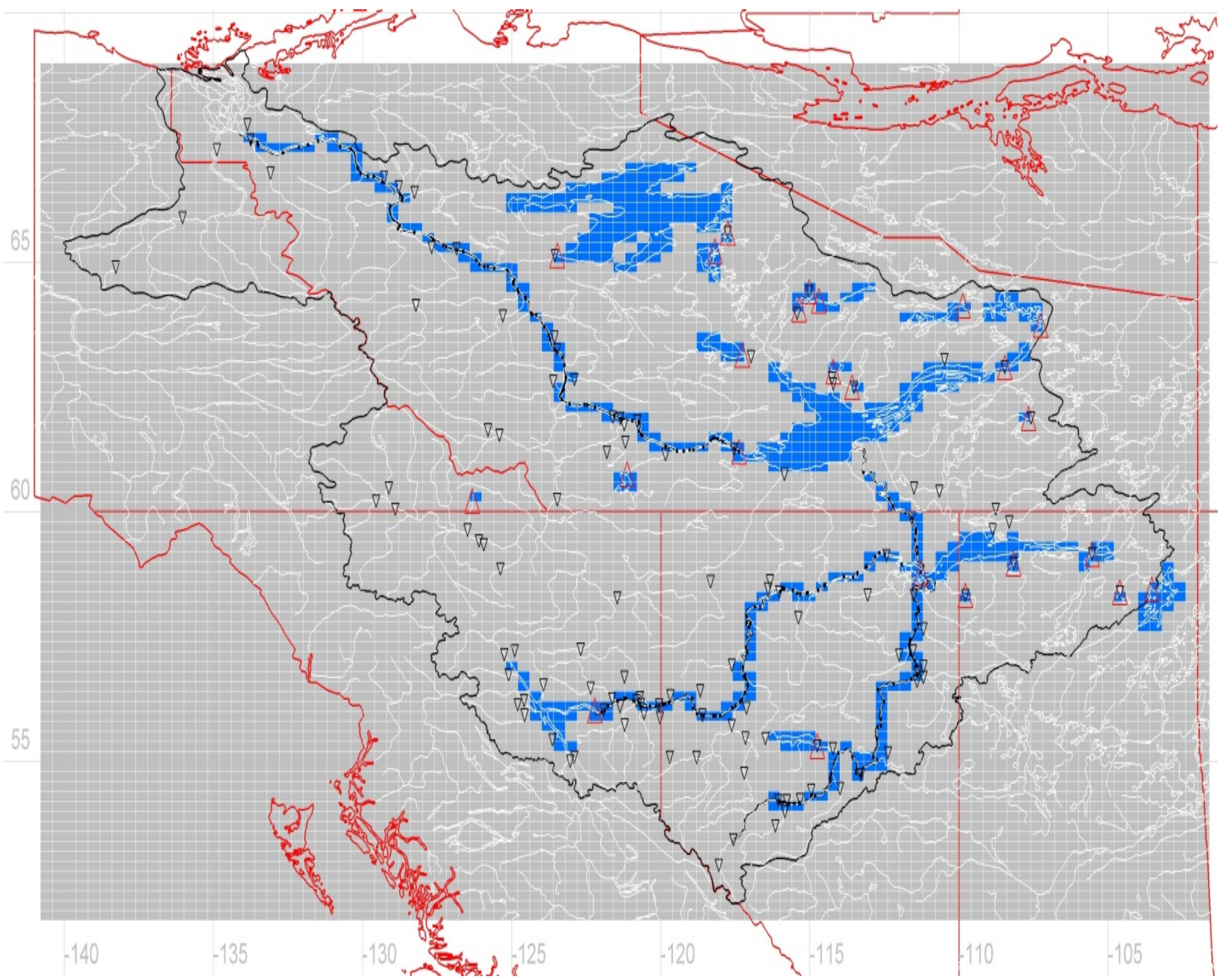

Figure 1 – Reaches for the Mackenzie River Basin Hydraulic Model

There are some other reaches to connect the various channels at Lake Athabasca but these are not of interest for the WF part of this work but Wollaston Lake, Saskatchewan, was included in this WF setup as it discharges some of its waters into the MRB.

The MRBHM has a computational node every river km (with nodes spaced more closely in key locations such as at abrupt changes in river bed slope) and all nodes can be used as inflow nodes but only a subset of nodes are needed to accept inflow, primarily where tributaries enter the main rivers or at lake outflow locations. Two such nodes are the outlets of Lake Athabasca and GSL – nodes 21-457 and 12-1385 respectively. Furthermore, nodes 32-1097.5 and 42-913.8 are the upstream inflow nodes for the Peace River at Hudson Hope and the Athabasca River at Windfall.

Appendix A is a table matching up the WF reach numbers in column 3 and the MRBHM nodes in column 4. Columns 1 and 2 are the Lat-Long locations of the nodes while the rest of the table has coefficients for the WF routing model. This table is in a file called **lake_rules_mrbhm.csv**, the last 21 entries are the lake rules for the lakes that are not part of the MRBHM routing model but are modelled in WF to give hydrographs downstream from lakes a proper lake-attenuated shape. A program called ECrel.exe is executed in the **watflood\mrb22\strfw\wsc_**data directory to create the **resrl\yyyymmdd_rel.tb0** file. This rel file along with setting the routeflg = ‘q’ in the **event\event.evt** file will create the master inflow file. The first few lines and columns of the master inflow file are found in Appendix B.

More detailed information on how to download precipitation, temperatures, flow and water level data will be described in Section 4.

Figure 1 shows the MRBHM grids and also other lakes in the WF model. But more to the point, the blue grids are referred to as WF “reaches”. The WF reach grids are numbered in white, visible in the close-up Fig. 2. In WF, lakes are referred to as reaches – i.e. each lake is given a reach number. In this case, Lake Athabasca is reach #2, Williston Lake is #1, Great Slave Lake is #3 and Great Bear Lake is #128.

In all, there are 148 “reaches” in WF of which the first 127 are matched up with MRBHM inflow nodes (as listed in Appendix A) and the rest are other lakes which were delineated as lakes because they were for the most part upstream of Water Survey of Canada (WSC) gauges and the hydrographs at these gauges could not be made to resemble lake outflow hydrographs unless a lake was modelled upstream.

Figure 2 is a close-up for the west portion of Lake Athabasca. The small dots are the computational nodes of the MRBHM. The larger numbered points are the inflow nodes for the MRBHM. The marker numbered 21 is a WSC flow gauge 07DC001 Firebag River near the mouth, 59 is Peace River at Peace Point 07KC001, 119 is the Birch River 10ED003; and the white triangle numbered 457 is the outflow location of Lake Athabasca.

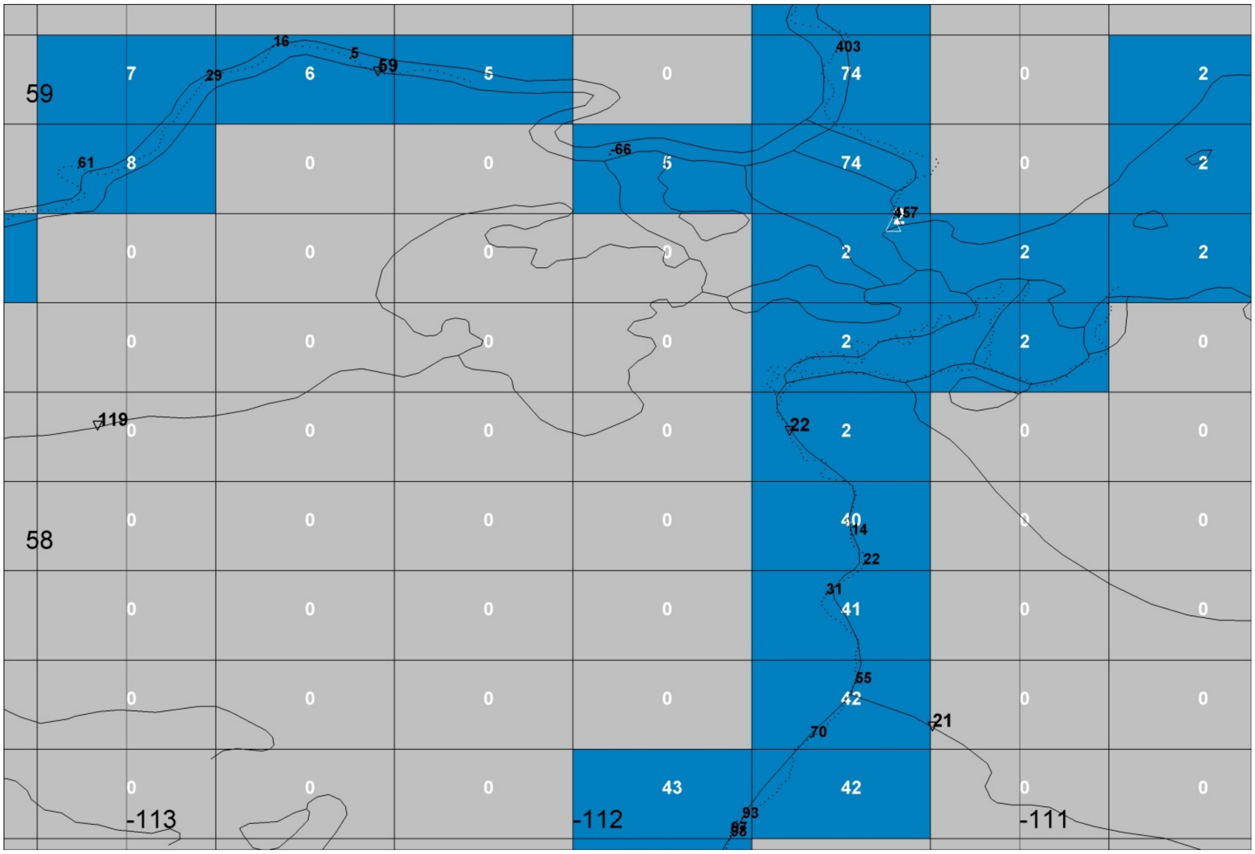

Figure 2 – WATFLOOD and MRBHM linking

WF computes the net inflow to Lake Athabasca – i.e. all the flow entering WF reach #2 plus precipitation on the lake and minus evaporation. This net lake inflow is written to the master inflow file for the MRBHM for node 21-457.

Similarly, all the flow computed into WF reach 40 is inflow for node 42-14, for WF reach 41 it goes to node 42-31 etc. WF reach 42 covers two WF grids because there is no MRBHM inflow node in the upstream WF grid. (MRBHM reach 42 is not to be confused with WF reach 42 – they just happen to be numbered the same in these two WF grids). Where two or more MRBHM nodes were located in one WF grid, the reach flow was added to the most downstream node, except if a major tributary was located nearer a more upstream node, in which case that upstream node was used.

Since the Firebag River is gauged, the flow as recorded at gauge # 21 (07DC001) is added to MRBHM node 42-55, along with any flow from the ungauged area contributing to WF reach 42. In other words, the flow at the WSC gauge is “nudged”. I.e. if there is recorded flow at the WSC gauge, it is transferred into WF reach 42. If there is missing data, the computed flow at gauge #21 is used instead.

MRBHM reach and node numbers increase upstream. Peace River node -66 in MRBHM reach 31 (at WF reach 5) is 66 km downstream of Peace Point gauge # 59 at node 32-0/31-0 (where MRBHM reaches 31 and 32 join, at WF reach 6). The negative node number indicates it is 66 km downstream of node 32_0 at Peace Point.

2.2 WATFLOOD model update to lat-long coordinates

The new WF setup is in lat–long. The previous 2009/2010 setup was in Polar Stereographic and dated back to the late 1990's. Since then, GK has been greatly enhanced and comes with maps in lat-long. Although GK has the facility to convert between various coordinate systems, it is a constant annoyance to be required to do this. Also, all the WSC and meteorological data is georeferenced in lat-long. GK is a pre and post processor for WF/CHARM and can be downloaded from:
http://www.nrc-cnrc.gc.ca/eng/solutions/advisory/green_kenue/download_green_kenue.html

2.3 WATFLOOD Basics

Some of what follows is repeated from the 2010 report.

WF is a hydrological modelling system comprised of several individual program components:

BSN*.exe	Converts basic observed watershed data like point elevations and distance to slope etc.
MOIST*.exe	Converts point initial soil moisture to gridded values
SNW*.exe	Converts point snow course snow water equivalent (swe) to gridded swe.
RAGMET*.exe	Converts point precip. data to gridded precip.
TMP*.exe	Converts point temperature data to gridded temperature and also calculates the daily difference between the max & min temperatures.
CHARM*.exe	The hydrological model called Canadian Hydrological And Routing Model (CHARM) in WF
	* refers to various modes: 64x & 32x for speed mode in 64 and 32 bit environments; 64d & 32d for debug mode in 64 & 32 bit environments.

There are other useful programs to convert the various formatted data from data providers but these are often custom for various WF users.

CHARM is a gridded hydrological and routing model. The main processes consist of the Hargreaves and Samani[2] evapotranspiration model or its updated 1985 version[3], Green-Ampt infiltration[4], Anderson[5] snow model, and hydraulic routing for streams, lakes and reservoirs. Glacier melt is a simple model which assumes an infinite source of ice and a melt factor multiplier is used due to the higher albedo for bare ice as compared to snow. Complete details of the model are found in the WF manual (http://www.watflood.ca).

The main input files for the CHARM model are a watershed file (shd), a parameter file (par), gridded precipitation (met) and temperature (tem) files. All files for the MRB WF model are provided on a separate DVD disk. Observed stream flow data is ingested by the model and becomes output along with computed values for easy plotting and the on-the-fly calculation of various statistics that are used by the Dynamically Dimensioned Search (DDS)[6] optimization algorithm. Recorded streamflow at the beginning of a simulation is required to properly initialize the water storages in channels, lakes and ground water. Although WF will execute without initial streamflow, the program will require a spin up time to initialize flows based on computed grid outflows.

If streamflow data is supplied to the WF model, the computed flows at a gauged location can be replaced by the observed flows simply be setting a flag in the EVENT file. There is a special input file called **nudge_flag.xyz** where the flags can be set for each flow station. Similarly, reservoir releases can be read and releases added to the river system at the appropriate locations. Natural lakes can be coded to allow storage-discharge routing through lakes.

The replacement of computed flows by observed flows at gauge sites (nudging) allows the best possible blend of observed flows and computed flows from ungauged watersheds. The observed and computed flows are routed together with the effect of one on the other being automatically incorporated.

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[2] Hargraeves, G.H., and Z.A. Samani. 1982. Estimating potential evapotranspiration. ASCE, J. Irrigation and Drainage Division, 108(3): 225-230.

[3] Hargreaves, G. L., Hargreaves, G. H., and Riley, J. P. , 1985. ‘‘Irrigation water requirements for Senegal River Basin.’’ J. Irrig. Drain. Eng., 111~3, 265–275.

[4] Green, W.H., and G.A. Ampt. 1911. Studies in soil physics. 1: Flow of air and water through soils. J. Agricultural Research, 4: 1-24.

[5] Anderson, E.A. 1973. National Weather Service River Forecast System-Snow Accumulation and Ablation Model. National Oceanographic and Atmospheric Administration, Silver Springs, Tech. Memo NWS_HYDRO-17.[5]

[6] Tolson, B.A., and C.A. Shoemaker. 2007. Dynamically Dimensioned Search Algorithm for Computationally Efficient Watershed Model Calibration. Water Resources Research, 43(1).

2.4 WATFLOOD™ model setup for the MRBHM

A WF setup for the MRBHM is different from a regular setup only in that the extra reaches for the MRBHM need to be coded into the **shd** and **rel** files and the **nudgeflg** in the **event.evt** file needs to be set = 1 in order to use the **nudge_flag.xyz** file. In this configuration, the reach WF inflows are written to the master inflow file instead of being routed within the WF model.

Originally, the WF model setup was applied to the Mackenzie GEWEX project[7]. A program called MAPMAKER was used to convert a DEM and Land cover map to a MAP file for WF. Next, a program called BSN was executed to convert map data in to the model's watershed data file. The grid size is 20 km and a total of 4791 cells made up the entire Mackenzie River watershed above Tsiigehtchic (Arctic Red River). Nine modeling units representing nine different land cover classes (barren, coniferous forest, mixed-deciduous, crops, glacier, bogs, fens, water and impervious) were employed. This method of modeling is called the Grouped Response Unit (GRU) method. The GRU is the basic modeling unit. Within each grid, water is routed from each GRU to the grid outlet. Next, water is routed from grid to grid following the river system.

For the current project, new WF watershed files were created in the lat-long coordinate system based on Canada 3D 30 arc-second DEM. Canada3D is a digital elevation model (DEM) produced by the Canadian Forestry Service, Ontario region. The DEM consists of an ordered array of ground elevations providing coverage of the entire Canadian landmass. It has been derived from the cells of the Canadian Digital Elevation Data (CDED) at the 1:250 000 scale. The elevation values are expressed in metres with respect to mean sea level (MSL), in accordance with the North American Datum of 1983 (NAD83). This product is no longer supported. The land cover data is the CCRS Northern Land Cover database[8] which is now available through Geobase http://www.geobase.ca. This land cover map has been problematic in that the land cover classification is not consistent between provinces. It has led to problems in this project as described below. This time, 15 land cover classes were used.

CHARM has its own internal routing scheme as noted above and is capable of independently calculating flows at all points along the above mentioned reaches. This allows CHARM parameters to be adjusted to obtain a good fit between computed and observed flows before flows are exported for use in the MRBHM.

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7 Soulis ED, Seglenieks F 2007. The MAGS integrated modeling system. In Cold Regions Atmospheric and Hydrologic Studies: the Mackenzie GEWEX Experience, Hydrologic Processes, vol. 2, Woo MK (ed). Springer-Verlag: Berlin Heidelberg; 445-474.

8 http://cmnmaps.ca/Metadata/Documents/NTSWA/Land_cover/lcc2000v_csc2000v_082l_1_0_fgdc_en.html

In the current version of the CHARM, wetlands can be separated in to bog and fens. A ratio 20% fens and 80% bogs between the two is a value that is commonly accepted and found to be reasonable in the Fort Simpson area using an isotope model and this value is used throughout the Mackenzie river basin as well as generally on other WF watershed models. Fens are hydraulically coupled to the adjoining stream thus the possibility of two-way flow results in substantial damping of the hydrographs which in turn allows more realistic river roughness values to be used. It also provides a mechanism to evaporate large amounts of water as water can be fed into the fens both from ground water and the rivers.

However, the CHARM routing is a kinematic wave routing scheme and as such is incapable of accounting for backwater effects, flow reversals, rapids or multiple channels. For this reason CHARM was interfaced with the MRBHM, where CHARM produced the calibrated blended inflow for each of the MRBHM reaches (or nodes).

2.4.1 Modification of the WF model setup for natural conditions

To compute natural flows with the WF model, the only changes that are needed is to remove the water area of Williston Lake and to remove the nudging at Hudson Hope. This was accomplished by reducing the water area to 1 or 2 percent of the grid area depending on the length of the watercourse in each grid, and to add the area removed to the dominant land cover in each grid. This dominant land cover was open coniferous forest. Removing nudging at Hudson Hope is accomplished by changing the nudge flag for that station in the **nudge_flags.xyz** file in the working directory.

2.5 Model Calibration for the Mackenzie River

The calibration is a multi-step process. An initial watershed file is created and to save computational time, some land covers are combined to reduce the number of land cover classes which are treated individually in the model. Next, parameters are adjusted to give the best possible computed flows at all available gauged flow stations. This in itself can be done in several steps: first the optimization scheme can be set up to just adjust the parameters that affect volumes and so get the best possible volumetric fit. After this, the parameter affecting timing can be adjusted using for instance the Nash-Sutcliffe criteria, R^2 or RMS values. After this, usually the storage discharge coefficient for each lake is adjusted by trial and error to give the best possible hydrograph fit (timing only) at a downstream flow gauge (This is why some lakes upstream from flow gauges are coded as reaches and others are not – although all larger lakes are coded as reaches regardless).

At this point, it may become clear that certain combinations of land cover are not possible to combine without causing unacceptable errors on some watersheds. This is especially true for a watershed as large as the Mackenzie. A good example of this is the coniferous (open) class. Figure 3 clearly shows that for this class, the classification for this class is different in the data originating in Alberta. If the coniferous(dense) class is combined with the coniferous(open) class and shown together, the border discontinuity in the land cover class disappears but then the discontinuity appears in a map of the evapotranspiration, with large errors in the streamflow on the Athabasca (it having less weight in the optimization), which is also not acceptable. In the end, these land covers were modelled separately as the lesser of two evils.

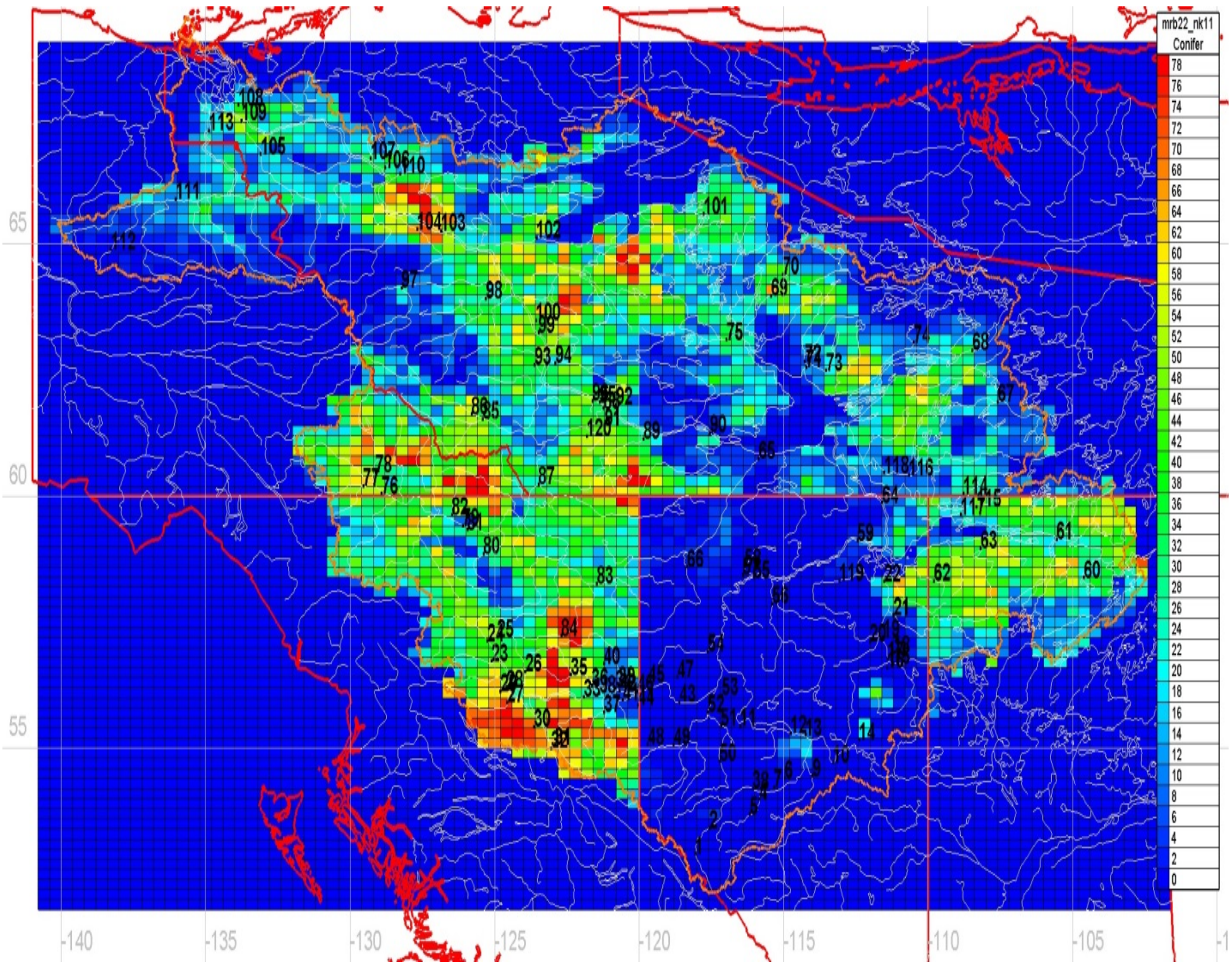


Figure 3 – conifer(open) discontinuity at the Alberta border

Problems remain in the calibration for some smaller watersheds but these problems were not addressed because they did not impact the generation of the flows in the master inflow file. The errors in the modelled flows are not reflected in the nudged (observed) flows for these problem watersheds. In the future, in order to make use of the Mackenzie watershed model for other purposes, more calibration and possibly the incorporation of another land cover dataset without these discontinuity problems may help improve the calibration for smaller sub-watersheds.

Ice is a major factor in shaping the hydrograph from freeze-up until the spring breakup. A degree-day scheme is incorporated in CHARM that simply reduced the flow a certain amount depending on –ve degree days. Degree days (-ve) were accumulated after October 1 of each year. For the breakup, the number of +ve degree days were accumulated after April 1. The degree-day relationship was already in the model from another application and appears to work well for the Mackenzie watershed. The details of the method are confidential but permission to incorporate it in the model has been obtained.

To make use of the ice correction factor, iceflg must be set to "y" in the event file.

2.6 Lake Athabasca Rules

A set of rules connecting the Lake Athabasca level and the discharge at Peace Point and Fitzgerald was provided by Ernst Kerkhoven of the Alberta Energy Regulator, Alberta Government[9]. Dr. Kerkhoven developed these rules during his earlier employment with Alberta Environment as a hydrologist:

```
Q_out = c * k *[abs(Z_LA – Z_P)]^n * [max(Z_1, Z_P, Z_LA) –
Z_1]^m

Where,

Z_P = (Q_PP/Q_ref)^a + Z_2

k = -1 when  Z_P > Z_LA
k = +1 when Z_P <= Z_LA

Z_LA = elevation of Lake Athabasca (m)
Q_PP = Peace River flow at Peace Point (m3/s)
Q_out = outflow from Lake Athabasca (m3/s)

a, c, n, m, Z_1, Z_2, and Q_ref are calibrated parameters:

a = 1.887
c = 143.719 (natural condition) or 199.219 (weir)
n = 1.269
m = 0.4290
Z_1 = 200.000 m (natural condition) or 206.964 m (weir)
Z_2 = 204.126 m
Q_ref = 3123 m3/s
```

These rules were coded into the lake routing routine in CHARM and used for all simulations in this report. Upon review of this report, a more recent calibration was received. Please see Appendix F.

[9] Personal communication, March 7, 2016

3 WATFLOOD/CHARM Model results

For this project, the emphasis is on producing the inflows from un-gauged areas to the Athabasca, Peace, Slave and Mackenzie rivers for the MRBHM. As such, the emphasis was to match as closely as possible the flow volumes observed at various WSC stations located along these rivers. Thus the goodness of fit of the computed hydrographs for the head waters for gauged rivers was not of great importance although the better this calibration, the more confidence can be had in the contributions from the ungauged areas.

A calibration was completed on March 30, 2016 but the problem with the discontinuity in the land cover map could not be resolved without a realignment of land cover classes. With this calibration, flow volumes and the value of the Nash – Sutcliffe efficiencies were quite good and based on experience elsewhere, the fit was probably as good as could be expected with little improvement in the statistics for the main rivers likely with further calibration. However, many problems remain in smaller sub-catchments where much improvement is possible with a re-jigging of the land cover classes, or more likely, a better land cover map that does not exhibit the discontinuities found in the one used for the project. Fortunately, such local problems tended to average out resulting in good results in the larger tributaries.

Another calibration was not undertaken because of the required delivery of the MRB_MASTER_INFLOWS.tb0 file to Amec Foster Wheeler for use with the MRBHM at about this point in time. A calibration run requires approximately three weeks so the schedule did not permit this. However, as stated above and as shown in the results below, it would appear that any improvements that can be gained for the purpose of the MRBHM are at best marginal.

The calibration period is from 2000 – 2006 and all available flow data in this period was used. Each station was weighted equally by using the mean flow as a weighting function. In other words, a small sub-watershed such as the Athabasca above Jasper had the same weight in the objective function as the station at Arctic Red River.

3.1 Computed versus Observed Hydrographs.

While statistics are useful to numerically rank various modelling results objectively, they do not give an impression of how well a model is performing or what might be the problem(s) causing a poor statistic. To obtain a good impression of the modelling results, a time series comparison of the modelled hydrographs to those observed have great value. Thus 12 graphs follow to make allow a visual evaluation.

For each flow station on the main rivers (those reaches covered by the MRBHM) two sets of hydrographs are shown for a validation period 2007 – 2015. For each station, the first set is for un-nudged flows while the second is for nudged flows. The nudged flows show the degree to which the computed flows are corrected by the observed flows at each of the WSC gauges on rivers that contribute to the main rivers, namely the Athabasca below Windfall, the Peace below

Hudson Hope, the Slave River and the Mackenzie River. No nudging is done on these main rivers.

Figure 4a shows the comparison of the computed WF flows to the observed flows for the Athabasca River. Figure 4b is with the observed flows inserted for all Athabasca River tributary stations (i.e. nudged). As shown by the difference between Figs. 4a and 4b, the WF model with nudged flows shows a notable improvement of the computed flows along the Athabasca River.

The improvement is visually noticeable and also shown by the two main statistics volumetric error Dv in % and the Nash-Sutcliffe efficiency e. <u>These statistics (and for all other plots) are for total 1960 – 2015 simulation,</u> not for just the 2007 – 2015 period shown. Only the last nine years are shown to make the hydrograph details more visible. By inference, this should give the necessary confidence that the computed inflow to the Athabasca River from the ungauged contributing area is realistic.

At two upstream locations, namely Windfall on the Athabasca and Hudson Hope on the Peace, the observed hydrographs are shaded. This is to indicate that at these locations the river flows on the model are nudged. Although the computed flows are shown, it is the observed flows that are routed downstream at these locations.

The same reasoning holds for the Peace River (Figs. 5 and 6), and the Slave and Mackenzie Rivers (Figs. 7, 8 and 9). For all main river stations, the volumetric errors are all within the normally accepted range of streamflow gauging errors, with the largest error for the Mackenzie at Norman Wells at 5.51%

For all gauged flows, the last two or three years were provisional flows. For some locations it is noticeable that the last two or three years the computed/observed fit is not as good as for the HYDAT data, likely due to the lack of quality control on the data.

Upon completion of the calibration, a special version of CHARM was executed with reach inflows written to **mrb_master_inflows.tb0** file and not routed by CHARM down the Athabasca, Peace, Slave and Mackenzie rivers.

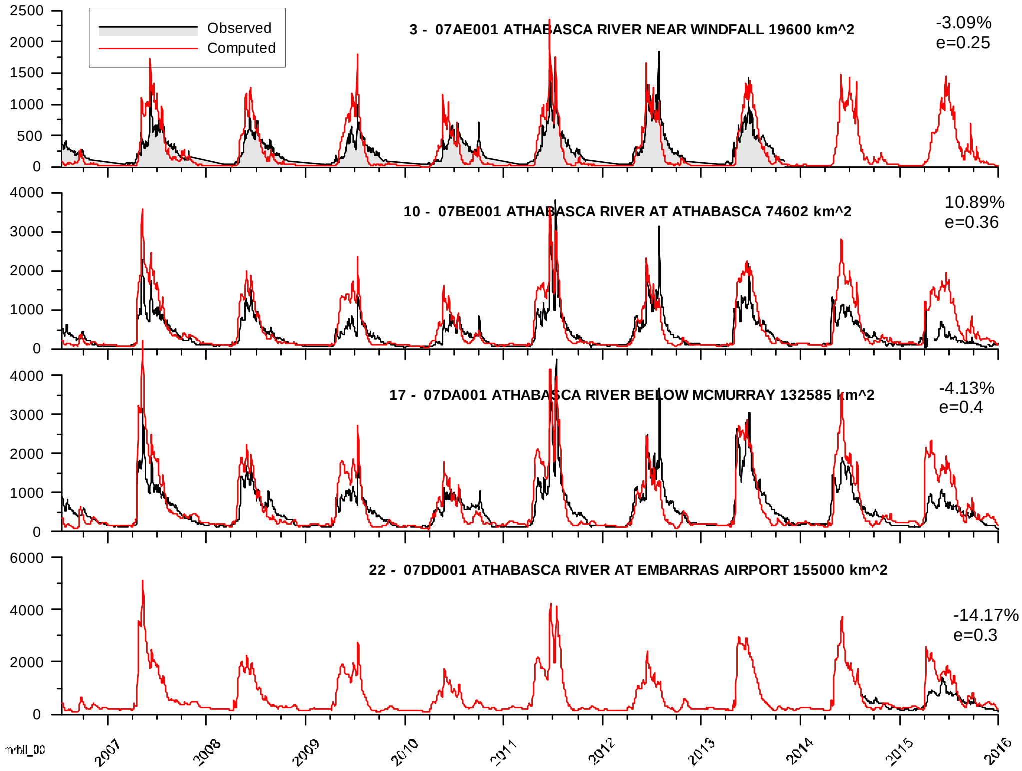


Figure 4a – Athabasca River computed and observed flows – not nudged

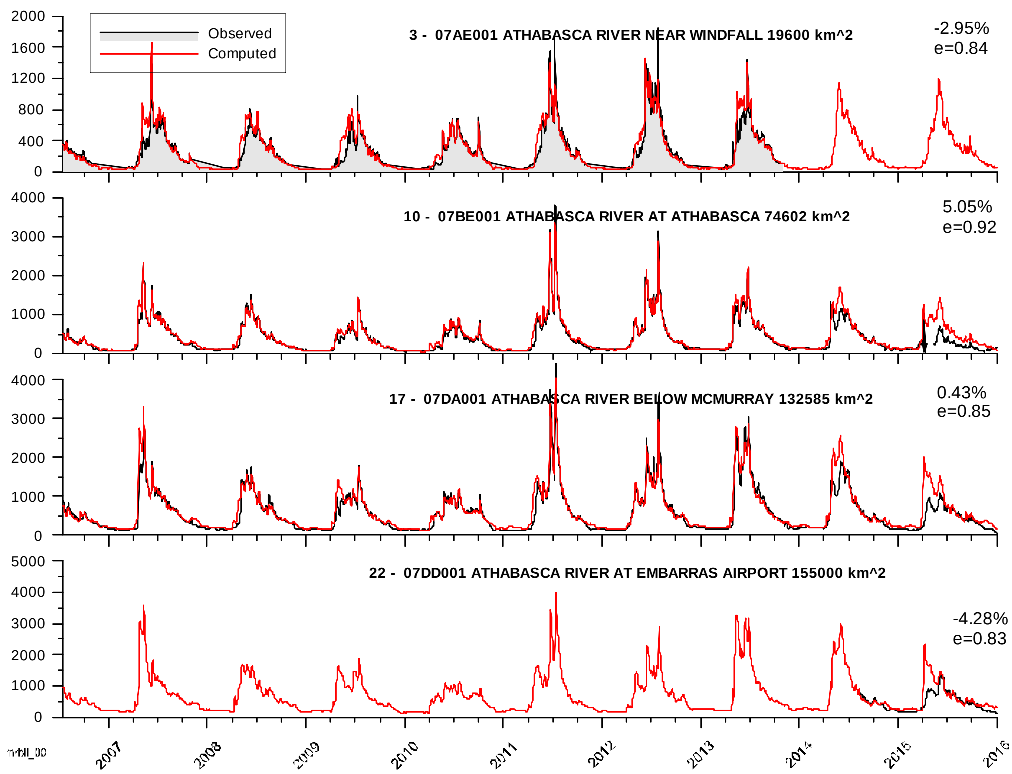


Figure 4b – Athabasca River computed and observed flows – nudged

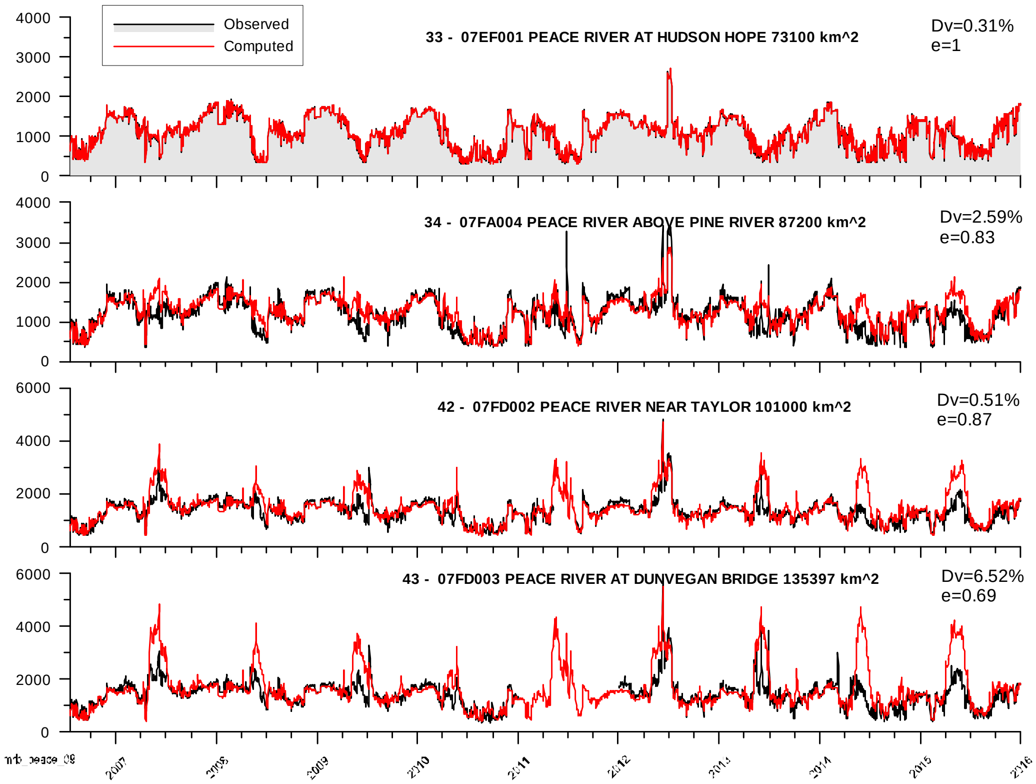


Figure 5a – Peace River computed and observed flows – nudged

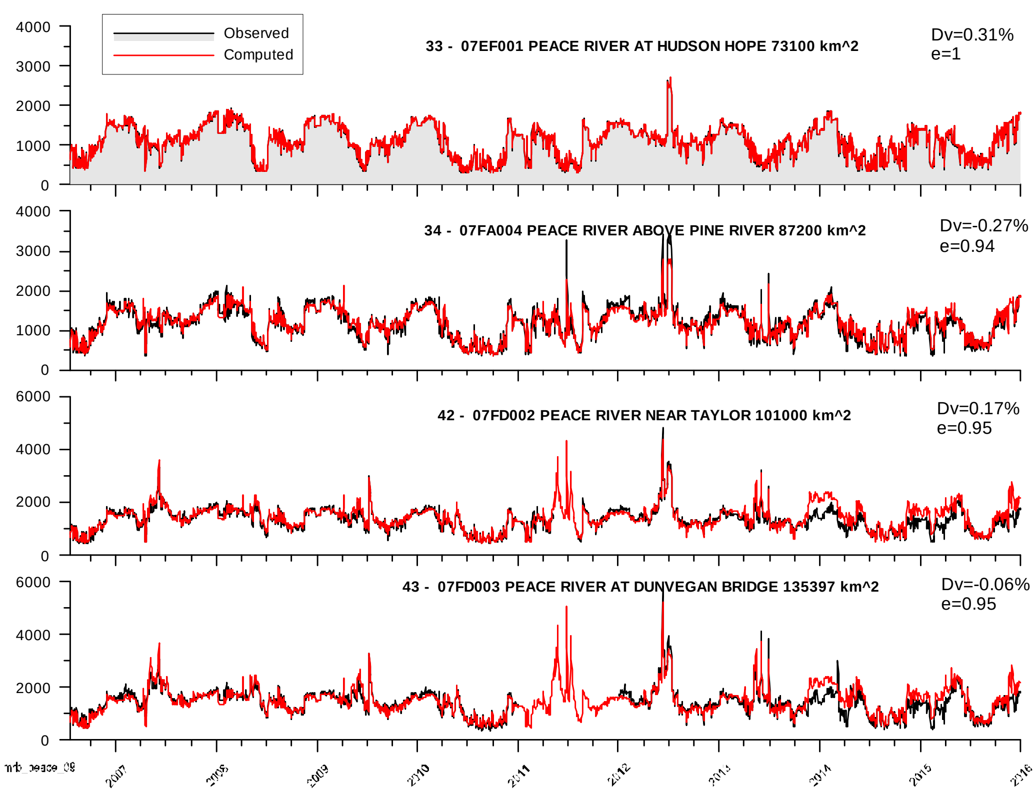


Figure 5b – Peace River computed and observed flows – nudged

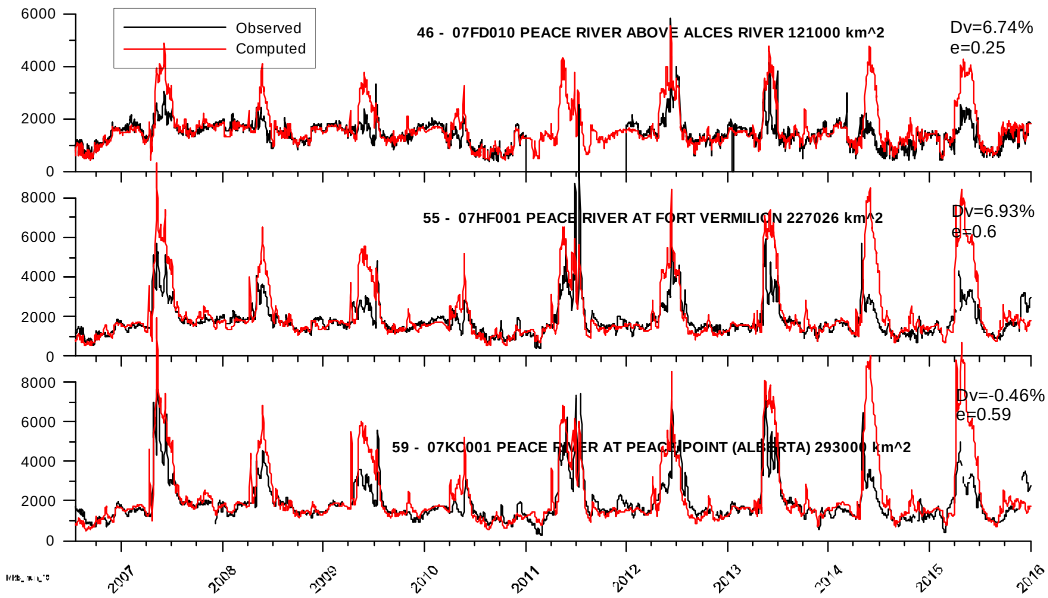


Figure 6a – Peace River computed and observed flows – NOT nudged

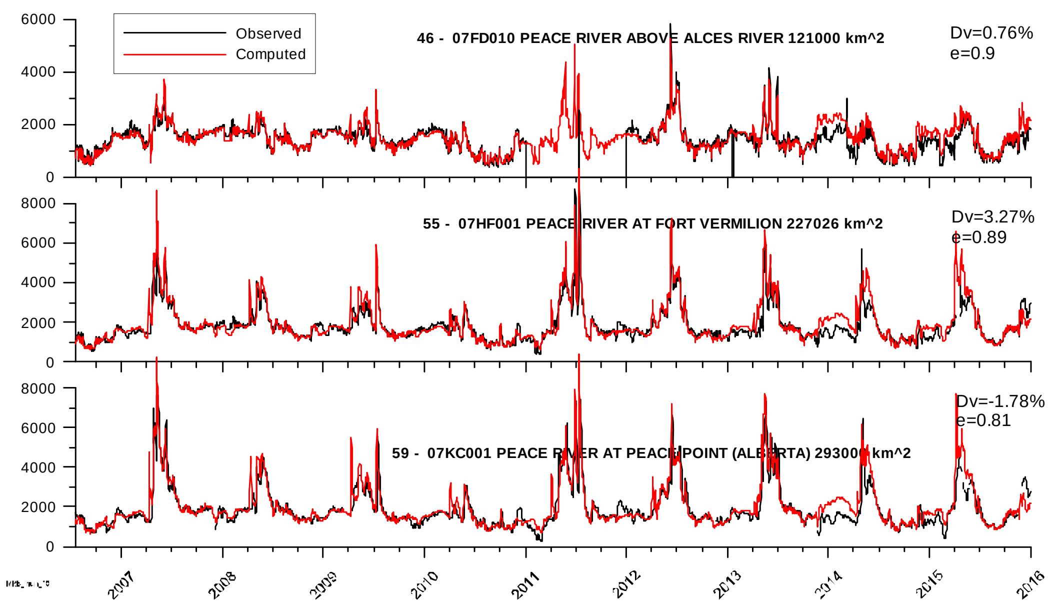


Figure 6b – Peace River computed and observed flows – nudged

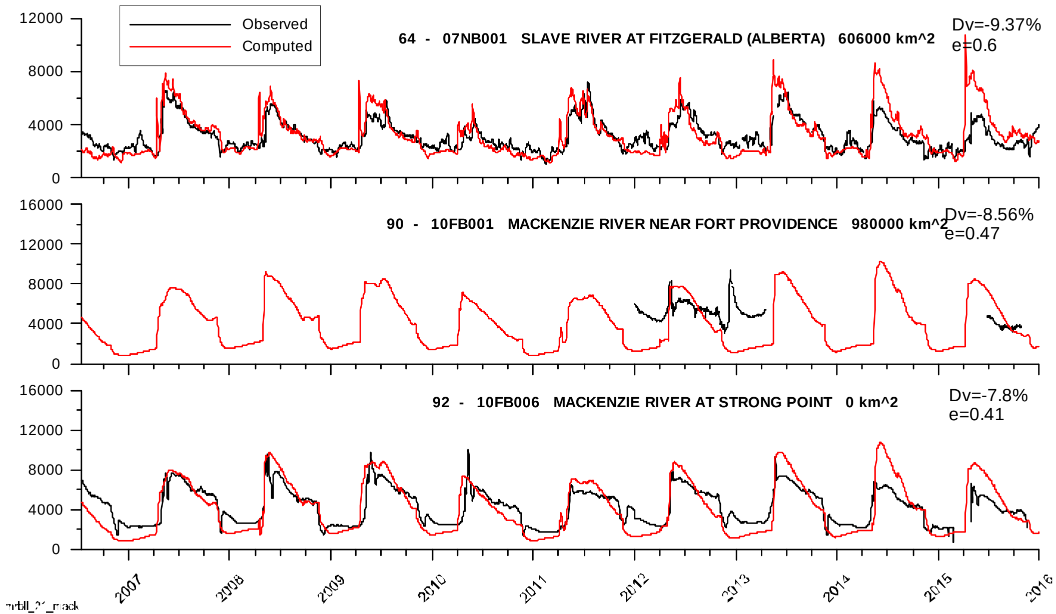


Figure 7a – Slave/Mackenzie Rivers computed and observed flows – NOT nudged

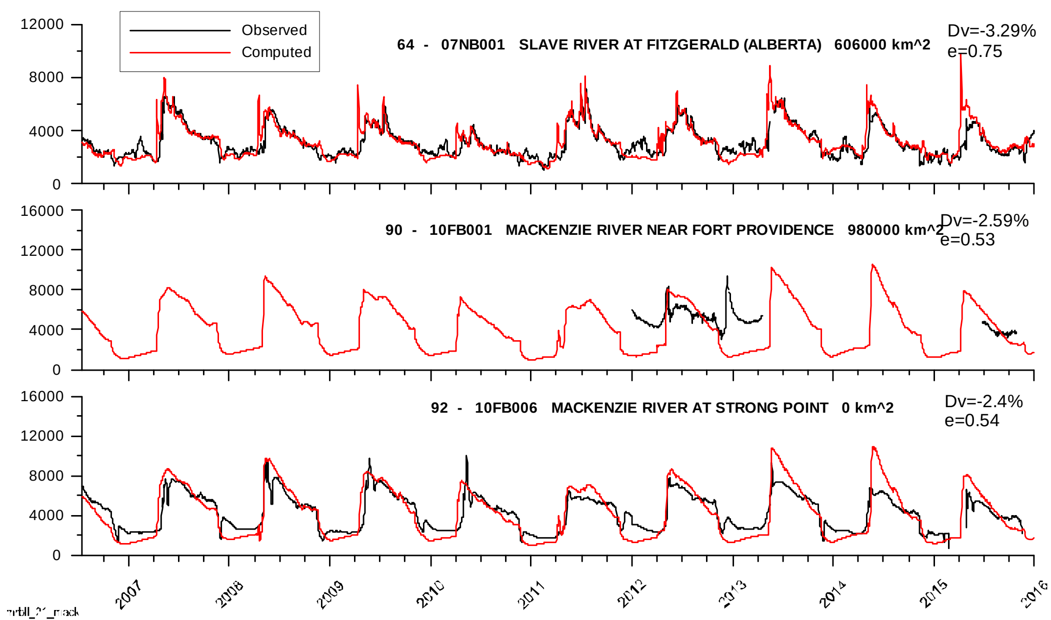


Figure 7b – Slave/Mackenzie Rivers computed and observed flows – nudged

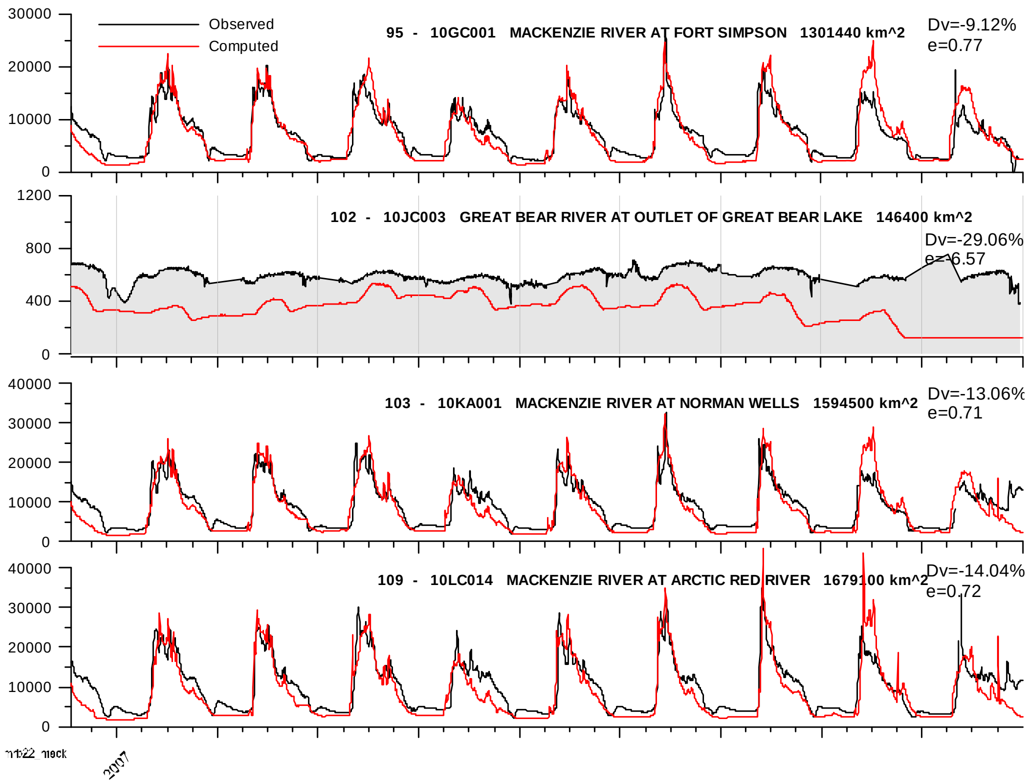


Figure 8a – Mackenzie River computed and observed flows – NOT nudged

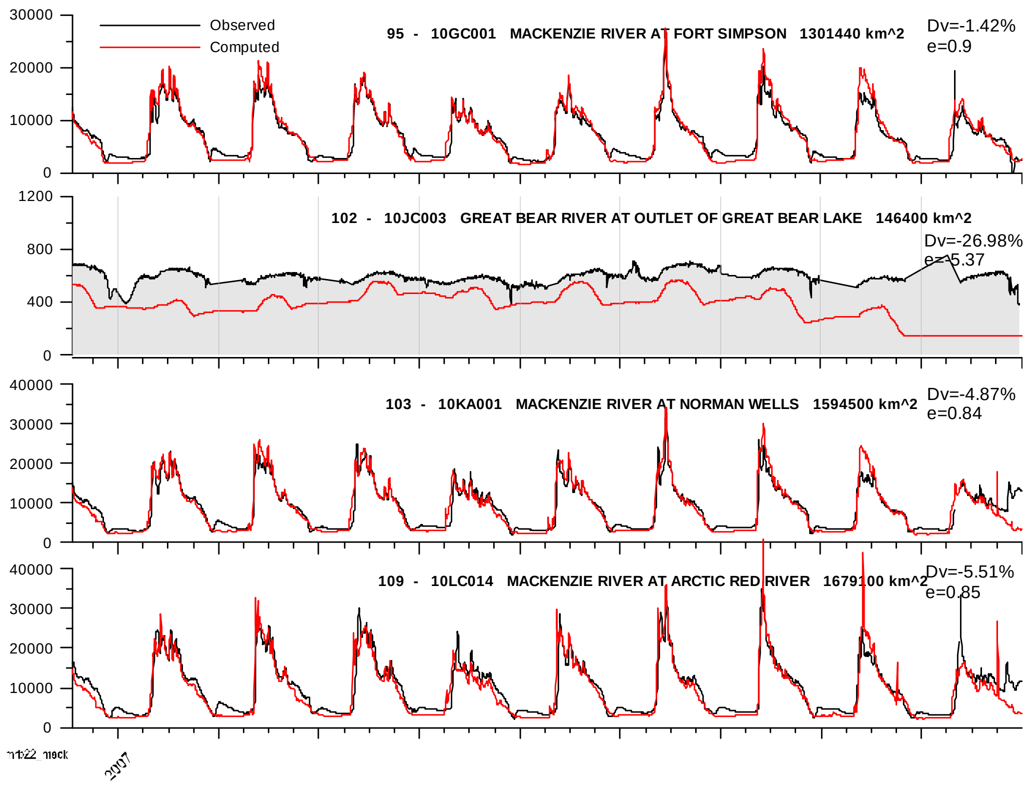


Figure 8b – Mackenzie River computed and observed flows – nudged

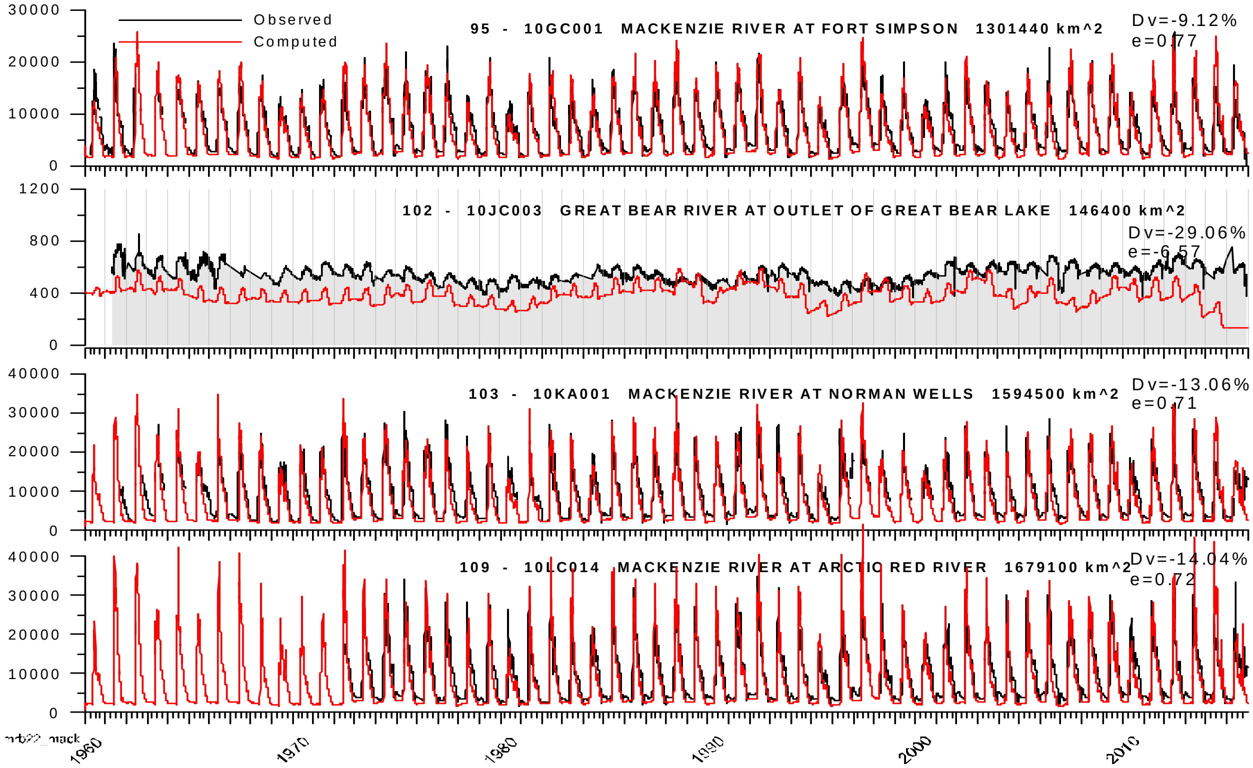


Figure 9a – Mackenzie River computed and observed flows – NOT nudged

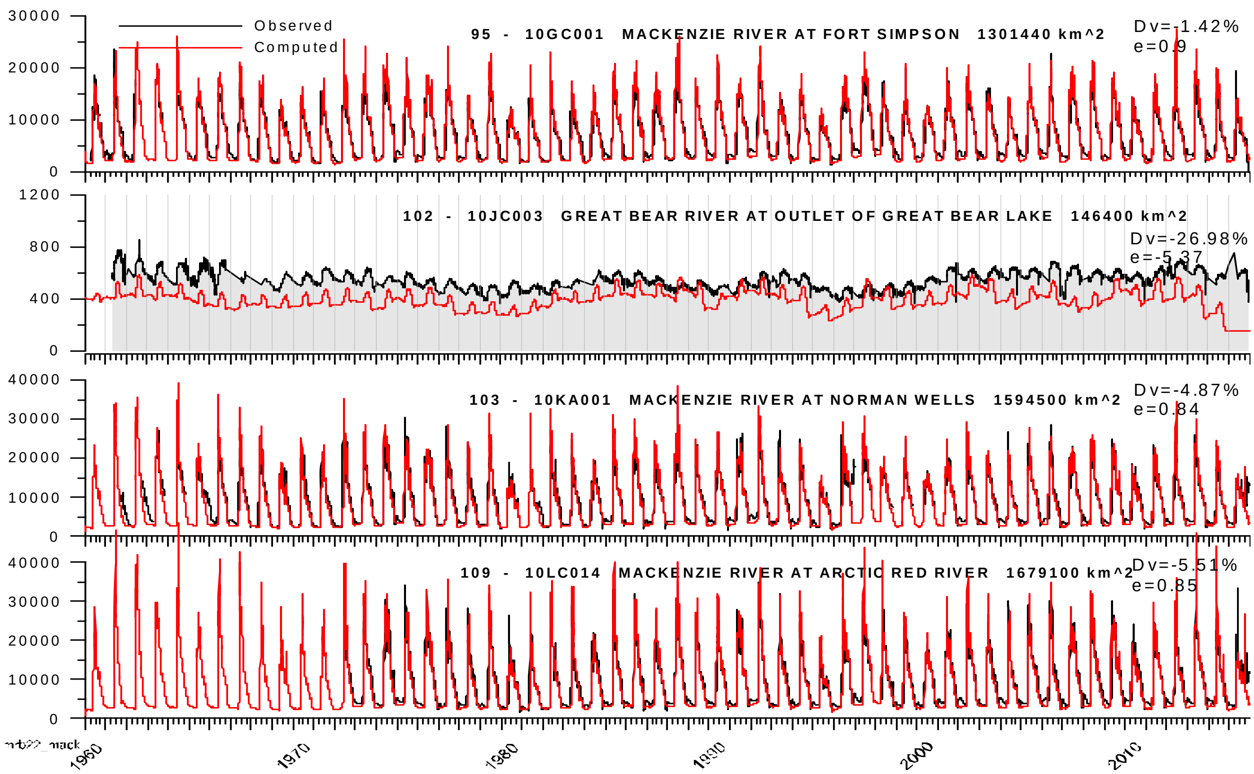


Figure 9b – Mackenzie River computed and observed flows – nudged

3.2 Computed versus Observed Mean Annual Flows

When comparing computed to observed flows there will always be differences simply because the correlation between the precipitation at two points over the distances between meteorological stations is simply not very good. Figure 10 compares the annual precipitation at Norman Wells to nearby (relatively speaking) Watson Lake in **black**. The distance between these stations (~600 km) is typical of the station spacing in the Mackenzie River watershed. The scatter in this plot is astonishingly large. Then it has to be considered that monthly and especially daily variations are even larger.

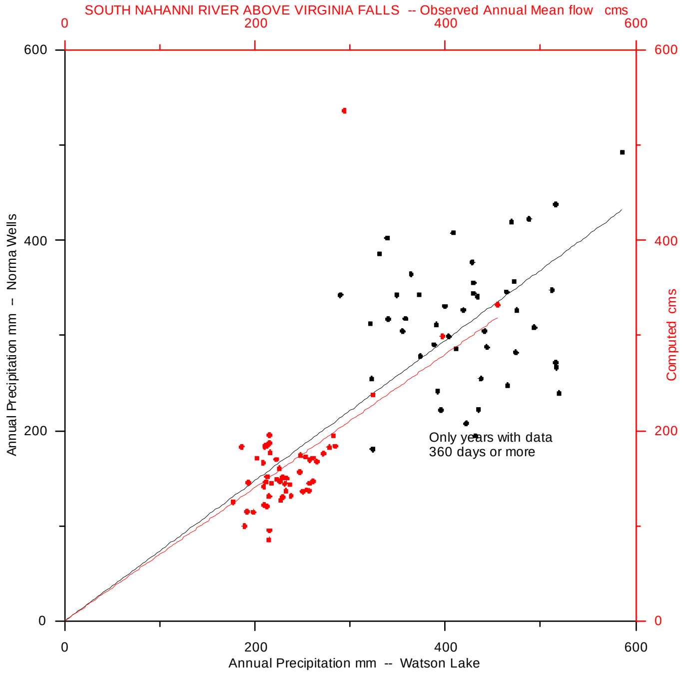


Figure 10 – A comparison of the annual precipitation for Norman Wells and Watson Lake

The South Nahanni River above Virginia Falls lies in-between these two precipitation stations. Interestingly, for this case the scatter in the mean annual flows is less than that of the precipitation data but this is likely due to having more than just these two precipitation stations affecting this watershed. Thus the errors of the precipitation are averaged out for this sub-watershed. In other studies, the flow errors were found to be of the same order as the precipitation differences between stations.

Given this amount of scatter, it cannot be expected that for watersheds in the intervening area, modelled flows would be very accurate, although over the long term, interpolation errors in the precipitation will average out. <u>Thus the best that can be hoped for is that there is no more scatter in the computed versus observed flows and there is no bias when the annual computed runoff is plotted against the annual observed runoff.</u> For the South Nahanni River above Virginia Falls, the scatter is surprisingly low but the mean annual flows are under-estimated.

Similarly, Fig. 11 shows a comparison for the mean annual precipitation at Hay River and Yellowknife. Here the distance is only ~200 km. Slightly less scatter between these two locations is evident. These two stations are on opposite sides of GSL. The precipitation on the lake is thus interpolated with these data and the implications on the correctness of any given amount of precipitation on the lake is completely unknown – although in the long run, it is likely to average out.

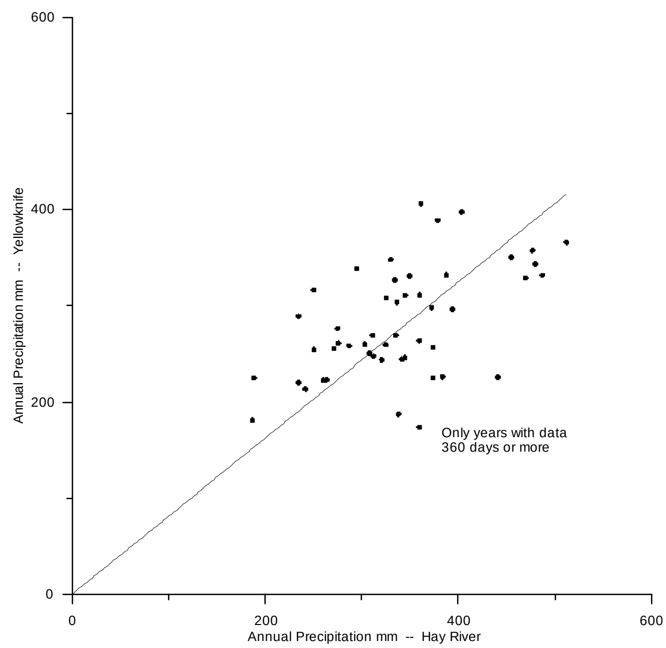


Figure 11 – A comparison of the annual precipitation for Yellowknife and Hay River

Figures 12a,b, 13a,b and 14a,b show pairs of observed versus computed for each of the Athabasca, Peace and Mackenzie rivers respectively, with the (a) plots for un-nudged and the (b) plots for nudged routing.. Each pair shows an improvement in the correlation of these data for the reaches modelled by the MRBHM when the flows are nudged. For un-nudged flows at these stations there is some bias for some of the streamflow stations. These plots show how well the computed annual flows that are fed to the MRBHM are correlated to the observed flows.

3.3 Modelling Summary

As noted above, the emphasis was on providing the best possible inflow estimates from the ungauged areas contributing to the Athabasca, Peace, Slave and Mackenzie Rivers. Obviously, the fit is not perfect but for the most part, with in the margin of error of streamflow measurement. However, with 20-20 hindsight at the conclusion of the project, it would appear that the errors can be reduced by carrying out a calibration with the flows nudged for the tributaries and the objective function based on only those stations within the MRBHM domain.

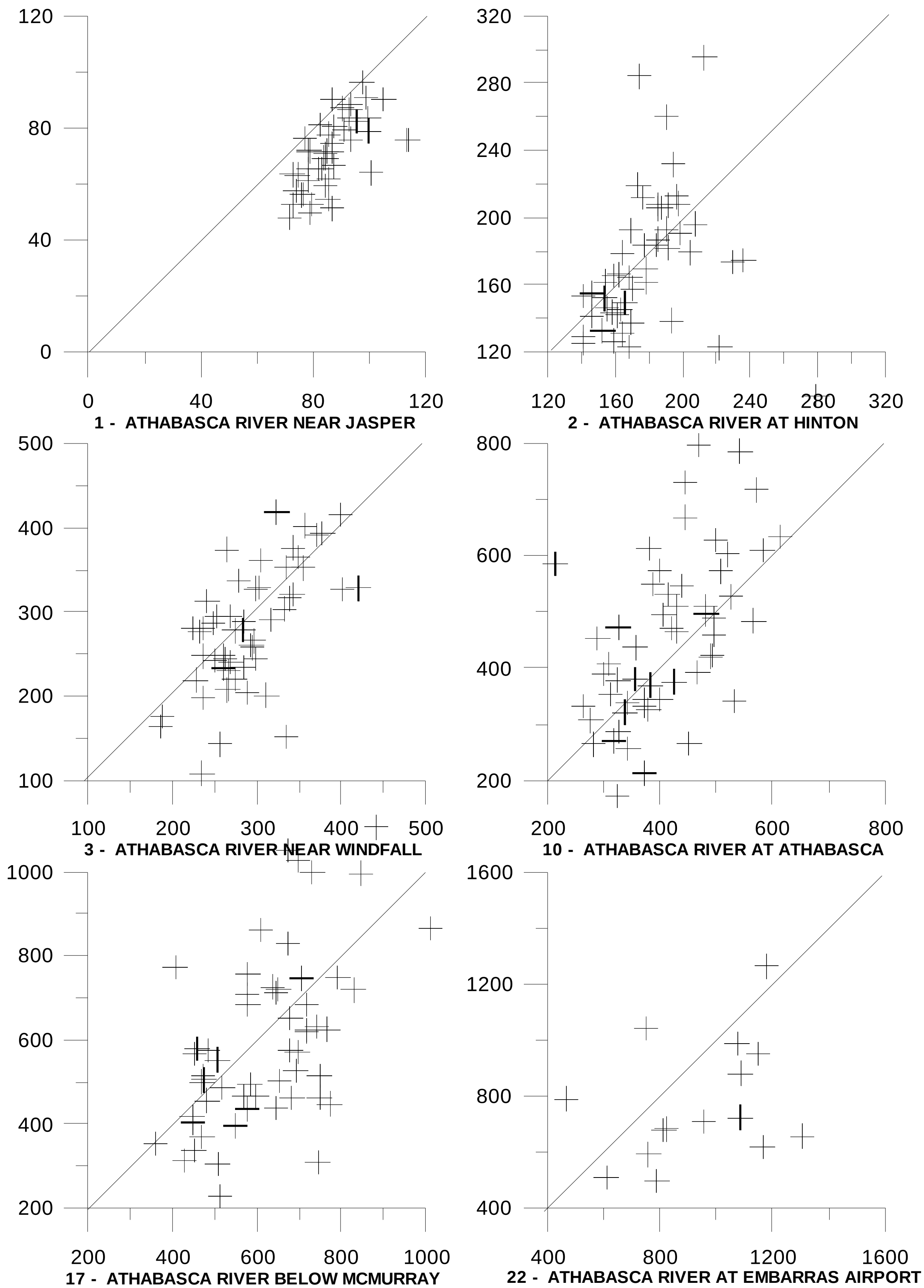


Figure 12a – Mean annual flow - Observed (x) versus Computed (y)

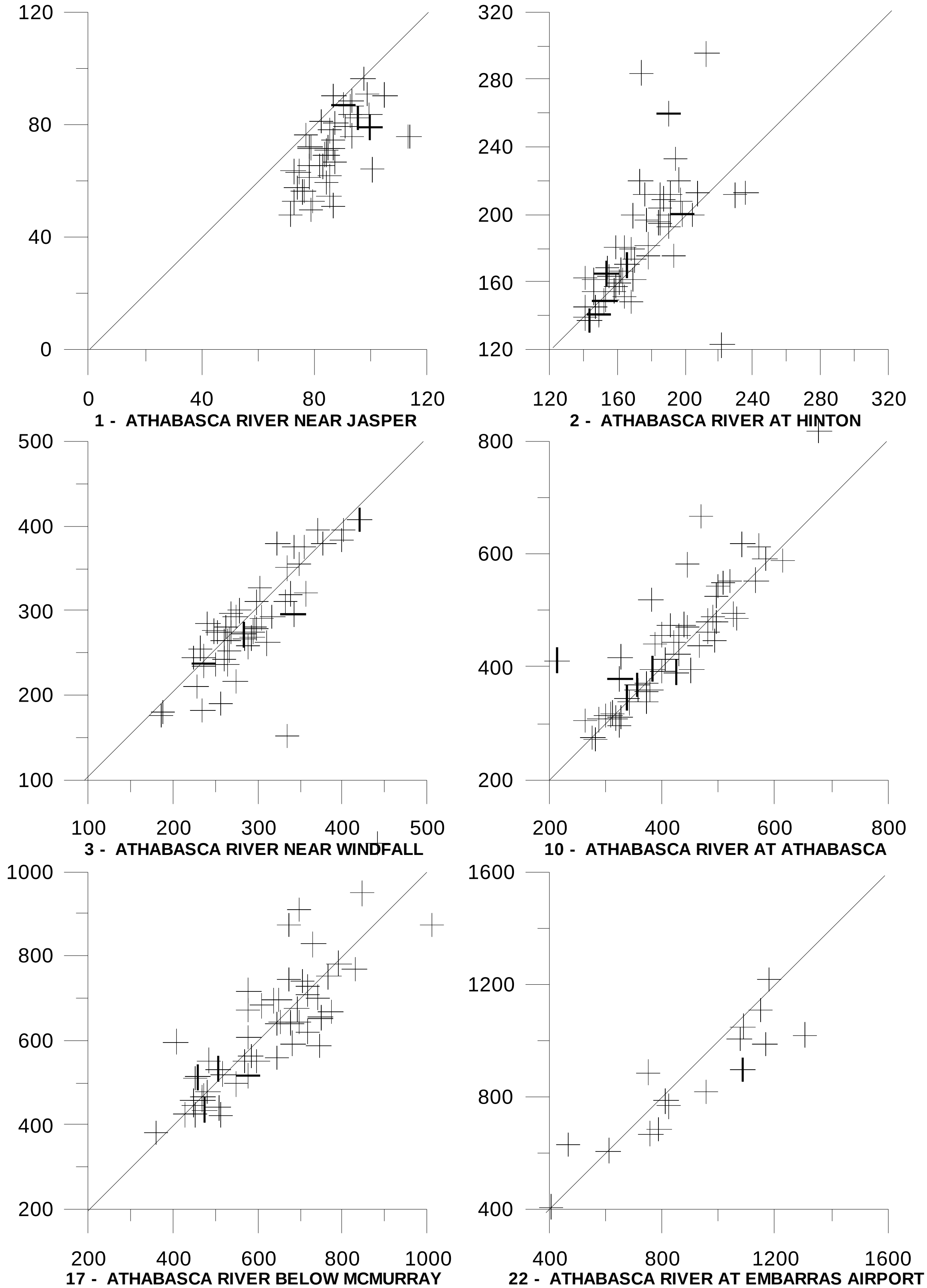


Figure 12b – Mean annual flow - Observed (x) versus Computed (y) - Nudged

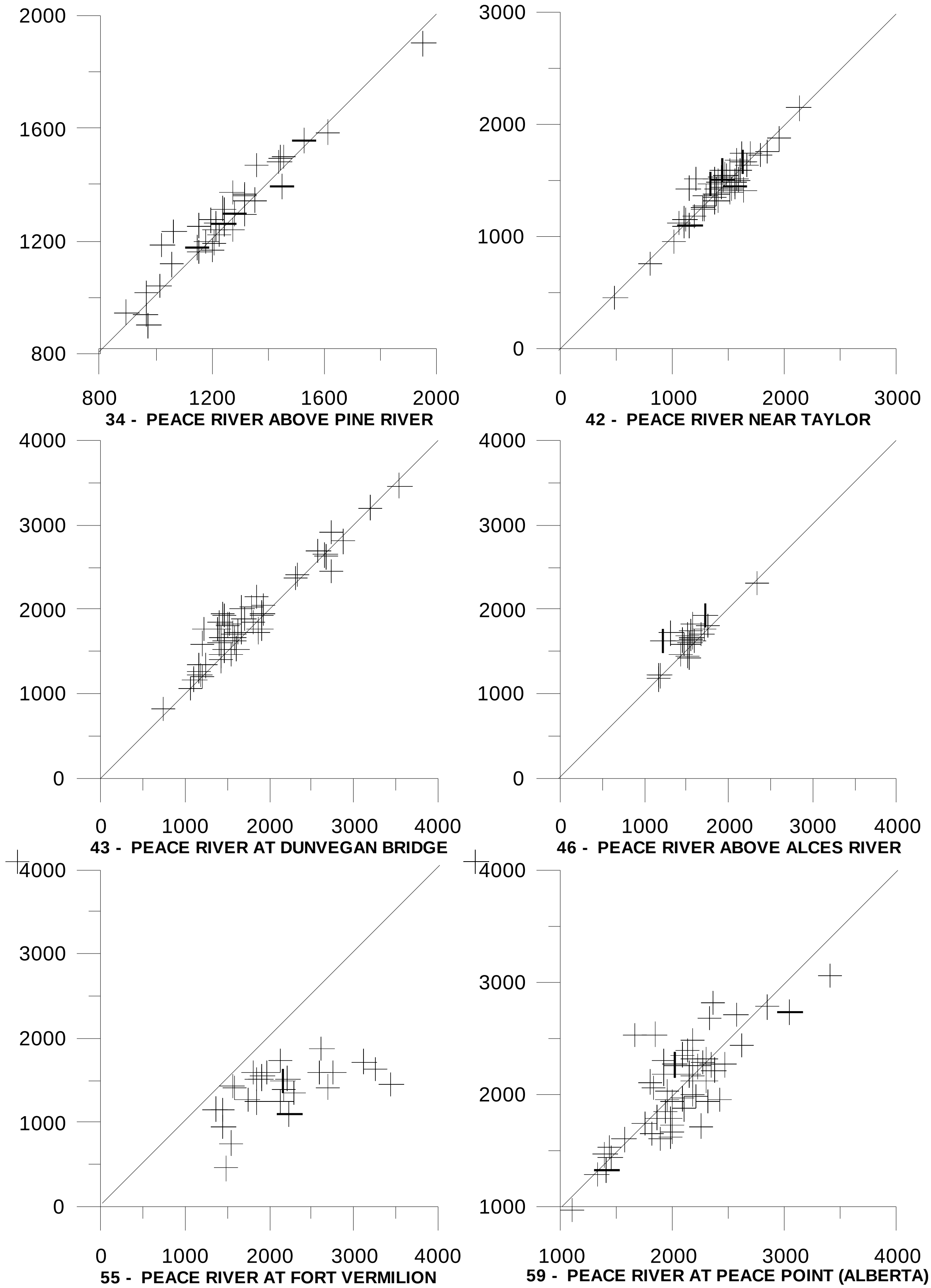


Figure 13a – Mean annual flow - Observed (x) versus Computed (y)

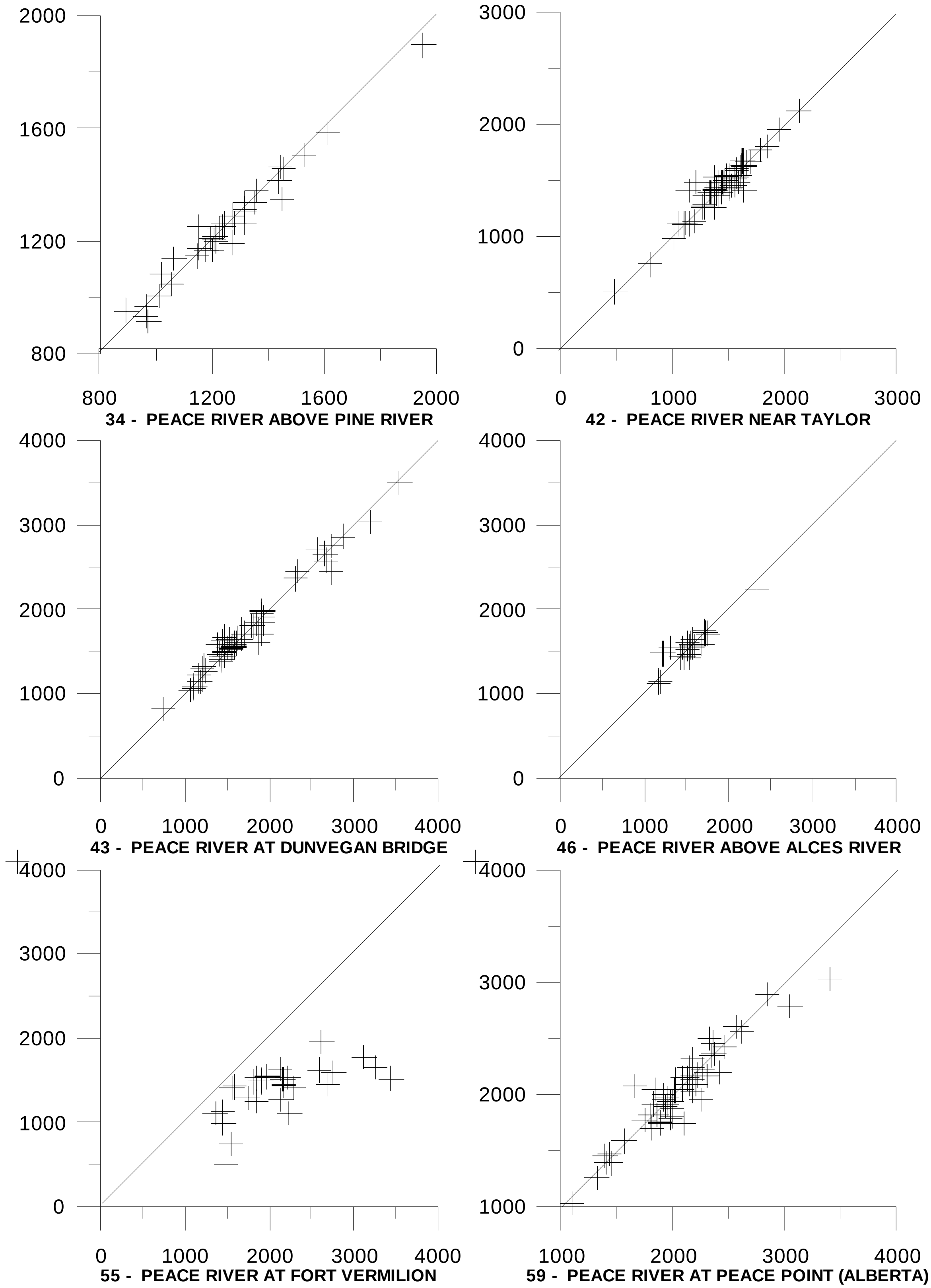


Figure 13b – Mean annual flow – Observed (x) versus Computed (y) - Nudged

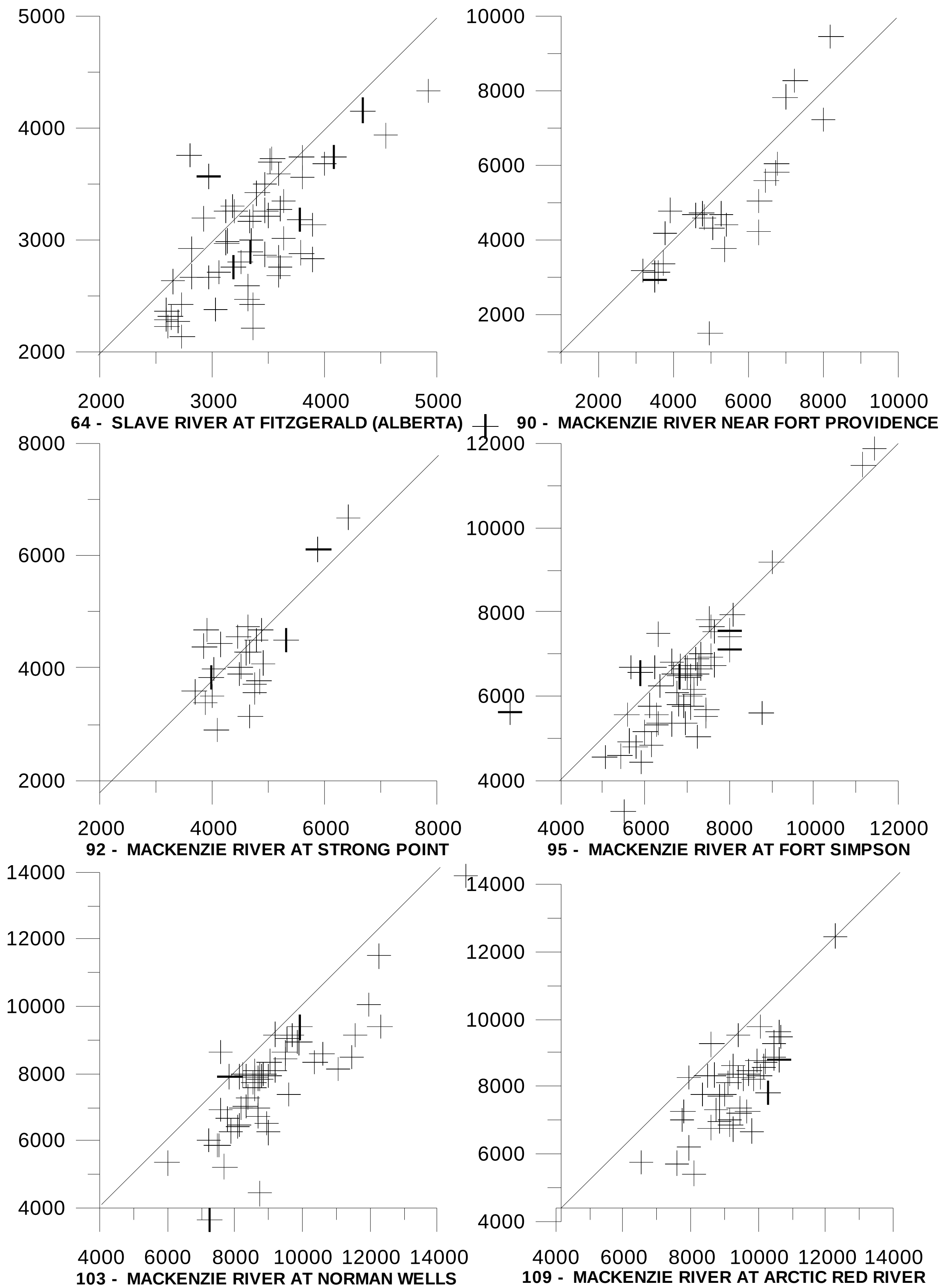


Figure 14a – Mean annual flow - Observed (x) versus Computed (y)

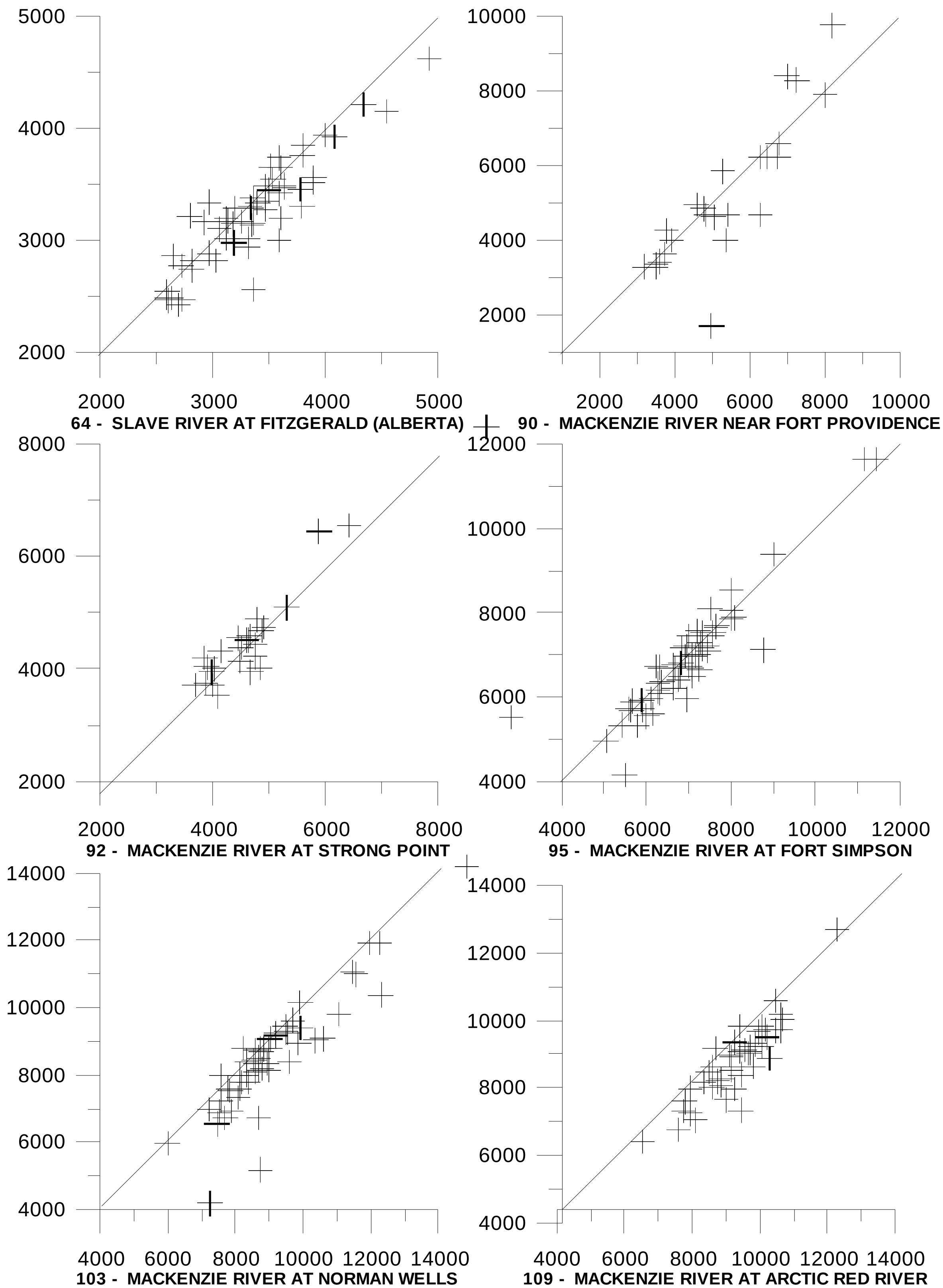


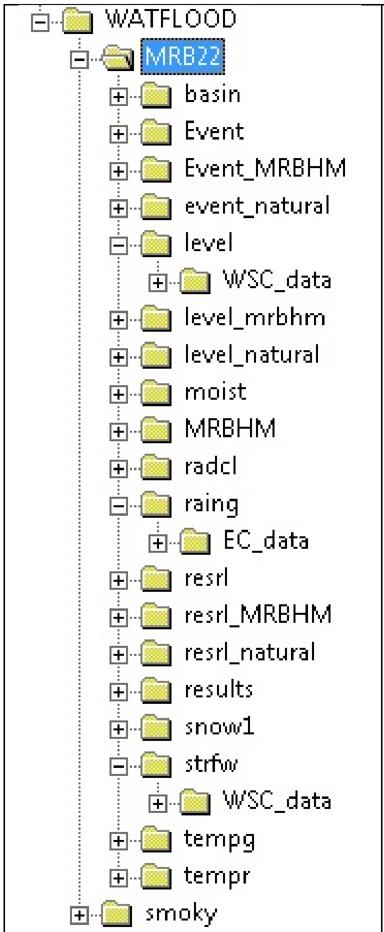
Figure 14b – Mean annual flow - Observed (x) versus Computed (y) – Nudged

4 Updating WATFLOOD

To update WF for additional years of data, two sets of data are required: the meteorological data from Environment Canada and the streamflow data from the Water Survey of Canada.

The process of updating the meteorological and discharge records is described in detail in a separate "Supplementary Utilities Manual" to WF/CHARM which can be downloaded from http://www.watflood.ca on the **"Executables"** page under the heading "**Env. Can. data conversion**"

This section is intended to provide an overview of the process. The table below shows the folder architecture for the Mackenzie River WF model along with a brief description. Another example is given in Appendix C.

<table>
<tr>
<td>


</td>
<td>

This graphic is an overview of the file structure for WF. A detailed description for each folder is given Sections 1.1.3 in the WF/CHARM Manual.
For the MRBHM application, there are 3 additional folders to allow CHARM to create the Master Inflow file, namely event_mrbhm, level_MRBHM and resrl_mrbhm for special input files and the MRBHM folder to accept the master inflow file. input files
For the NATURAL flow application, there are another 3 extra folders namely event_natural, level_natural, and resrl_natural
A new feature in WF created for this project are three separate folders to house the raw, downloaded meteorological and discharge data:

Level\WSC_data contains WSC water level data extracted from HYDAT with the ECDE.
Raing\EC_data contains the downloaded EC meteorological data – both precipitation and temperature
Strfw\WSC_data contains the WSC gauges discharge extracted from HYDAT with the ECDE.

</td>
</tr>
</table>

Table 1 – Folder structure for the MRB hydrological model

Chapter 5 will describe in more detail the steps required to run these scenarios.

4.1 Updating Precipitation and Temperature files

It appears that online, it is only possible to download the meteorological data for one station for one year at a time. The most recent copy of **Station Inventory EN.csv** was requested from Climat Ontario / Climate Ontario (EC/EC) ec.climatontario-climateontario.ec@canada.ca. This is a list of over 12000 climate stations in Canada. From the stations listed in this file, 86 stations were selected based on obtaining a fairly uniform geographical distribution and those with the longest record in the 1960 – 2015 period. The station list is found in the file **watflood\mrb22\raing\EC_data\met_sta_list.txt** The program **ECmet.exe** will read this list and the downloaded EC data files. The file naming convention is **sta_nnnn_yyyy.csv** where **nnnn** is the station number (3-5 digits) and **yyyy** is the year of the data. Each file has to be downloaded separately. For this, a program like the I**nternet Download Manager** http://www.internetdownloadmanager.com can be used to batch download all years for a particular station at once. Example URL for station=5584 and year=2000: http://climate.weather.gc.ca/climate_data/bulk_data_e.html?timeframe=2&stationID=5584&Month=2&Year=2000&format=csv

Once all files are downloaded, **ECmet.exe** is executed in the **watflood\mrb22\raing\ec_data** directory which creates the radcl**yyyymmdd_met.r2c** and **tempr\yyyymmdd_tmp.r2c** files – gridded precipitation and temperature respectively - which in turn are read by CHARM.

For detailed instructions, please see Section 2 of the Supplementary Utilities Manual

4.2 Updating the discharge files

For the past two – three years, only provisional data are available. Further back, the final quality checked data are available in the Environment Canada Data Explorer (ECDE) which along with the most up-to-data HYDAT data can be downloaded from

https://ec.gc.ca/rhc-wsc/default.asp?lang=En&n=0A47D72F-1

Once the ECDE is installed on a computer, the HYDAT favourite station list can be imported. This list is included on the accompanying data disk as
\watflood\mrb22\strfw\wsc_data\flow_stations.tb0

This favourite station list, among all other station attributes, has the latitude and longitude for each station. In this list, some of these have been altered to suit the WF model grid – i.e. to ensure properly modelled drainage areas of the sub-watersheds. Because of this, this file may be imported into the ECDE but it should not be saved from the ECDE with this same name. If stations are to be added, a new fav_hydat_stations.tb0 file should be saved in ECDE and the appropriate stations copied to the flow_stations.tb0 file.

To update the flow files for WF, a two-step process is required. First, the provisional flows from the last update need to be replaced by the final flows from the HYDAT and second, the most recent 2-3 years of data not yet in HYDAT must be requested from the WSC. These two sets of data have different file names and formats to ensure the data types are not confused.

Example HYDAT file name: 07EF001_Daily_Flow_ts.csv

Example Provisional file name: Flow_07EF001.csv

Both sets of data are found in the **\watflood\mrb22\strfw\wsc_data** folder.

Detailed step-by-step instructions are found in Section 3 of the Supplementary Utilities Manual

The meaning of "Provisional Data" is simply that it has not passed through the entire approval process. It can be totally raw – straight off the data logger – or completely processed but not "Approved". In the provisional files, there are two column headings "ProvisionalApprovalLevel" Fig. 15 and "ProvisionalGrade" Fig. 16. These are codes that indicate the current state of the data processing.

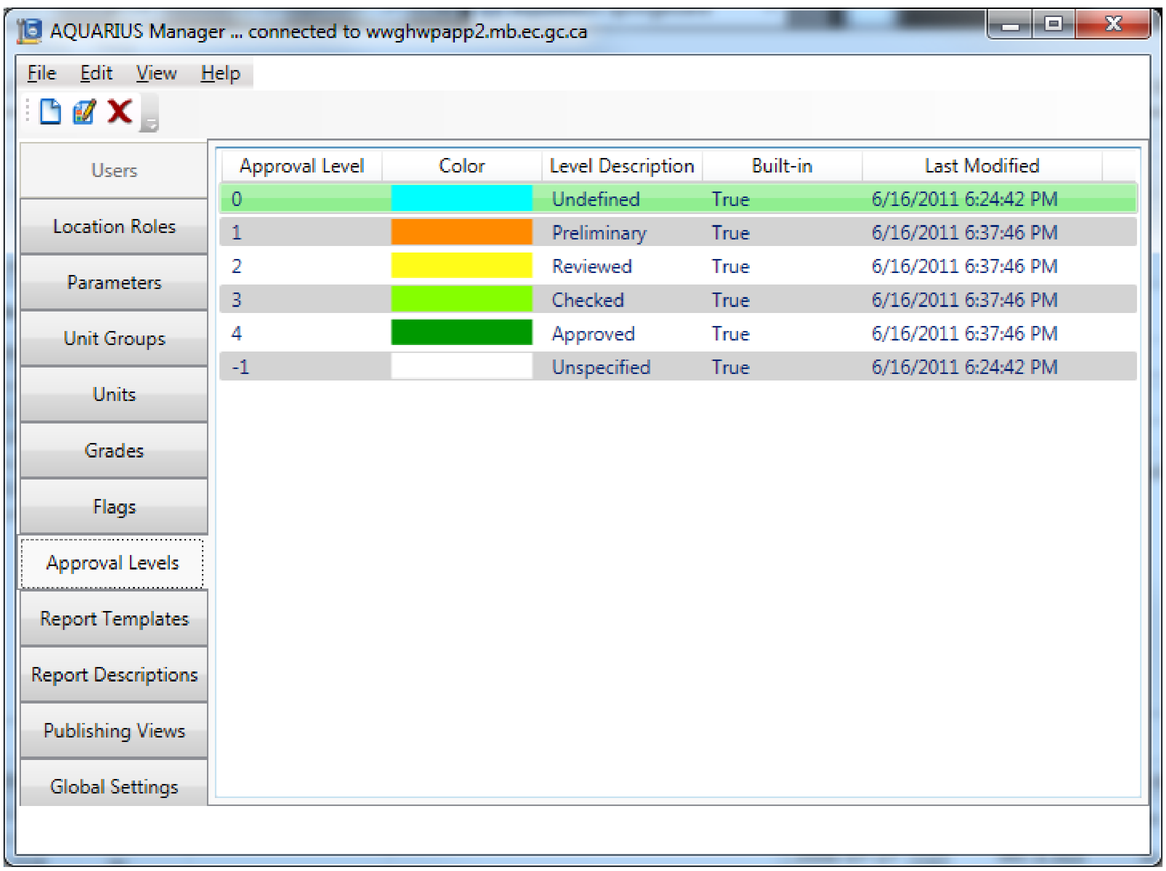


Figure 15 – WSC Aquarius Manager showing Approval levels

For this project, the provisional data was supplied by the WSC head office in Ottawa but normally the data is requested from the regional office. The format of the date is that obtained on a Hydrometric Work Station through the Aquarius software. This same format should be available given this process.

Provisional data are also available in real-time for the past 31 days. A task can be set up in WINDOWS to download the last 31 days on the first day of each month by running a batch file and the use of the widely used WGET program http://gnuwin32.sourceforge.net/packages/wget.htm.

For example, the 4 lines below will download the provisional data for 4 sample stations in the Mackenzie River basin and will be written in the working directory. The end result will be a file for each station for each month. These can then be read by a program to create the \strfw*_str.tb0 file:

```
wget  http://dd.weather.gc.ca/hydrometric/csv/NT/daily/NT_10LC014_daily_hydrometric.csv
wget  http://dd.weather.gc.ca/hydrometric/csv/AB/daily/AB_07AA002_daily_hydrometric.csv
wget  http://dd.weather.gc.ca/hydrometric/csv/BC/daily/BC_07EA004_daily_hydrometric.csv
wget  http://dd.weather.gc.ca/hydrometric/csv/SK/daily/SK_07QC002_daily_hydrometric.csv
```

A similar setup can be used to download provisional level data. The program is available on request. Over time, a data base will be built up to cover the period after approved hydrometric data becomes available in HYDAT.

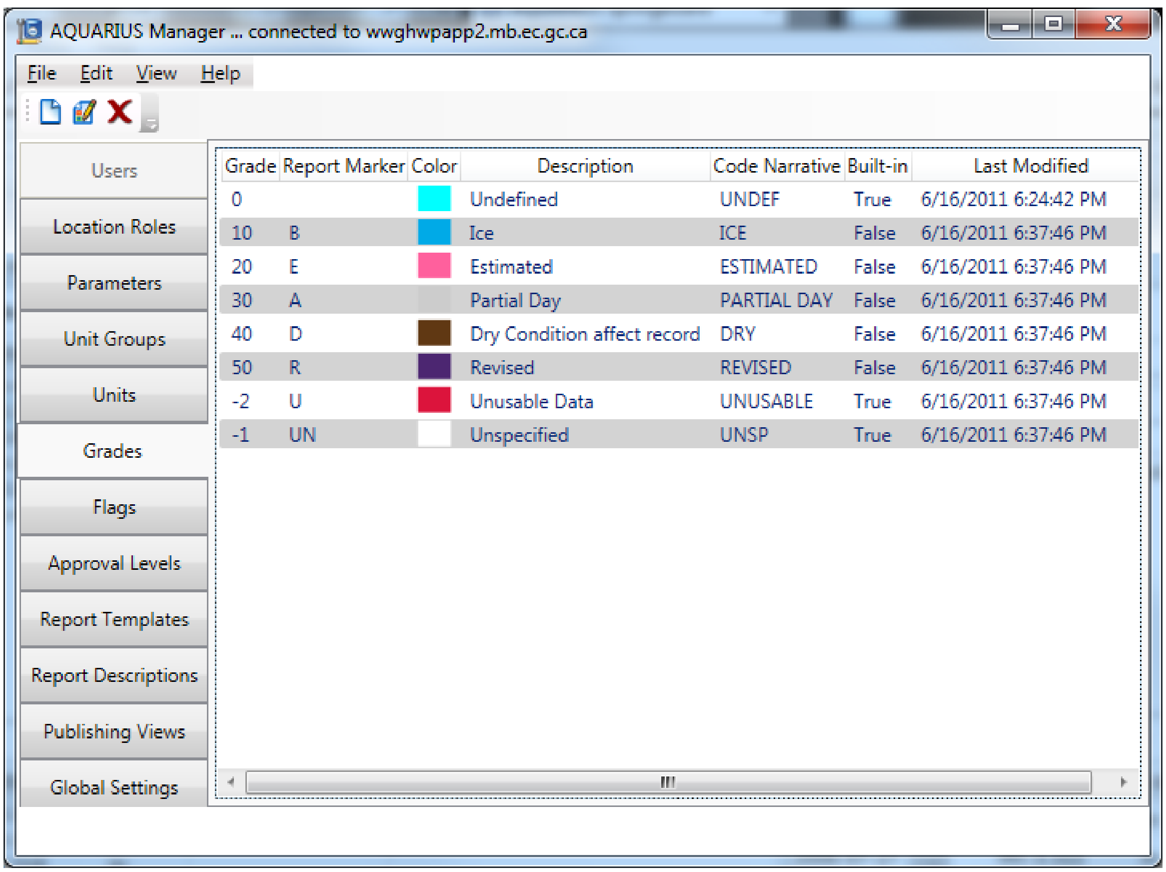


Figure 16 – WSC Aquarius Manager showing Provisional Grades

4.3 Updating the reservoir/lake release and initial lake level files

Any discharge files required for adding reservoir releases to a downstream reach, such as at the Bennett Dam are also included in the **flow_stations.tb0 list**.

To create the reservoir release files, run the program **ECrel.exe (ECrel32.exe for 32 bit).** This program requires one of three input files with the coefficients lake/reservoir storage-discharge relationship as well as the lake's datum (sill elevation), lake initial water elevations and the lake depth. There is one file for each of three options:

1. Existing conditions: **lake_rules.csv**
2. Natural conditions: **lake_rules_natural.csv**
3. Creation of the master inflow file for the MRBHM: **lake_rules_MRBHM.csv**

These files are also located in the **\watflood\mrb22\strfw\wsc_data** folder and presented in Appendix A in Excel format.

For natural conditions, the **lake_rules.csv** file is modified by taking out the releases from Williston Lake and having a very small off-line lake to replace Williston Lake to avoid having to change the number of lakes in the model and having to re-number the remaining lakes..

For the MRBHM, this file is modified to include a reach for every MRBHM inflow node. Here the MRBHM nodes are placed ahead of the lakes that are coded for lake routing but that are not included in the MRBHM for routing. CHARM has been hard-coded to write data to the MRB_MASTER_INFLOW.tb0 file for only the first 127 entries.

When executing the **ECrel.exe** program, a choice is required to create the corresponding ***.rel.tb0 file**. The **ECrel.exe** output files will be automatically written in the **MRB22\resrl** for option 1; the **MRB22\resrl_natural** for option 2; and **MRB22\resrl_MRBHM** for option 3.

The choice of the event file will determine which set of files to use.

Detailed step-by-step instructions to create the various input file for WF/CHARM are found in Section 4 of the Supplementary Utilities Manual and a short version in Appendix D.

5 Executing WATFLOOD/CHARM options

The WF files accompanying this report are structured so that it is possible to execute WF/CHARM for three distinct scenarios:

1. Modelling the existing Mackenzie River watershed (including Williston Lake and the Bennet Dam) to create a synthetic flow record for any grid in the WF model, including computed flows at all gauging stations.
2. Modelling the Mackenzie River watershed to provide inflow data for the MRBHM made up of gauged river flows where WSC stations provide a record with the ungauged areas filled in by the model.
3. Modelling the Mackenzie River watershed with Williston Lake and the Bennett dam removed in the model to create “naturalized” flows at downstream locations.

To enable each of these options certain steps need to be undertaken as outlined in the following sections. Separate folders have been created for each of these options where the input data needs to be differentiated as shown in Table 1. Both the **level** and **resrl** folders need to have three versions to accommodate the different reservoir configurations for the three options. For each case, the **ECrel.exe** program needs to be executed before executing the model (**CHARM*.exe**)

The first and third options reflect the normal use of the WF/CHARM model. The second option, namely the creation of inflows for the MRBHM involves custom coding in CHARM.

Each option can be chosen by including the relevant files in the **mrb22\event\event.evt** file.

It is assumed that all runs will be from 1960 to the present (2015 at time of writing)

All files in the r**aing/, radcl/, moist/, snow1/, tempg/, tempr/** and **strfw/** directories are common to all options. The files in the resrl and level/ directories are not and need to be individually created by **ECrel.ex**e in the **MRB22\strfw\WSC_data** directory.

In the **basin/** directory, there are three watershed files: **mrb22_shd.r2c** for the regulated and nudged applications, **mrb22_natural_shd.r2c** for the natural application and **mrb22_mrbhm_shd.r2c** to create files for the MRBHM.

There are four event files in the **event**\ directory, one for each application:

1960.evt for the regulated case;
1960_natural.evt for natural flows;
1960_mrbhm.evt to create the files for the MRBHM; and
1960_nudged.evt to nudge all tributary flows for the regulated – i.e. existing conditions.

Each of these can be copied into the **event.evt** file for each particular application.

5.1 Nudging

There are three conditions where "nudging" of the flows at WSC flow stations is required. Normally, for calibration and the use of CHARM as a straight forward hydrological model, nudging is not used. In this way, errors in the model are propagated downstream and areas where the model does not perform well are visible and corrections to the parameters and other model input can be made. However, for the MRBHM, flows are nudged at all WSC stations that are not on the main branches of the Peace, Athabasca, Slave and Mackenzie rivers and at Hudson Hope on the Peace River and at Windfall on the Athabasca. In this way, the best possible data is entered into the MRBHM.

A second condition for nudging the flows at these same locations is to see how well the WF/CHARM model computed the flows for the ungauged parts of the MRB. By nudging the flows for the tributaries and at the upstream locations of the Peace and Athabasca Rivers the remaining errors at the flow stations along the main rivers are is all due to model errors in the ungauged areas. These will also be the errors ending up in the MRBHM.

The third reason for nudging is to make the best estimate of naturalized flows. In this case, the flows are also nudged at the stations in tributaries above Hudson Hope and for this case the flows at Hudson Hope and Windfall are NOT nudged. With Williston Lake and the Bennet Dam removed from the model, this option provides the WF generated naturalized flows. The results of executing this option are presented in the next chapter.

5.2 Mackenzie River Basin model (default WF file names):

The WF/CHARM model can be used to model the Mackenzie River basin in its existing state by simply computing flow contributions from each grid and routing these flows downstream where they can be compared to observed flow data. The releases from Williston Lake are assumed to be the flows at Hudson Hope and these flows are used as input to the Peace River at this location. This is also the approach for optimizing the parameter set where by using the Dynamically Dimensioned Search (DDS) program, the model errors are minimized. The optimization process is described in detail in the WF manual.

To execute this option:

1. In the directory **mrb22\strfw\WSC_data** run the program **ECrel.exe** - This will create the proper files in the **MRB22\resrl** and **MRB22\level** folders. These files will have the reservoir releases from Williston Lake and the routing coefficients for all other lakes in the MRB. **ECrel.exe** will read the **lake_rules.csv file** which has the coefficients for the **MRB22\resrl*rel.tb0** as well as the datum, initial lake level and lake depth for each lake. The answers for the questions: natural flows = **n**, Start year = **1960**, last year = **2015**, option 1 = **lake_rules.csv -**

2. In the working directory ***\MRB22** enter the command **copy event\1960.evt event\event.evt -** This is the master file that points to all files that need to be used for this option.
3. Edit the **event\event.evt** file to ensure **:nudgeflg = n**
4. Next run **SNW*.exe, MOIST*.exe, RAGMET*.exe, TMP*.exe and CHARM*.exe**
5. The results are in the **MRB22\results** directory. To save the results for this option (existing conditions), create the directory **MRB22\results_regulated** and copy all txt, csv, r2c & tb0 files in the **results** directory to the **results_regulated** directory.
6. Use various visualization options (e.g. GreenKenue, Grapher, Excel, etc.) to show the results

Steps 2 – 5 can be done automatically with the batch file **run_regulated.bat**

5.3 Mackenzie River Basin model for natural conditions:

The WF/CHARM model can be used to synthetically create natural flows at Hudson Hope by computing flow contributions from each grid as above and routing these flows downstream. For this option, the water area of Williston Lake has been removed but a very small lake is left to keep the number of lakes the same but this lake is not on the Peace River itself. To execute this option:

1. In the directory: **mrb22\strfw\WSC_data** run the program **ECrel.exe** - This will create the proper files in the **MRB22\resrl_natural** and **MRB22\level_natural** folders. These files will have the routing coefficients for all other lakes in the MRB. **ECrel.exe** will read the **lake_rules_natural.csv file** which has the coefficients for the **MRB22\resrl_natural*rel.tb0** as well as the datum, initial lake level and lake depth for each lake. The answers for the questions: natural flows = **y**, Start year = **1960**, last year = **2015**, option 3 = **lake_rules_natural.csv**

2. In the working directory ***\MRB22** enter the command **copy event\1960_natural.evt event\event.evt -** This is the master file that points to all files that need to be used for this option

3. Edit the **event\event.evt** file so **:nudgeflg = 1** In this option, all tributary flows to the Peace, Athabasca, Slave and Mackenzie rivers will be nudged and calculated flows from the ungauged areas will be blended. **CHARM*.exe** will look for the file **nudge_flags.xyz** where the nudging can be turned on/off by setting the value in column 3 = **2** for nudging and = **1** for NOT nudging. The contents of **nudge_flags.xyz** file are shown in Appendix D <u>Note that for this option, the flows at Hudson Hope are **NOT** nudged.</u>
4. In the strfw directory, copy **nudge_flags_natural.xyz** into **nudge_flags.xyz** **CHARM*.exe** will look for the file **nudge_flags.xyz** where the nudging can be turned on/off by setting the value in column 3 = **2** for nudging and = **1** for NOT nudging.

5. Next run **CHARM*.exe** (assuming the pre-procesing programs have been executed as in Section 5.3).
6. The results are in the **MRB22\results** directory. To save the results for this option (existing conditions), create the directory **MRB22\results_natural** and copy all txt, csv, r2c & tb0 files in the **results** directory to the **results_natural** directory.
7. Use various visualization options (e.g. GreenKenue, Grapher, Excel, etc.) to show the results

Steps 2 – 6 can be done automatically with the batch file **run_natural.bat**

5.4 Mackenzie River Basin Hydraulic Model (MRBHM):

The WF/CHARM model can be used to create the input files for MRBHM by computing flow contributions from each grid as above and routing these flows downstream where they can be written to the **MRB_MASTER_INFLOWS.tb0** file. As above, the releases from Williston Lake are assumed to be the flows at Hudson Hope and these flows are used as input to the Peace river at this location and reappear as inflow to the MRBHM at the Hudson Hope node. To execute this option:

1. In the directory **mrb22\strfw\WSC_data** run the program **ECrel.exe** - This will create the proper files in the **MRB22\resrl** and **MRB22\level** folders. These files will have the reservoir releases from Williston Lake and the routing coefficients for all other lakes in the MRB. **ECrel.exe** will read the **lake_rules_mrbhm.csv file** which has the coefficients for the **MRB22\resrl*rel.tb0** as well as the datum, initial lake level and lake depth for each lake. The answers for the questions: natural flows = **n**, Start year = **1960**, last year = **2015**, option = **lake_rules_mrbhm.csv -**

2. In the working directory ***\MRB22** enter the command **copy event\1960_MRBHM.evt event\event.evt -** This is the master file that points to all files that need to be used for this option.

3. Edit the **event\event.evt** file to ensure **:nudgeflg = 1**
4. In the strfw directory, copy **nudge_flags_mrbhm.xyz** into **nudge_flags.xyz** In this option, all tributary flows to the Peace, Athabasca, Slave and Mackenzie rivers will be nudged and calculated flows from the ungauged areas will be blended for inflow to the MRBHM. The contents of **nudge_flags.xyz** file are shown in Appendix D. <u>Note that for this option, the flows at Hudson Hope are nudged.</u>

5. Next run **CHARM*.exe** (assuming the pre-procesing programs have been executed as in Section 5.3).

6. The results are in the **MRB22\results** directory. To save the results for this option (existing conditions), create the directory **MRB22\results_mrbhm** and copy the files from **MRB22\results** to **MRB22\results_mrbhm**

7. Use various visualization options (e.g. GK, Grapher, Excel, etc.) to show the results

Steps 2 – 6 can be done automatically with the batch file **run_mrbhm.bat**

5.5 Mackenzie River Basin with nudging tributary flows:

To check the volumetric error of the flows generated for the MRBHM the model can be executed as described in Section 5.2 but this time with all tributary flows nudged as in Section 5.4. Again, the releases from Williston Lake are assumed to be the flows at Hudson Hope and these flows are used as input to the Peace River at this location and reappear as inflow to the MRBHM at the Hudson Hope node. This time, the **MRB_MASTER_INFLOWS.tb0** file is not written but the flows are routed by CHARM. To execute this option:

1. Repeat step 1 Section 5.2
2. In the working directory ***\MRB22** enter the command **copy event\1960_nudged.evt event\event.evt**
3. Edit the **event\event.evt** file to ensure **:nudgeflg = 1**
4. In the strfw directory, copy **nudge_flags_nudged.xyz** into **nudge_flags.xyz**
5. Next run **CHARM*.exe**
6. The results are in the **MRB22\results** directory. To save the results for this option (existing conditions), create the directory **MRB22\results_nudged** and copy all txt, csv, r2c & tb0 files in the **results** directory to the **results_nudged** directory.
7. Use various visualization options (e.g. GK, Grapher, Excel, etc.) to show the results

Steps 2 – 6 can be done automatically with the batch file **run_nudged.bat**

6 WATFLOOD/CHARM Naturalized Flows

6.1 Lake Athabasca inflows

Figure 17 shows three flow hydrographs from 1960 to 2015 at Hudson Hope, BC. The black line is the observed flow and the red line is the computed flow at Hudson Hope which is the same as the observed flow because the releases from Williston Lake are the observed flows at Hudson Hope.

The green lines are the naturalized flows as computed by the model with flows nudged at the 10 WSC stations above Hudson Hope. For this case, the area above Hudson Hope and the upper reaches of adjoining rivers was extracted from the MRB model and a calibration was carried out using the two land cover classes dominant in the high country that were not also in the remainder of the MRB. This recalibration improved the fit of the computed hydrograph somewhat but the recording of flow in the upper Pease River did not generally start until the early 1980's. So it was not possible to calibrate the model with flow data for the period 1960 - 1968 when natural flow conditions existed at Hudson Hope. As a result, the generated hydrographs at Hudson Hope for this natural flow period are somewhat under estimated. However, for the period 1960 – 2015, the computed flows at Hudson Hope were under estimated by only 0.7%.

Figure 17 clearly shows the difference between the actual and natural conditions at Hudson Hope. The winter flows are somewhat low for the "natural" period.

Figure 18 shows the natural versus the regulated flows at Peace Point with the same colour scheme. At Peace Point the flows during the natural period match quite well and again, the differences between natural and actual conditions are quite clear.

Figure 19 shows the computed and observed flow for the Athabasca River at Athabasca where the flow record is complete. Based on Figs. 18 and 19 it is apparent that the major computed flows affecting Lake Athabasca are reasonably well computed.

6.2 Lake Athabasca levels

Figures 20a, b & c show the lake levels in the bottom graph with grey as the observed (Crackingstone Point, SK; Fort Chipewyan, AB; Bustard Island, AB), red for the regulated (existing) conditions and green for the naturalized case. The middle graph shows the lake inflow in grey and lake outflow in green – both for the natural condition. The regulated inflow/outflow is not shown. (The legend applies to the top and bottom graphs only and the same explanation applies to Figs. 21a, b &c). The top figure shows the observed flow at Fitzgerald in black, the regulated flow in red and the natural in green. The differences in flow volume for the two cases are only 0.11% over the 1960-2015 modelling period..

For the 1960 – 1968 period, the model underestimates the lake levels but the WF/CHARM naturalized levels compare very well with the regulated levels based on the case with nudged flows at Hudson Hope, BC. For period after 1968, the computed Lake Athabasca level gradually recovers somewhat but then the lake levels for the naturalized flows remain lower than for the regulated and observed lake levels but show a greater amplitude.

For the entire simulation period the Lake Athabasca levels appear to be consistently under estimated by approximately 0.5 m. This can be avoided by simply raising the datum in the routing model, but at the time of writing there is no information available to justify such an arbitrary adjustment. Upon review of this report, other possible rules for Lake Athabasca came to light and work to improve the model will continue in the future.

6.3 Great Slave Lake levels

Figures 21a, b & c show the results for GSL in a similar way (Hay River, NT; Fort Resolution, NT; Snowdrift, NT). Fig. 21 shows a very similar pattern for the GSL levels for the pre-Williston period but for the period afterwards, shows quite a different pattern. It is noted that the range in annual water levels for Lake Athabasca is from 1 to 2 m but for GSL it usually less than half this amount as a result of its larger surface area. For the 1960 – 1968 period the computed green and red lake level hydrographs agree reasonable well and have roughly the same amplitude as the observed (at Yellowknife Bay, at Hay River, and at Snowdrift).

Neither of the computed hydrographs follow the full extent of the observed downward trend during the Williston filling period. This is likely due to an erroneous rating curve for the outflow of GSL. In this case, a simple power curve was fitted to best match the downstream flows observed at Strong Point without the same weight given to fitting the GSL water levels. In all likelihood, a polynomial equation is needed, to better reflect actual conditions. An attempt was made to employ the rating curve used in the MRBHM but it resulted in severe instability of the solution due to exceeding the limits for which the rule is valid. Time did not permit to debug this.

For the period after the flows became regulated there are marked differences between the naturalized and regulated lake levels for GSL. As expected, the summer lake levels for the naturalized lake levels are higher due to the higher flows from the upper Peace River when these are not captured in Williston Lake and during the winter the releases from the lake result in higher levels. The naturalized flows have falling water levels in GSL which is in contrast to the levels from regulated flows, which tend to rise during the winter months.

That the rating curve for GSL outflow needs to be improved is noticeable in Fig. 21a where the computed water levels for the regulated condition do not follow the observed downward trend during the Williston filling period 1968 – 1970. However, the computed outflows for this period do clearly show the same lower flows as the observed record as shown in Figs. 9a & b. Thus it appears that the GSL levels are not very sensitive to the flow – i.e. a very flat rating curve of elevation versus flow – and that the rating curves currently in the model for open water and ice conditions will need some revision.

6.4 Comparison of naturalized flows: BC Hydro/WATFLOOD

BC Hydro provided the MRBB with a set of naturalized outflows from Lake Williston based on continuity considerations of the lake. These BC Hydro naturalized flows are compared to those generated by WF in the manner described in Section 6.1. The results are show in Fig. 22. Again the early years of the WF flows are somewhat under estimated with visibly better results after 1980, when the WSC flow gauges in the upper reaches of the Peace River came on-line.

6.5 Summary – naturalized flows

The WF/CHARM model under-estimates the flows for the Peace River at Hudson Hope for the period when these can be checked, namely 1960 – 1968. The WSC flow stations came on-line above the Bennett Dam in the early 1980's and thus the naturalized flow for the Peace River at Hudson hope as generated by CHARM for the period post Bennett Dam will be more accurate.

This analysis must be viewed as preliminary. Improvements in the calibration for both the entire MRB model and the Upper Peace River in particular are possible.

For GSL a simple power function was used between lake storage and outflow. The coefficients were found by trial and error to give the best match for the lake level. Further improvements here are possible. There is a need for an automatic calibration of the routing coefficients for lakes in the model as the trial and error method now used is too time consuming.

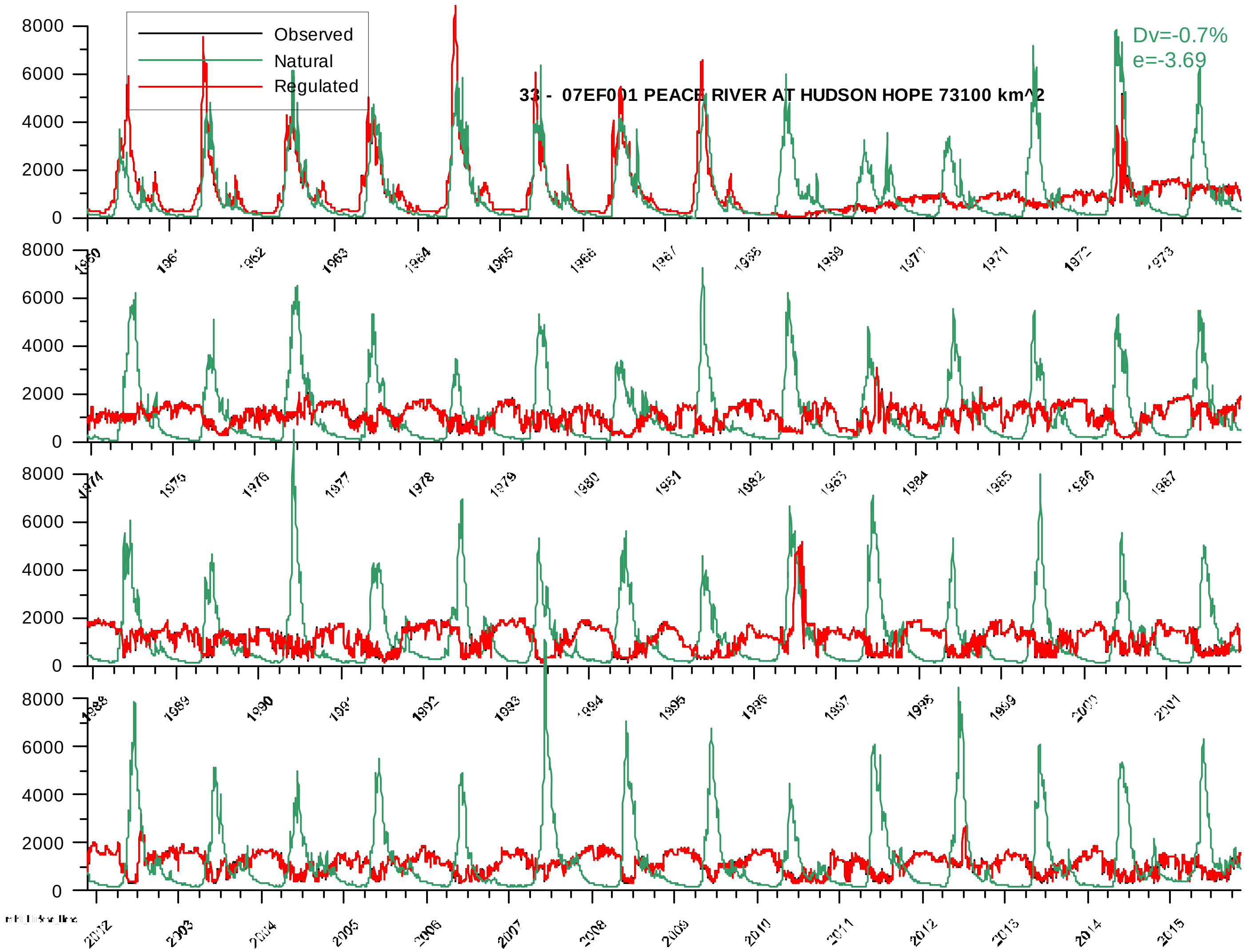


Figure 17 – Naturalized hydrograph at Hudson Hope, BC

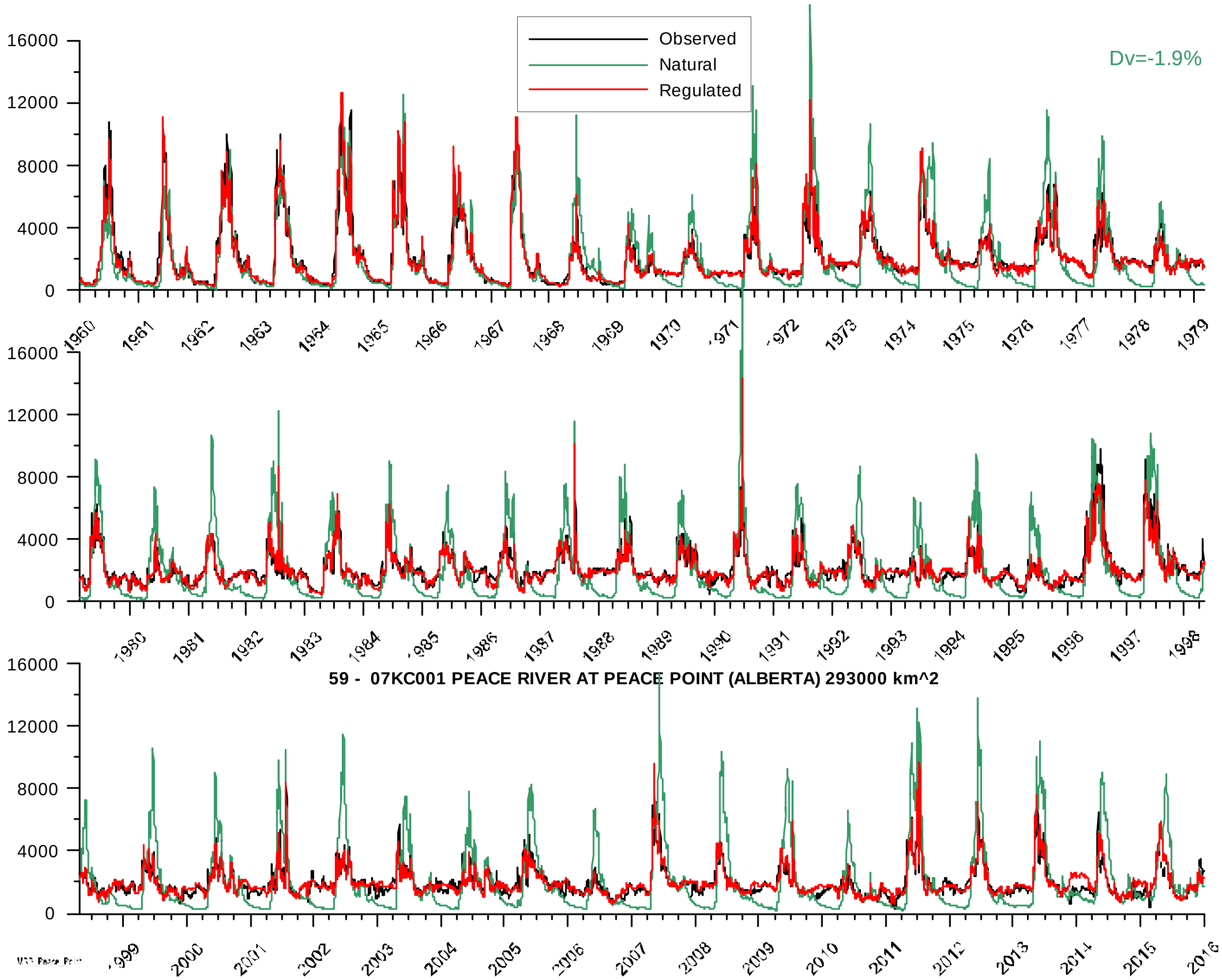


Figure 18 – Naturalized hydrograph at Peace Point, Ab.

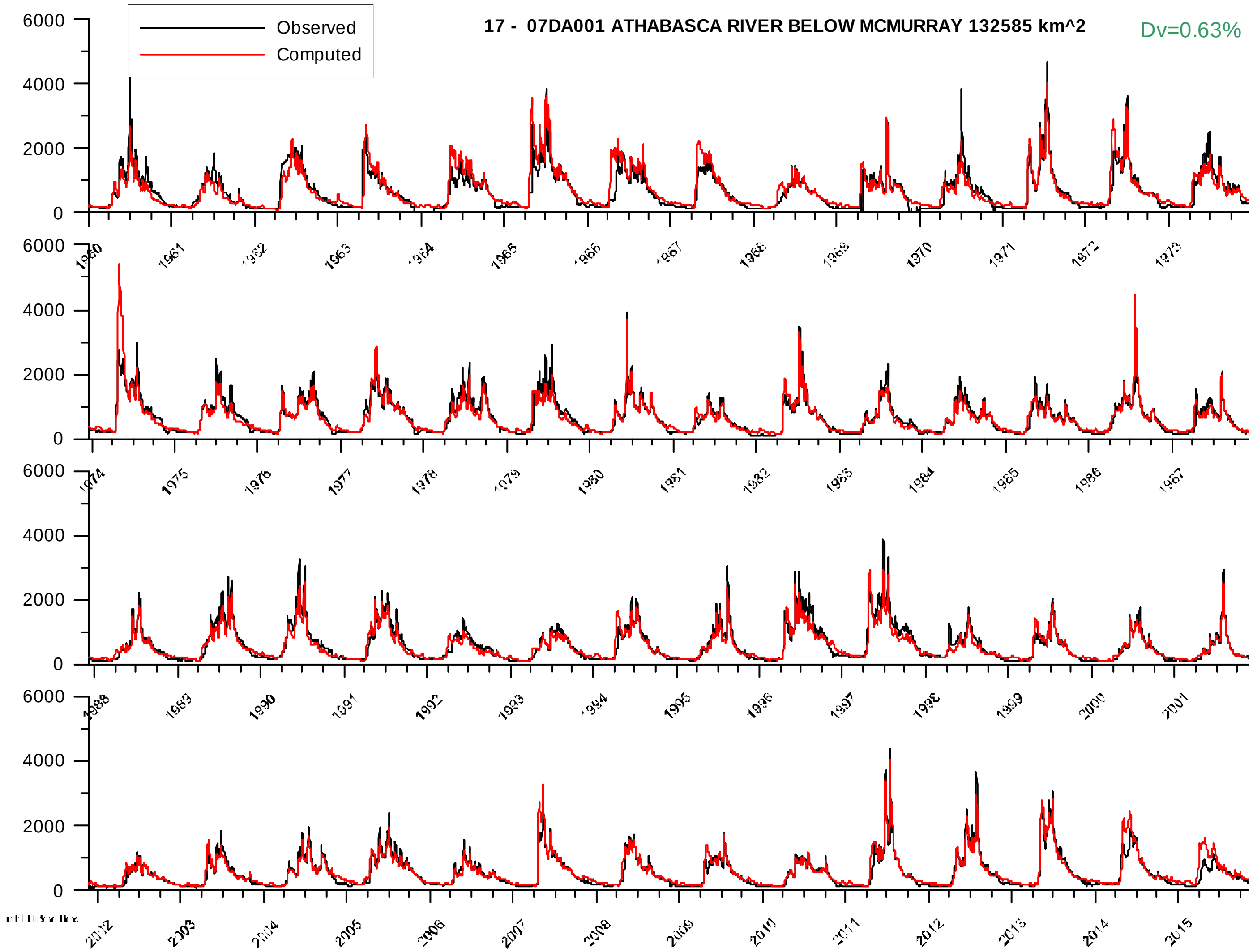


Fig. 19 – Athabasca River Hydrograph at Athabasca

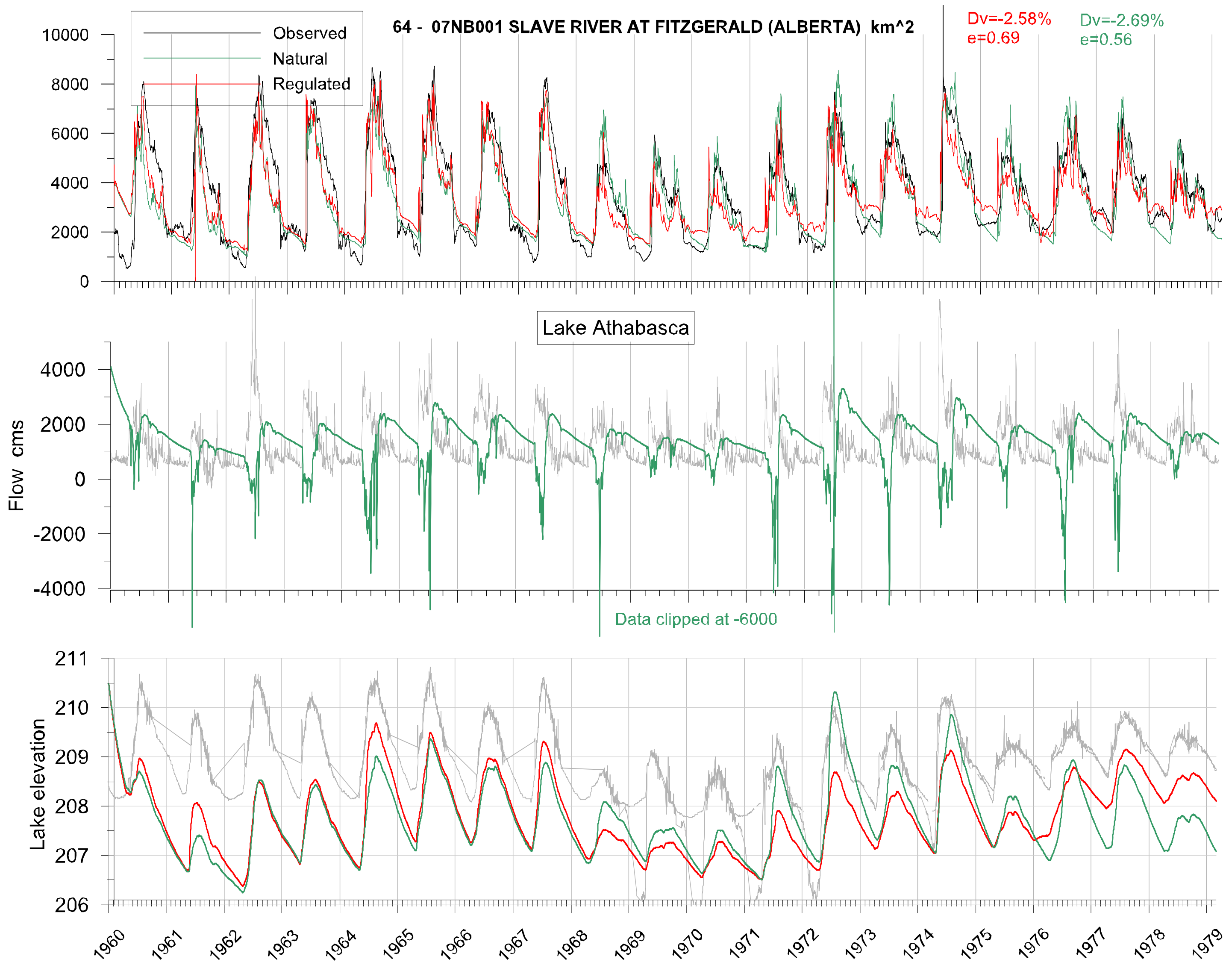


Figure 20a – Lake Athabasca hydrographs

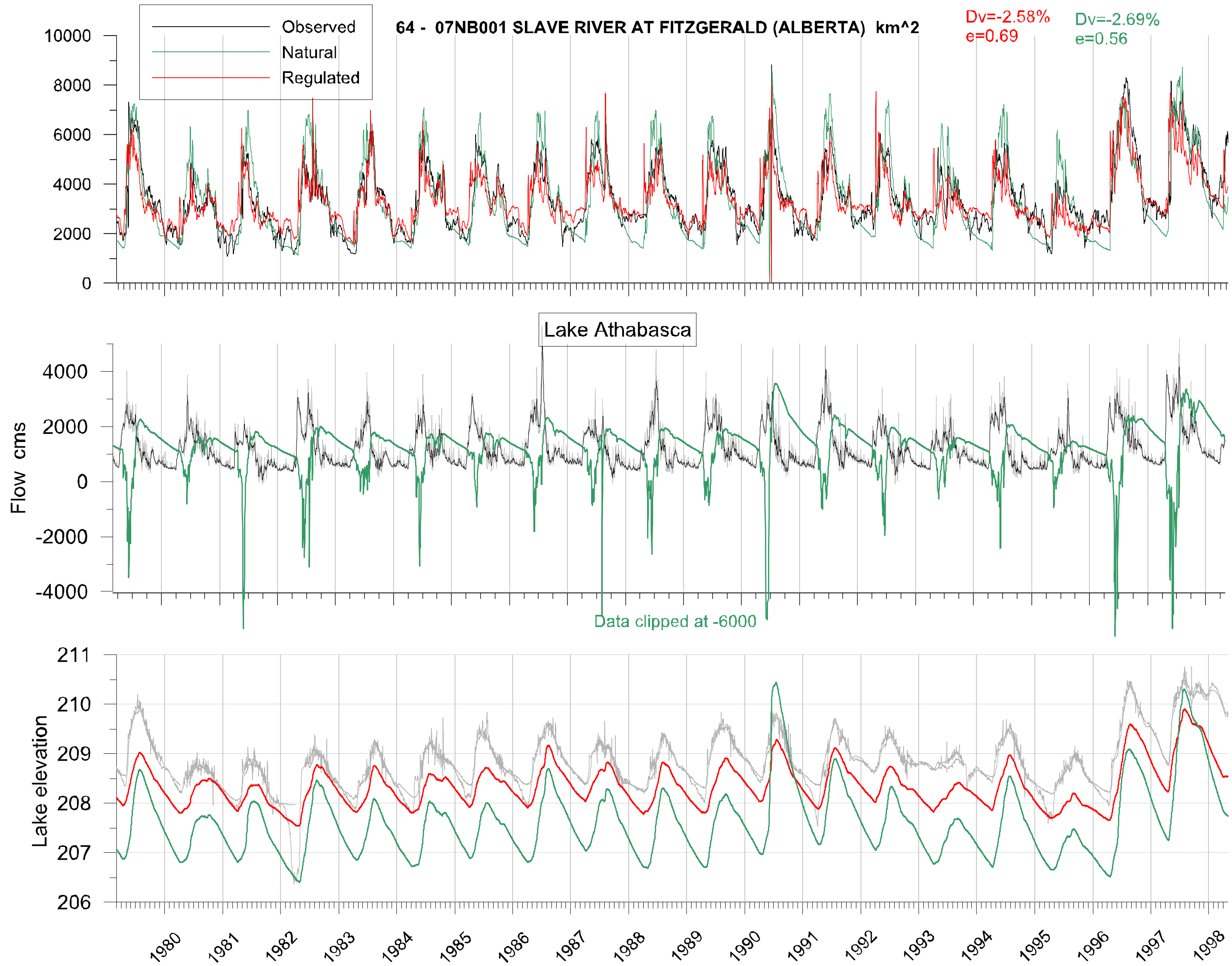


Figure 20b – Lake Athabasca hydrographs

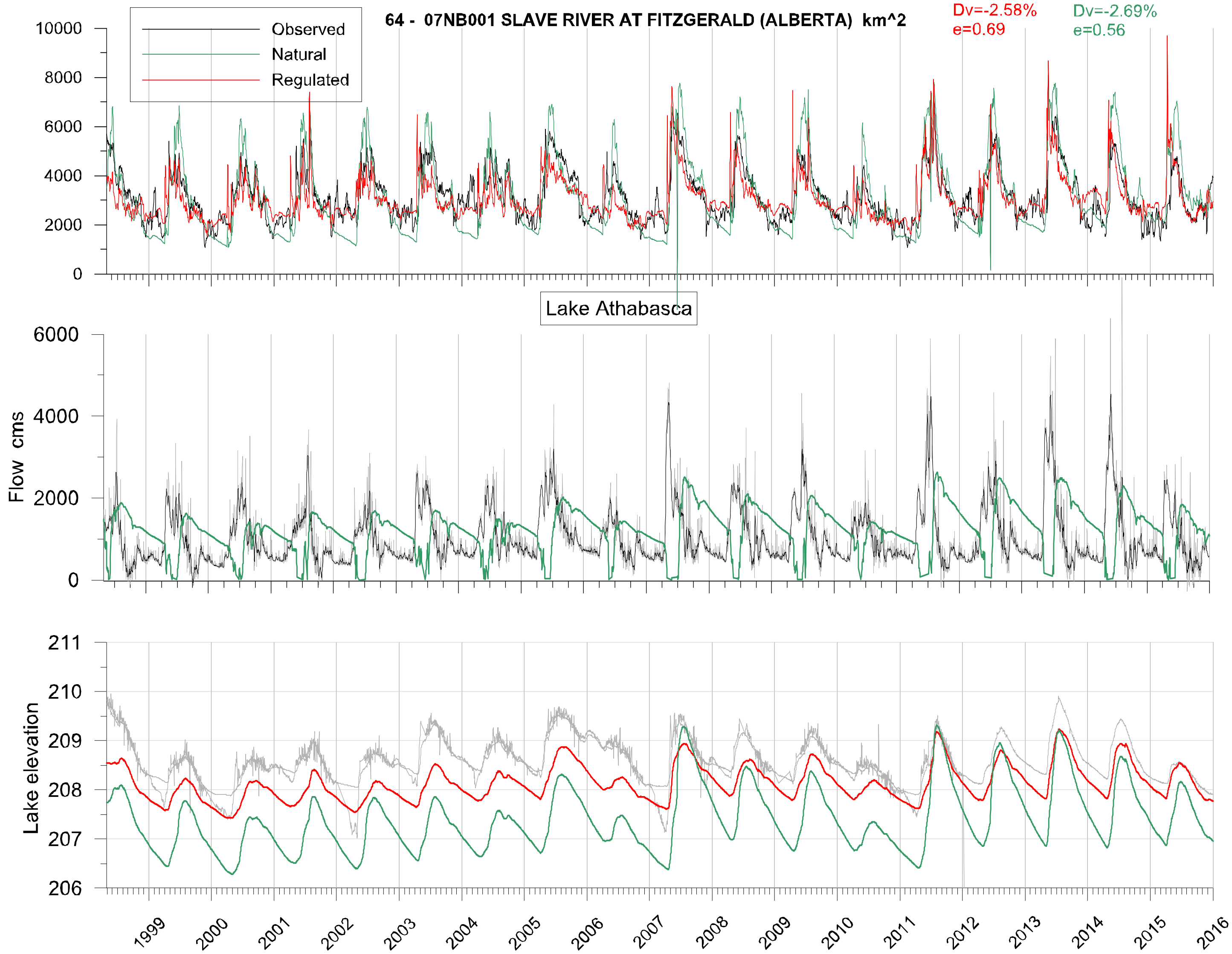


Figure 20c – Lake Athabasca hydrographs

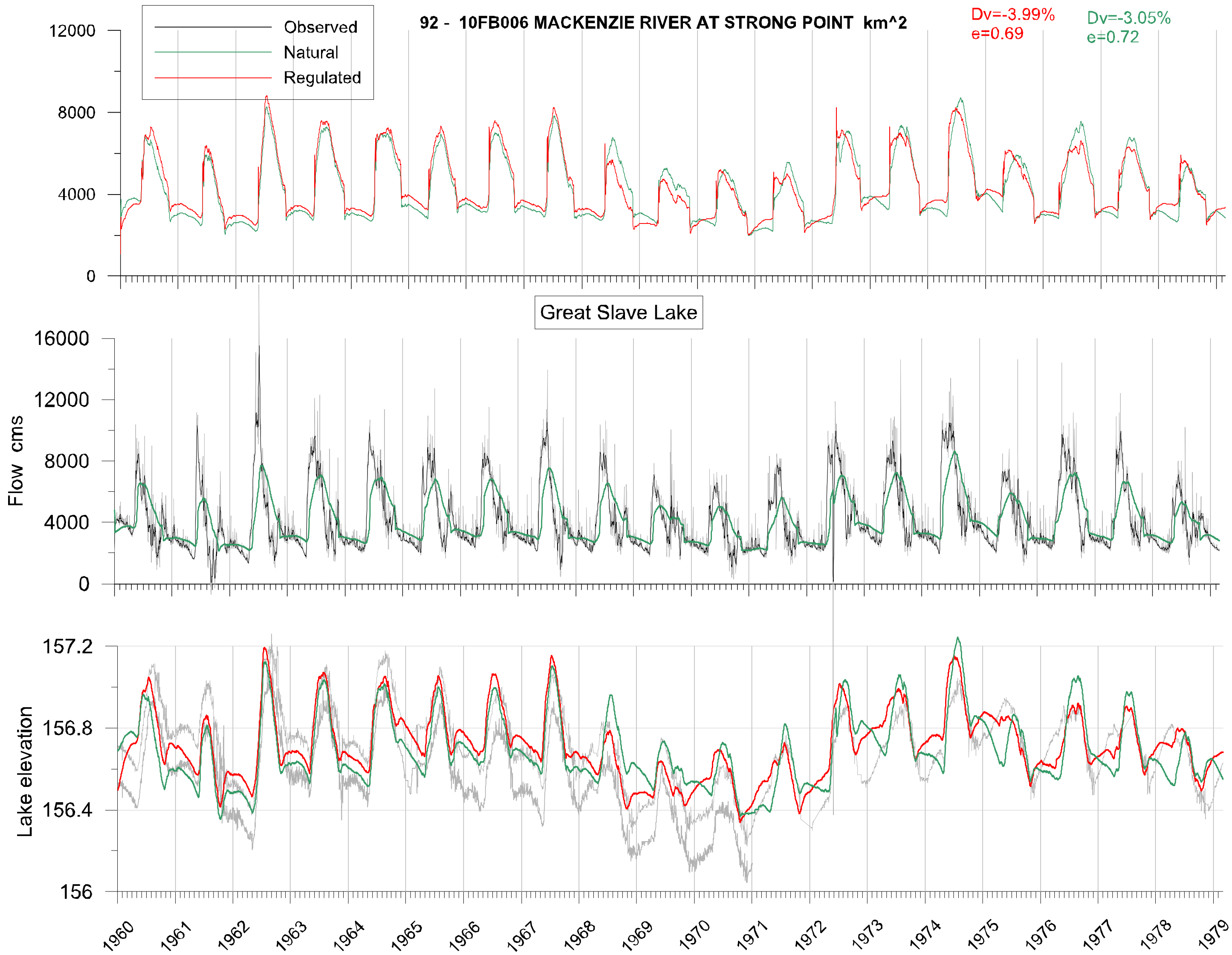


Figure 21a – Great Slave Lake hydrographs

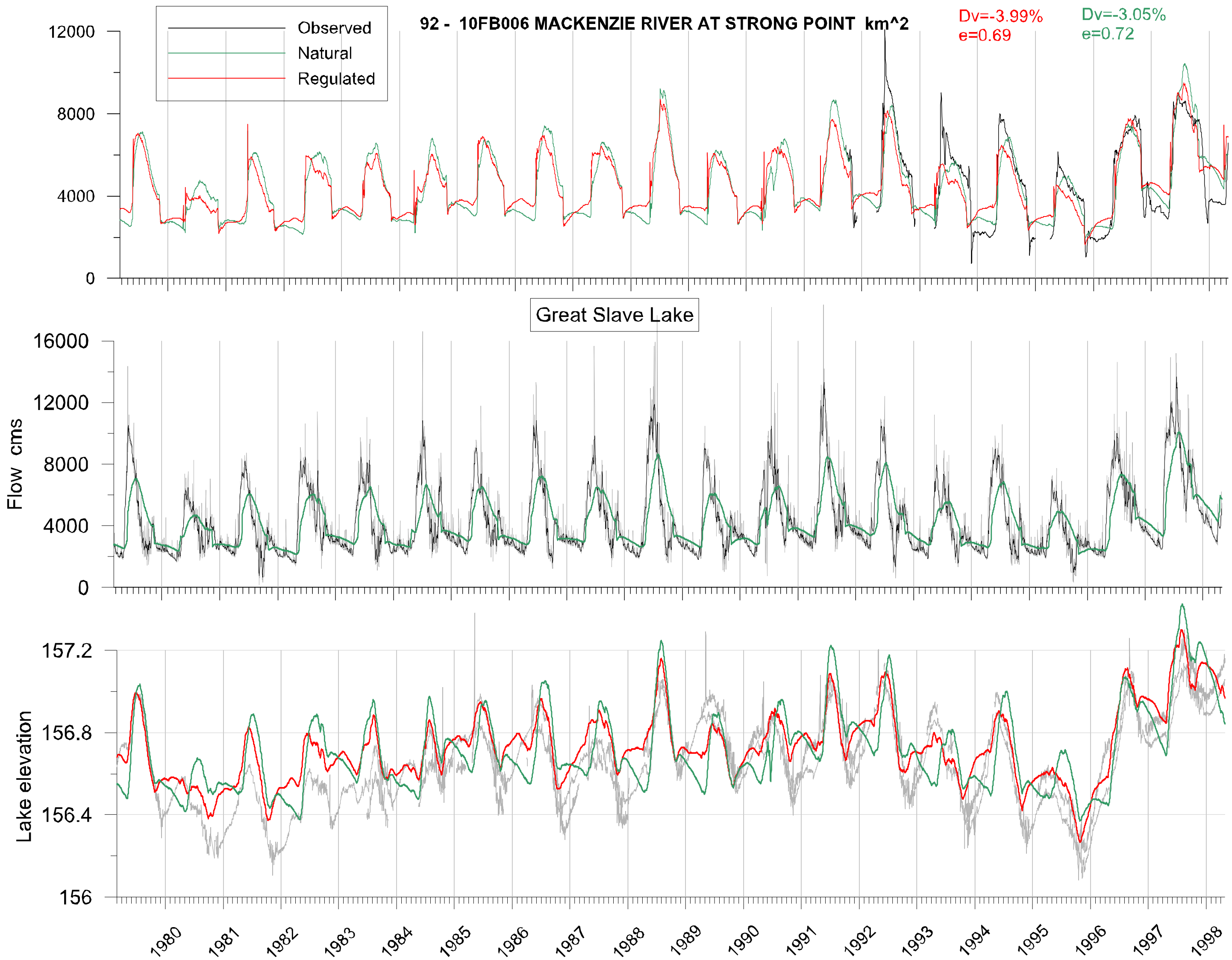


Figure 21b – Great Slave Lake hydrographs

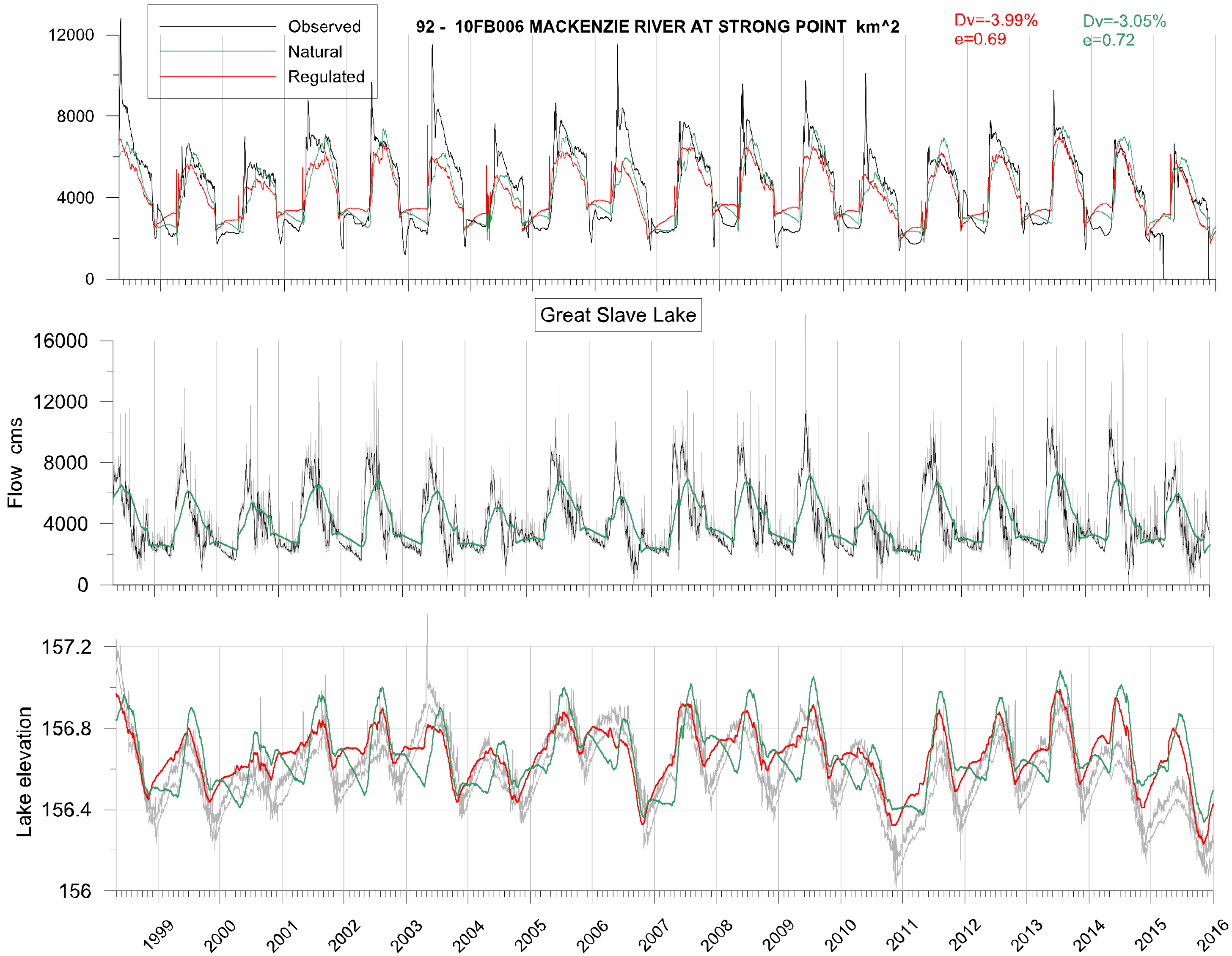


Figure 21c – Great Slave Lake hydrographs

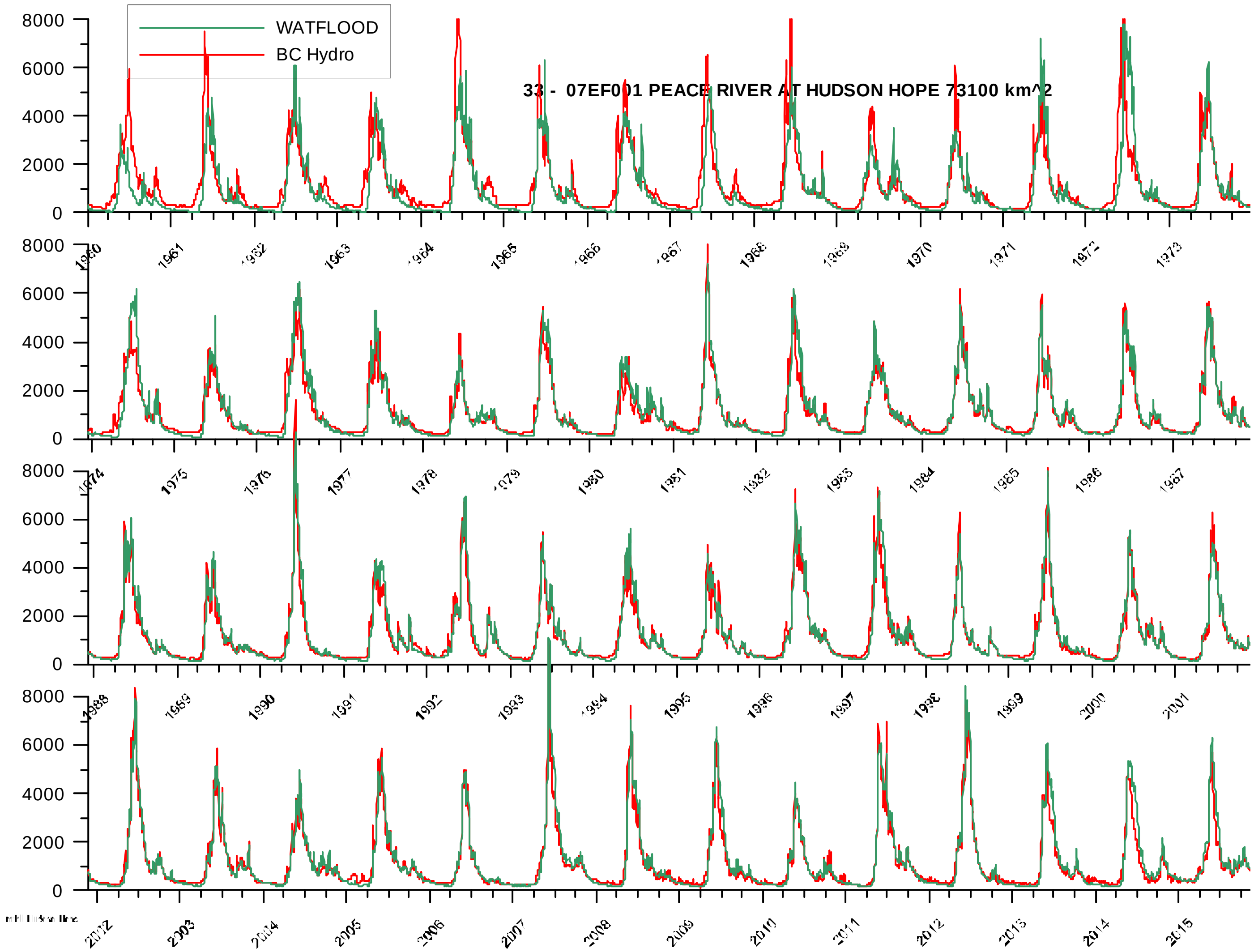


Figure 22 – Comparison of naturalized flows BC Hydro versus WF/CHARM

7 Final Chapter

As stated at the outset, the goal of this project was to create a master inflow file for the Mackenzie River Basin Hydraulic Model where observed flows at WSC flow stations are blended with modelled flows for those areas where inflows to the Peace, Athabasca, Slave and Mackenzie rivers are not measured. This was accomplished as intended with a new lat-long based WF/CHARM model.

At the June 7/8, 2016 workshop in Edmonton, Alberta, it became apparent that it would also be useful to set up the WF/CHARM model to generate naturalized flows at the Williston Lake outlet. This would serve an independent check in the naturalized flows provided by BC Hydro and as well, allow for future climate change impact studies should these be desirable.

The calibration effort required for this project was not as demanding as what is the norm although it is still a time-consuming effort. Roughly 60 percent of the MRB tributaries are gauged. At this time, some of the calibration in the headwaters are not satisfactory but since these watersheds are gauged, the lack of a good calibration does not affect the accuracy of the inflows for the MRBHM as the erroneous computed flows are replaced by the gauged flows. In the future, further calibration work on the MRB model will be carried out.

The WF/CHARM model for the Mackenzie River basin is to be viewed as a work in progress. The errors in the computed flows for the MRBHM are within the normally accepted errors for gauged flows, especially under ice conditions, and as such provides the best possible set of values for the MRBHM.

It may be possible to reduce the error for the master inflow file by calibrating only on the flow stations along the Peace, Athabasca, Slave and Mackenzie rivers while nudging all tributary stations. This would focus the calibration on the area that is most important for the MRBHM.

Development on the model will continue with further calibration of problematic sub-watersheds and lake outflow rating curves. Eventually over time, the reliability of the model may be further improved through the use of isotope data and the tracer and isotope models embedded in CHARM.

Appendix A

File name: strfw\WSC_data\lake_rules_mrbhm.csv - used to create **yyyymmdd_rel.tb0** for a normal WF watershed model

LongDecim	LatDecima	No	StationID	coef1	coef2	coef3	coef4	coef5	start_elv	datum	depth
-122.217	56.0167	1	07EF001	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	34.8	34	100
-111.283	58.777	2	Athabaska	5.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	208.5	205	26.1
-117.381	61.20279	3	Gr_Slave	5.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	156.7	156.2	41
-123.474	65.144	4	Gr_Bear	1.60E-16	1.75E+00	0.00E+00	0.00E+00	0.00E+00	6.25	5.3	71.7
-117.758	65.598	5	Clut_L	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	107	100	12
-114.217	62.8083	6	Prosperou	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.4	100	12
-114.756	55.305	7	Lssr_Slave	4.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	576.4	575.7	11.4
-117.27	63.1444	8	LacLaMatr	2.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.2	100	12
-121.131	60.757	9	Trout_lake	2.00E-13	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.3	100	12
-108.175	58.967	10	Davy_Lake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	102	100	12
-104.608	58.386	11	Theriau_La	2.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.7	100	12
-105.539	59.147	12	BlackLake	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.8	100	12
-107.67	61.876	13	PorterLake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	105	100	12
-108.466	62.894	14	ArtilleryLal	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101	100	12
-113.59	62.5	15	ReidLake	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.7	100	12
-126.323	60.222	16	UnknownL	1.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	116.5	100	12
-109.786	58.322	17	CluffLake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	106	100	12
-118.19	65.23	18	HottahLak	2.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.5	100	12
-107.27	63.745	19	ClintonGol	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.1	100	12
-109.871	64.133	20	MacKayLa	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.1	100	12
-115.365	64.063	21	ChalcoLak	5.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.4	100	12
-114.7	64.23	22	WekwetiLa	1.00E-12	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.05	100	12
-115.02	64.415	23	IndinRiver	5.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.15	100	12
-103.54	58.45	24	Wollaston	8.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.55	100	12

Appendix A - Continued

File name: strfw\WSC_data\lake_rules_mrbhm.csv - used to create **yyyymmdd_rel.tb0** for the MRBHM. For an explanation of the column entrees please see the WF manual. Column 4 are the node ID's as described in Section 2.1

LongDecimal	LatDecimal	No	StationID	coef1	coef2	coef3	coef4	coef5	Start_elv	datum	depth
-121.98393	55.984564	1	32_1097	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.281219	58.791044	2	21_457	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	26
-117.38085	61.202787	3	12_1385	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	41
-116.054521	54.201	4	42_913	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.917048	58.933216	5	31_-66.1	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.498127	59.148611	6	32_5	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.823102	59.098043	7	32_29	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-113.108015	58.902997	8	32_61	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-113.408641	58.776569	9	32_93	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-113.868429	58.700418	10	32_139	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-114.490082	58.536116	11	32_182	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-115.070704	58.37997	12	32_226	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-115.324659	58.352449	13	32_242	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-115.575318	58.428252	14	32_260	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-115.861219	58.461278	15	32_283	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-116.009963	58.39	16	32_296	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-116.667527	58.077825	17	32_390	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-116.838794	58.09555	18	32_401	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.112332	57.901162	19	32_436	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.111349	57.785684	20	32_456	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.140068	57.285322	21	32_552	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.100746	57.189783	22	32_567	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.253327	56.884613	23	32_618	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.18315	56.722376	24	32_649	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.095962	56.517108	25	32_682	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.175097	56.366391	26	32_700	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.292534	56.229857	27	32_719	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.342458	56.181118	28	32_726	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.607422	56.075315	29	32_747	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-118.015784	55.905006	30	32_781	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-118.560123	55.915427	31	32_817	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-118.922379	56.05435	32	32_849	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-118.947647	56.254307	33	32_874	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-119.715961	56.173199	34	32_931	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.168979	56.096697	35	32_963	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.694012	56.139775	36	32_997	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.919789	56.204916	37	32_1015	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-121.233849	56.260575	38	32_1038	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-121.766608	56.105219	39	32_1077	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.377014	58.081537	40	42_14	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.432613	57.947942	41	42_31	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.368006	57.748058	42	42_55	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.620457	57.445802	43	42_93	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.673557	57.325483	44	42_107	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.628931	57.163868	45	42_126	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.483019	57.017856	46	42_145	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.435303	56.926446	47	42_156	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.38599	56.742948	48	42_177	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1

Appendix A - Continued

-111.775289	56.596827	49	42_195	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.192458	56.547172	50	42_241	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.712781	56.439492	51	42_293	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.514779	56.196508	52	42_325	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.63452	55.852602	53	42_376	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.61316	55.717287	54	42_394	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.755217	55.45556	55	42_437	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.886637	55.087057	56	42_486	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.743688	55.014798	57	42_500	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-113.277647	54.722893	58	42_560	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-113.58279	55.085318	59	42_616	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-114.05506	55.163852	60	42_666	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-114.28895	54.744957	61	42_720	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-114.822947	54.306642	62	42_807	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-115.357186	54.163955	63	42_860	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-115.693803	54.153973	64	42_885	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-116.01	54.169794	65	42_908	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-113.19	60.778237	66	21_96	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.343	60.260485	67	21_235	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-112.222111	60.112211	68	21_253	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.801344	59.989176	69	21_287	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.585828	59.874604	70	21_307	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.44265	59.649847	71	21_336	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.429615	59.572785	72	21_345	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.404834	59.292506	73	21_379	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-111.410284	59.16268	74	21_403	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-133.736421	67.414864	75	12_0	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-133.528233	67.406462	76	12_12	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-133.502936	67.347504	77	12_19	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-132.671607	67.201	78	12_64	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-132.142425	67.313572	79	12_91	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-131.826011	67.360463	80	12_106	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-131.497751	67.435923	81	12_123	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-130.756616	67.327527	82	12_167	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-130.39	67.277621	83	12_184	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-130.176637	66.89503	84	12_230	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-130.071318	66.780636	85	12_244	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-129.821038	66.728176	86	12_257	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-129.58626	66.707938	87	12_266	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-129.285933	66.594777	88	12_284	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-128.743959	66.359533	89	12_327	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-129.074355	66.124766	90	12_365	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-128.758218	65.737498	91	12_416	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-128.26389	65.605519	92	12_452	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-127.646749	65.461881	93	12_487	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-127.291336	65.336247	94	12_510	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-127.19	65.310447	95	12_515	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-126.620877	65.213132	96	12_545	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1

Appendix A - Continued

-126.186191	65.04712	97	12_574	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-126.092344	64.970196	98	12_584	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-125.906994	64.917244	99	12_596	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-125.152731	64.847927	100	12_635	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-124.941347	64.565963	101	12_678	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-124.779828	64.411795	102	12_693	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-124.554313	64.298539	103	12_719	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-124.358782	63.982892	104	12_758	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.905016	63.71316	105	12_801	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.751076	63.531304	106	12_823	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.571943	63.245766	107	12_857	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.292005	63.103182	108	12_879	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.228625	62.934323	109	12_899	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.201	62.697365	110	12_927	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.26441	62.449988	111	12_956	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.3256	62.25188	112	12_982	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-123.056708	62.16112	113	12_1000	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-122.559057	62.153071	114	12_1028	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-122.212802	62.088919	115	12_1049	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-121.306428	61.852094	116	12_1106	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.957523	61.832562	117	12_1125	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.744378	61.802458	118	12_1137	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.711858	61.780932	119	12_1140	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-120.665737	61.552211	120	12_1168	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-119.843375	61.316317	121	12_1223	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-119.464546	61.214967	122	12_1248	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-119.038802	61.238145	123	12_1272	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-118.572409	61.298092	124	12_1299	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-118.313111	61.447406	125	12_1322	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-117.931933	61.399	126	12_1347	0.00E+00	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.6	100	-1
-122.217	56.0167	127	07EF001	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	34.8	34	100
-123.474	65.144	128	Gr_Bear	1.60E-16	1.75E+00	0.00E+00	0.00E+00	0.00E+00	6.25	5.3	71.7
-117.758	65.598	129	Clut_L	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	107	100	12
-114.217	62.8083	130	Prosperou	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.4	100	12
-114.756	55.305	131	Lssr_Slave	4.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	576.4	575.7	11.4
-117.2698	63.1444	132	LacLaMatr	2.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.2	100	12
-121.131	60.757	133	Trout_lake	2.00E-13	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.3	100	12
-108.175	58.967	134	Davy_Lake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	102	100	12
-104.608	58.386	135	Theriau_La	2.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.7	100	12
-105.539	59.147	136	BlackLake	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.8	100	12
-107.67	61.876	137	PorterLake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	105	100	12
-108.466	62.894	138	ArtilleryLal	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101	100	12
-113.59	62.5	139	ReidLake	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.7	100	12
-126.323	60.222	140	UnknownL	1.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	116.5	100	12
-109.786	58.322	141	CluffLake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	106	100	12
-118.19	65.23	142	HottahLak	2.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.5	100	12
-107.27	63.745	143	ClintonGol	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.1	100	12
-109.871	64.133	144	MacKayLa	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.1	100	12
-115.365	64.063	145	ChalcoLak	5.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.4	100	12
-114.7	64.23	146	WekwetiLa	1.00E-12	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.05	100	12
-115.02	64.415	147	IndinRiver	5.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.15	100	12
-103.54	58.45	148	Wollaston	8.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.55	100	12

Appendix A - Continued

File name: strfw\WSC_data\lake_rules_natural.csv - used to create **yyyymmdd_rel.tb0** for naturalized flows

LongDecin	LatDecima	No	StationID	coef1	coef2	coef3	coef4	coef5	start_elv	datum	depth
-122.217	56.0167	1	Dummy	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	34.8	34	10
-111.283	58.777	2	Athabaska	1.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	208.5	205	26.1
-117.381	61.20279	3	Gr_Slave	2.50E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	156.5	156	41
-123.474	65.144	4	Gr_Bear	1.60E-16	1.75E+00	0.00E+00	0.00E+00	0.00E+00	6.25	5.3	71.7
-117.758	65.598	5	Clut_L	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	107	100	12
-114.217	62.8083	6	Prosperou	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.4	100	12
-114.756	55.305	7	Lssr_Slave_	4.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	576.4	575.7	11.4
-117.27	63.1444	8	LacLaMatr	2.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.2	100	12
-121.131	60.757	9	Trout_lake	2.00E-13	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.3	100	12
-108.175	58.967	10	Davy_Lake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	102	100	12
-104.608	58.386	11	Theriau_La	2.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.7	100	12
-105.539	59.147	12	BlackLake	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.8	100	12
-107.67	61.876	13	PorterLake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	105	100	12
-108.466	62.894	14	ArtilleryLal	1.50E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101	100	12
-113.59	62.5	15	ReidLake	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.7	100	12
-126.323	60.222	16	UnknownL	1.00E-15	1.75E+00	0.00E+00	0.00E+00	0.00E+00	116.5	100	12
-109.786	58.322	17	CluffLake	1.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	106	100	12
-118.19	65.23	18	HottahLak	2.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.5	100	12
-107.27	63.745	19	ClintonGol	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.1	100	12
-109.871	64.133	20	MacKayLa	7.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.1	100	12
-115.365	64.063	21	ChalcoLak	5.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	101.4	100	12
-114.7	64.23	22	WekwetiLa	1.00E-12	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.05	100	12
-115.02	64.415	23	IndinRiver	5.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.15	100	12
-103.54	58.45	24	Wollaston	8.00E-14	1.75E+00	0.00E+00	0.00E+00	0.00E+00	100.55	100	12

Appendix B – Master Inflow file

Sample file for the MRBHM (header and sample entries)

Note that only the first 5 inflow nodes are shown – corresponding to the first 5 entries in Appendix A

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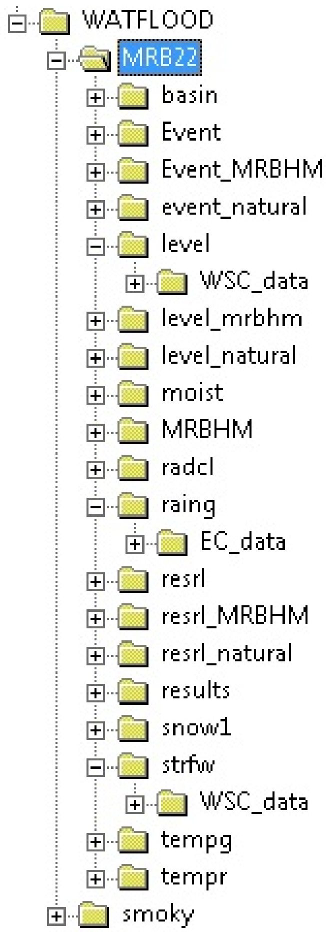
########################################
:FileType tb0  ASCII  EnSim 1.0
# DataType               Time Series
#
:Application             EnSimHydrologic
:Version                 2.1.23
:WrittenBy          watflood
:CreationDate       2016-04-08  14:56
#
#---------------------------------------
#
#SourceFile                   last spl run
:Name               MRBB_MASTER_INFLOWS
#
:StartTime          1960/1/1     0:00:00
:DeltaT  24:00:00.000   //1 day
#
:ColumnMetaData
   :ColumnType        float       float       float       float       float
   :ColumnName       32_1097.5     21_457      12_1385     42_913      31_-66.1
:EndColumnMetaData
#
:endHeader
                  90.695     639.601    1567.356      60.657      71.443
                 345.819     520.083     869.290      31.745      66.019
                 344.191     499.999     774.805      21.974      56.994
                 336.892     465.816     606.683      16.992      41.972
                 339.368     577.918     684.153      16.271      38.021
                 341.798     605.678     746.659      16.142      34.673
                 335.430     524.348     505.889      16.388      28.409
                 332.021     550.899     518.556      15.995      25.495
                 331.813     548.735     497.389      15.740      22.718       .
.
.
.
.
```

Appendix C – EC data conversion

Create files for WF from Env. Can. data

a. Note the extra data folders **WSC_data** & **EC_data** :



b.

c. The raw downloaded data is put in these **data** folders and processed there as follows:

d. **cd c:\\↵** will put you in the root

e. **cd \watflood\mrb22\raing\EC_data**

f. **ECmet↵** Will create the **raing\yyyymmdd_rag.tb0** & **tempg\yyyymmdd_tag.tb0** files for **RAGMET.exe** & **TMP.exe**

g. **cd c:\\↵** will put you in the root

h. **cd \watflood\mrb22\strfw\WSC_data**

i. **ECflw↵** Answer "**y**" for natural flows. Will create the **strfw\yyyymmdd_str.tb0** files Will take a few minutes.

j. **ECrel↵** Answer "**n**" to inser reservoir releases into the rel files. Will create the **resrl\yyyymmdd_rel.tb0 & level\yyyymmdd_ill.pt2** files Just do 1960-1961 To the question to run **natural** flow, answer **y** only for the **natural** flow case and **n** for the other 3 cases. Answer **1** for the regulated case; Answer **2** to do the rel files for the MRBHM and nudging options and answer **3** for the natural option.

k. **cd c:\↵** will put you in the root
l. **cd \watflood\mrb22\level\WSC_data**
m. **EClvl↵** Will create the **level\yyyymmdd_lvl.tb0** files Just do 1960-1961

Appendix D – Nudge flags

The file **nudge_flags.xyz** is located in the **MRB22\strfw** directory. It is activated if the **nudgeglg** = **1**in the **MRB22\event\event.evt** file. The '1' indicated that this set of nudge flags will be read in the first event and used throughout the CARM run. The data below is set up to create the **MRB_MASTER_INFLOWS.tb0** file for the MRBHM.

A value of 0 in column 3 means that the errors will not be calculated during a CHARM model run and is used to exclude these station in the objective function for the optimization runs. A value of 1 in column 3 means the the error will be calculated but the flow will NOT be nudged at that streamflow station. A value of 2 will result in the flow being nudged at that WSC station – i.e. The observed flows if available will be routed downstream instead of the computed flows.

For the CHARM runs to created naturalized flows downstream from the Bennett Dam the only change needed it at Hudson Hope, where the flag is changed from 2 to 1. This means that the computed flows from the upper Peace River will be routed downstream. To obtain naturalized flows, the watershed file is also modified by removing Williston Lake and the Bennett Dam as 'reaches'.

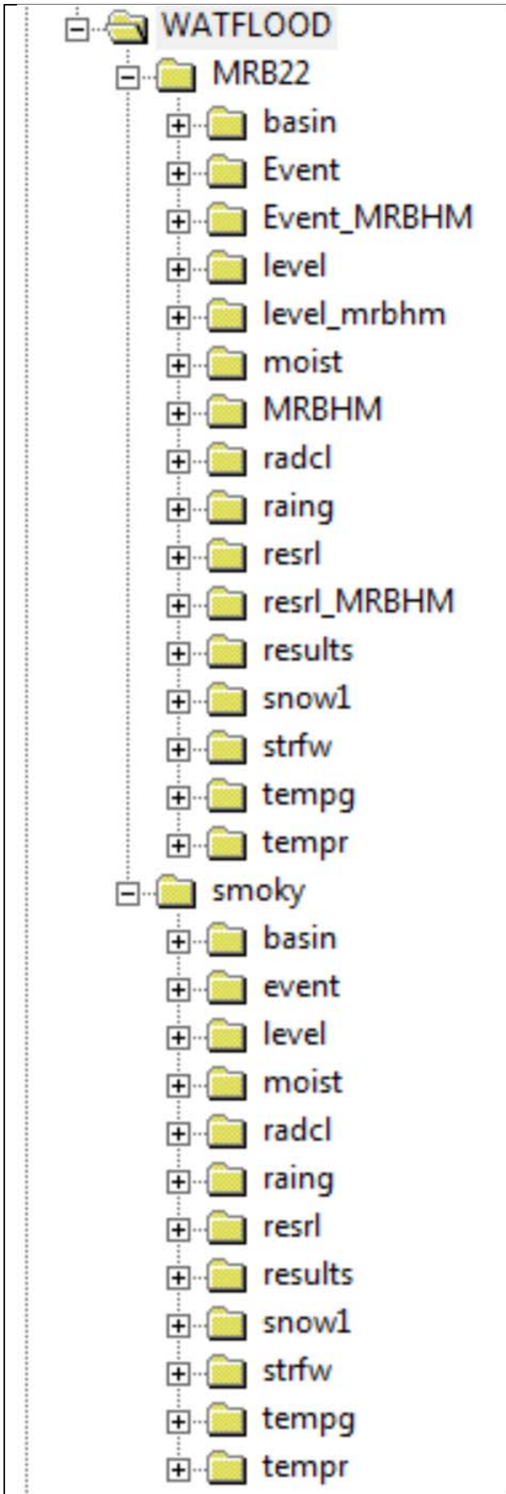
-118.059	52.910	2	07AA002	ATHABASCA RIVER NEAR JASPER	3873.
-117.569	53.424	2	07AD002	ATHABASCA RIVER AT HINTON	9765.
-116.063	54.208	2	07AE001	ATHABASCA RIVER NEAR WINDFALL	19600.
-115.840	53.990	2	07AG004	MCLEOD RIVER NEAR WHITECOURT	9109.
-116.162	53.697	2	07AG007	MCLEOD RIVER NEAR ROSEVEAR	7143.
-114.960	54.410	2	07AH001	FREEMAN RIVER NEAR FORT ASSINIBOINE	1662.
-115.332	54.228	2	07AH002	CHRISTMAS CREEK NEAR BLUE RIDGE	423.
-115.779	54.201	2	07AH003	SAKWATAMAU RIVER NEAR WHITECOURT	1145.
-113.993	54.450	2	07BC002	PEMBINA RIVER AT JARVIE	13104.
-113.288	54.722	1	07BE001	ATHABASCA RIVER AT ATHABASCA	74602.
-116.493	55.448	2	07BF002	WEST PRAIRIE RIVER NEAR HIGH PRAIRIE	1152.
-114.756	55.305	2	07BK001	LESSER SLAVE RIVER AT SLAVE LAKE	13567.
-114.231	55.256	2	07BK007	DRIFTWOOD RIVER NEAR THE MOUTH	2100.
-112.385	55.168	2	07CA006	WANDERING RIVER NEAR WANDERING RIVER	1120.
-111.195	56.680	2	07CD001	CLEARWATER RIVER AT DRAPER	30792.
-111.410	56.595	2	07CD004	HANGINGSTONE RIVER AT FORT MCMURRAY	962.
-111.402	56.780	1	07DA001	ATHABASCA RIVER BELOW MCMURRAY	132585.
-111.195	56.890	2	07DA006	STEEPBANK RIVER NEAR FORT MCMURRAY	1320.
-111.548	57.210	2	07DA008	MUSKEG RIVER NEAR FORT MACKAY	1457.
-112.010	57.120	2	07DB001	MACKAY RIVER NEAR FORT MACKAY	5569.
-111.195	57.651	2	07DC001	FIREBAG RIVER NEAR THE MOUTH	5988.
-111.515	58.313	1	07DD001	ATHABASCA RIVER AT EMBARRAS AIRPORT	155000.
-125.105	56.731	2	07EA004	INGENIKA RIVER ABOVE SWANNELL RIVER	4140.
-125.251	57.130	2	07EA005	FINLAY RIVER ABOVE AKIE RIVER	15600.
-124.899	57.210	2	07EA007	AKIE RIVER NEAR THE 760 M CONTOUR	1690.
-123.936	56.524	2	07EB002	OSPIKA RIVER ABOVE ALEY CREEK	2190.
-124.568	55.917	2	07EC002	OMINECA RIVER ABOVE OSILINKA RIVER	5560.
-124.582	56.214	2	07EC003	MESILINKA RIVER ABOVE GOPHERHOLE CREEK	3060.
-124.802	56.127	2	07EC004	OSILINKA RIVER NEAR END LAKE	1950.
-123.633	55.427	2	07ED003	NATION RIVER NEAR THE MOUTH	6790.
-122.905	55.078	2	07EE007	PARSNIP RIVER ABOVE MISINCHINKA RIVER	4930.
-123.037	54.999	2	07EE010	PACK RIVER AT OUTLET OF MCLEOD LAKE	3710.
-121.909	56.027	2	07EF001	PEACE RIVER AT HUDSON HOPE	73100.

-120.814	56.205	1	07FA004	PEACE RIVER ABOVE PINE RIVER	87200.
-122.355	56.460	2	07FA005	GRAHAM RIVER ABOVE COLT CREEK	2140.
-121.629	56.251	2	07FA006	HALFWAY RIVER NEAR FARRELL CREEK	9340.
-121.212	55.718	2	07FB001	PINE RIVER AT EAST PINE	12100.
-121.367	56.092	2	07FB008	MOBERLY RIVER NEAR FORT ST. JOHN	1520.
-120.700	56.278	2	07FC001	BEATTON RIVER NEAR FORT ST. JOHN	15600.
-121.222	56.678	2	07FC003	BLUEBERRY RIVER BELOW AITKEN CREEK	1770.
-120.564	55.957	2	07FD001	KISKATINAW RIVER NEAR FARMINGTON	3630.
-120.672	56.139	1	07FD002	PEACE RIVER NEAR TAYLOR	101000.
-118.607	55.919	1	07FD003	PEACE RIVER AT DUNVEGAN BRIDGE	135397.
-120.030	55.865	2	07FD007	POUCE COUPE RIVER BELOW HENDERSON CREEK	2860.
-119.680	56.308	2	07FD009	CLEAR RIVER NEAR BEAR CANYON	2879.
-120.057	56.127	1	07FD010	PEACE RIVER ABOVE ALCES RIVER	121000.
-118.680	56.405	2	07FD012	MONTAGNEUSE RIVER NEAR HINES CREEK	230.
-119.702	55.079	2	07GD004	REDWILLOW RIVER NEAR RIO GRANDE	1249.
-118.803	55.071	2	07GE001	WAPITI RIVER NEAR GRANDE PRAIRIE	11300.
-117.206	54.752	2	07GG001	WASKAHIGAN RIVER NEAR THE MOUTH	1040.
-117.162	55.456	2	07GH002	LITTLE SMOKY RIVER NEAR GUY	11100.
-117.623	55.715	2	07GJ001	SMOKY RIVER AT WATINO	50300.
-117.130	56.056	2	07HA003	HEART RIVER NEAR NAMPA	1968.
-117.618	56.920	2	07HC001	NOTIKEWIN RIVER AT MANNING	4679.
-116.029	58.388	1	07HF001	PEACE RIVER AT FORT VERMILION	227026.
-115.389	57.875	2	07JD002	WABASCA RIVER AT HIGHWAY NO. 88	35800.
-116.405	58.448	2	07JF002	BOYER RIVER NEAR FORT VERMILION	6660.
-116.340	58.610	2	07JF003	PONTON RIVER ABOVE BOYER RIVER	2436.
-112.437	59.118	1	07KC001	PEACE RIVER AT PEACE POINT (ALBERTA)	293000.
-104.606	58.388	2	07LB002	WATERFOUND RIVER BELOW THERIAU LAKE	3160.
-105.543	59.150	2	07LE002	FOND DU LAC RIVER AT OUTLET OF BLACK LAK	50700.
-109.789	58.319	2	07MA003	DOUGLAS RIVER NEAR CLUFF LAKE	1690.
-108.173	58.967	2	07MB001	MACFARLANE RIVER AT OUTLET OF DAVY LAKE	9120.
-111.583	59.872	1	07NB001	SLAVE RIVER AT FITZGERALD (ALBERTA)	606000.
-115.860	60.743	2	07OB001	HAY RIVER NEAR HAY RIVER	51700.
-118.334	58.597	2	07OC001	CHINCHAGA RIVER NEAR HIGH LEVEL	10370.
-107.585	61.876	2	07QD004	TALTSON RIVER ABOVE PORTER LAKE OUTFLOW	9660.
-108.466	62.894	2	07RD001	LOCKHART RIVER AT OUTLET OF ARTILLERY LA	26600.
-115.433	63.974	2	07SA002	SNARE RIVER BELOW GHOST RIVER	13300.
-115.022	64.410	2	07SA004	INDIN RIVER ABOVE CHALCO LAKE	1520.
-114.220	62.559	2	07SB002	YELLOWKNIFE RIVER AT OUTLET OF PROSPEROU	16300.
-114.261	62.672	2	07SB003	YELLOWKNIFE RIVER AT INLET TO PROSPEROUS	11300.
-113.523	62.491	2	07SB010	CAMERON RIVER BELOW REID LAKE	3630.
-110.488	63.048	2	07SC002	WALDRON RIVER NEAR THE MOUTH	1830.
-116.975	63.108	2	07TA001	LA MARTRE RIVER BELOW OUTLET OF LAC LA M	13900.
-128.907	60.051	2	10AA001	LIARD RIVER AT UPPER CROSSING	32600.
-129.550	60.204	2	10AA004	RANCHERIA RIVER NEAR THE MOUTH	5100.
-129.119	60.474	2	10AB001	FRANCES RIVER NEAR WATSON LAKE	12800.
-126.097	59.412	2	10BE001	LIARD RIVER AT LOWER CROSSING	104000.
-125.383	58.855	2	10BE004	TOAD RIVER ABOVE NONDA CREEK	2540.
-125.940	59.336	2	10BE007	TROUT RIVER AT KILOMETRE 783.7 ALASKA HI	1170.
-126.481	59.630	2	10BE013	SMITH RIVER NEAR THE MOUTH	3740.
-121.464	58.271	2	10CA001	FONTAS RIVER NEAR THE MOUTH	7400.
-122.691	57.238	2	10CB001	SIKANNI CHIEF RIVER NEAR FORT NELSON	2180.
-125.411	61.530	2	10EA003	FLAT RIVER NEAR THE MOUTH	8560.
-125.797	61.636	2	10EB001	SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS	14500.
-123.475	60.242	2	10ED001	LIARD RIVER AT FORT LIARD	222000.
-121.228	61.743	2	10ED002	LIARD RIVER NEAR THE MOUTH	275000.
-119.843	61.140	2	10FA002	TROUT RIVER AT HIGHWAY NO. 1	9270.
-117.545	61.261	1	10FB001	MACKENZIE RIVER NEAR FORT PROVIDENCE	980000.
-121.190	61.390	2	10FB005	JEAN-MARIE RIVER AT HIGHWAY NO. 1	1310.
-120.792	61.817	1	10FB006	MACKENZIE RIVER AT STRONG POINT	0.
-123.610	62.610	2	10GA001	ROOT RIVER NEAR THE MOUTH	9820.
-122.899	62.650	2	10GB006	WILLOWLAKE RIVER ABOVE METAHDALI CREEK	20200.
-121.359	61.868	1	10GC001	MACKENZIE RIVER AT FORT SIMPSON	1301440.

-121.612	61.794	2	10GC003	MARTIN RIVER AT HIGHWAY NO. 1	2050.
-128.214	64.137	2	10HA004	KEELE RIVER ABOVE TWITYA RIVER	11200.
-125.297	63.924	2	10HB005	REDSTONE RIVER 63 KM ABOVE THE MOUTH	15400.
-123.481	63.244	1	10HC007	HODGSON CREEK NEAR THE MOUTH	0.
-123.569	63.492	2	10HC008	OCHRE RIVER NEAR THE MOUTH	0.
-117.758	65.598	2	10JA002	CAMSELL RIVER AT OUTLET OF CLUT LAKE	32100.
-123.551	65.128	2	10JC003	GREAT BEAR RIVER AT OUTLET OF GREAT BEAR	146400.
-126.850	65.272	1	10KA001	MACKENZIE RIVER AT NORMAN WELLS	1594500.
-127.683	65.295	2	10KB001	CARCAJOU RIVER BELOW IMPERIAL RIVER	7400.
-133.090	66.787	2	10LA002	ARCTIC RED RIVER NEAR THE MOUTH	18750.
-128.790	66.515	2	10LB004	LOON RIVER NEAR THE ARCTIC CIRCLE	0.
-129.283	66.693	1	10LB007	TIEDA RIVER NEAR THE MOUTH	0.
-133.863	67.754	2	10LC003	RENGLENG RIVER BELOW HIGHWAY NO. 8 (DEMP	1300.
-133.753	67.456	1	10LC014	MACKENZIE RIVER AT ARCTIC RED RIVER	1679100.
-128.260	66.401	2	10LD004	HARE INDIAN RIVER NEAR FORT GOOD HOPE	0.
-136.038	65.893	2	10MA001	PEEL RIVER ABOVE CANYON CREEK	25500.
-138.276	64.901	2	10MA003	BLACKSTONE RIVER NEAR CHAPMAN LAKE AIRST	1180.
-134.889	67.259	2	10MC002	PEEL RIVER ABOVE FORT MCPHERSON	70600.
-108.774	60.050	2	07QC005	ABITAU RIVER ABOVE CUMING LAKE	3780.
-108.318	59.794	2	07QC006	TAZIN RIVER ABOVE TAZIN LAKE	2170.
-110.664	60.409	2	07QC007	TAZIN RIVER NEAR THE MOUTH	0.
-108.871	59.641	2	07QC008	CHARLOT RIVER AT OUTLET OF WEBB LAKE	169.
-111.512	60.467	2	07QD007	TALTSON RIVER BELOW HYDRO DAM	0.
-113.065	58.325	2	07KE001	BIRCH RIVER BELOW ALICE CREEK	9856.
-121.810	61.189	2	10ED003	BIRCH RIVER AT HIGHWAY NO. 7	542.

Appendix E –Workshop “hands-on”

WATFLOOD file structure



- The file structure is explained in Section 1.1.3 of the WATFLOOD manual. Each type of data file is in a separate directory.
- It is recommended that the WATFLOOD directory be in the root directory on the C: drive and that it be in the computer's path so all executables can be put there.
- Each watershed model has its own directory under WATFLOOD
- Names are meant to be self-explanatory:
    - basin for watershed files
    - event is for config files
    - level is for water level data
    - moist is for initial moisture
    - MRBHM for the master inflow file
    - radcl for gridded precip.
    - raing for point precip
    - resrl for reservoir/lake rules & releases
    - results for model output
    - snow1 for SWE data
    - strfw for flow data
    - tempg for point temperatures
    - tempr for gridded temperature
- For the MRBHM there are 3 extra directories as in addition to the lakes(=reaches) that are normally incorporated in the watershed file, there are additional reaches needed to create inflows at the inflow nodes of the MRBHM. This requires separate files for the level and reservoir data for each reach
- The 2 sets of event files point to the respective sets of files
- the MRBHM directory receives the MRB_master_inflow.tb0 file
- ***Point data files for both MRB22 & Smoky are the same. Gridded files match watershed grid.***

Some basic DOS commands

Start in the root directory: C:

cd \\↵	makes the root directory the working directory – same drive
dir↵	shows the files in the working directory
cd watflood↵	makes watflood the working directory
cd smoky↵	makes smoky the working directory
cd ..\mrb22↵	changes from the smoky to the mrb22 directory
cd .. ↵	
dir event↵	shows files in the event directory
dir *.csv file_names.txt	creates a txt file with the list of csv files
del filename.extension↵	deletes this file
del *.* ↵	deletes all files in the working directory
copy junk.txt garbage.*↵	copies file to a different name but same extension
del *.bak ↵	deletes all files with extension bak
cls ↵	clears the screen – often handy
PATH=%PATH%;C:\WATFLOOD↵	Adds the C:\WATFLOOD directory to the path

WATFLOOD commands (i.e. programs)

eg. executables in the PATH::

ECmet↵	creates point precip & temp files
ECflw↵	creates flow files
ECrel↵	creates rel files
EClvl↵	creates level files
moist64↵	executes the soil moisture distribution model
snw64↵	distributes point swe to gridded swe
ragmet64x	distributes point precip to gridded precip
tmp64x	distributes point temperatures to gridded temepratures
charm64x↵	executes the model (please download from watflood.ca/executables) OR,

with the executables in the watflood directory (folder)

..\\..\\..\ecMET↵	creates point precip & temp files
..\\..\\..\ECflw↵	creates flow files
..\\..\\..\ECrel↵	creates rel files
..\\..\\..\EClvl↵	creates level files
..\moist64↵	executes the soil moisture distribution model
..\snw64↵	distributes point swe to gridded swe
..\ragmet64x	distributes point precip to gridded precip
..\tmp64x	distributes point temperatures to gridded temepratures
..\charm64x↵	executes the model (please download from watflood.ca/executables)

WATFLOOD Session

1. Open a window and create a directory called **WATFLOOD** – preferably in the root of C:
2. Add the WATFLOOD directory to your path with the command in a DOS window: **PATH=%PATH%;C:\WATFLOOD↵**
3. Open your DVD drive in another window AND:
    a. Drag the MRB22 & Smoky folders into the C:\WATFLOOD directory (folder)
        i. Do the **smoky** first, then **MRB22**
    b. For 64 bit, drag all execs into C:\WATFLOOD (or where you have your path)
    c. For 32 bit, open the 32bit_execs folder and drag those execs into C:\WATFLOOD
4. Open the WATFLOOD folder and right click on **MRB22**, then click on P**roperties**, and then on the **Read-only box** to make it blank and **Apply**. Then OK
5. Do the same on the Smoky folder
6. From the start menu, open a **Window**.
    a. Go to the **watflood\mrb22\basin** folder and copy **Mack_LC_theme.thm**
    b. Go to the **c:\program Files\CHC\GreenKenue64\Templates\GeoTIFF** window and paste the file there (if you have permission to do this)
7. Open a **DOS** window: If it is not in your **Windows Start** menu, open it in "**Search for programs and files**" with **CMD.**
    a. Maximize the window
    b. Click in the top bar and under properties set the **buffer size** to **999**
    c. Go to the **C:** drive
8. Enter **cd \watflood\smoky**
    a. The Smoky watershed is set up to run from 1960 – 2015 but we will run only 2007 - 2015
    b. Enter **moist64** This creates an initial gridded soil moisture file from point values (for 32 bit users, replace 64 by 32 for the rest of the day)
    c. Enter **snw64** This creates an initial gridded SWE file from point values
    d. Enter **ragmet64x** (or ragmet32x if you are on a 32 bit pc – ditto for other programs) This creates a gridded precip file from point data
    e. Enter **tmp64x** This creates a gridded temp file from point data and also a gridded file with daily temp differences needed for the Hargreaves ET model
    f. Enter **charm64x** This will run the model
9. **Intro to Green Kenue**
    a. Open **Green Kenue** (GK)
    b. Maximize GK window
    c. In the **file** menu, open **c:\watflood\mrb22\basin\mrb22.wsd**
    d. Double Click on **DEM,** drag into the 2D view, and change **wireframe** to **surface**
    e. Double click on **DEM** and then **colour scale** and the **levels** to 40, and change **Linear** to **Quadratic** and hit **apply**
    f. **Now** click on **Colour Scale** and double click on the top colour grid. Change it to **red** and then click on **Colours** and then **Apply**

g. Drag **Channels** into the 2D view
h. double click on **Channels** and in **display** change the point size to 1; change to **monochrome** and the colour to **white**
i. Open **c:\watflood\smoky\flow_station_location.xyz** – in the bottom right dialogue box look for **Point Sets xyz**
j. Drag the **flow_station_location** into the 2D view
k. Double click on **flow_station_location** and change to **monochrome** and check the **show node label**s , change to bold and make the **point size = 16**
l. The **Smoky River at Watino** is station #52. Find this station and zoom in so it ends up near the top of the 2D view
m. Click on **Channels** in the left menu bar to activate this item in the 2D view. Now double click on the channel at station 52 and see a info box appear. The left click there, add basin and call it **Smoky**
n. Double click on **Smoky** in the left menu bar and change colour to **black**
o. For fun, click on **File, Base Maps, 1:1,000,000 & Cities**
p. **Save the workspace: File, Save Workkspace** as **Smoky** in the **c:\watflood\smoky directory**

10. Looking at the Smoky results

a. **In GK: File → Open .wfo file type: smoky\results\ watflood.wfo**
b. Drag **Grid Outflow** into the 2D view
c. Drag **Channels, Smoky, Cities & flow_station_location** to the top of the 2D view list
d. Change the colour of the **flow_station_location** points to white: double click on the name and use the dialogue box
e. <u>Left</u> click on **Grid Outflow** and click on **animate**
f. Double click on **Grid Outflow,** click on **ColourScale** and change **linear** to **NLog**, **min** to **0**, **Levels** to **40,** check **Show Legend** & **Apply**
g. Fix the colour scale – click on **Col,** change the top box to **red, and click on Col** again and then **OK** Then resize he legend: click on it, drag it to a better place and resize.
h. Double click on the box at station # **52, then right click** and **extract time series**
i. Open a 1D view (squiggly line), place at bottom of the viewing area and reduce its size. Resize the 2D view to a larger view
j. Click on the top bar of the 1D view and in **View → Select Sync. View** and answer with 2D View (1)
k. Drag the **Grid Outflow** (X….. in to **1DView (2)** in the left dialogue bar. This shows the time of the 2D view
l. Hit the **play** button to see the animation. You can jump to anywhere in the time series by clicking the cursor on the play bar.
m. You can zoom in on any part of the hydrograph by messing with your mouse – dragging it & running the wheel and holding down the right key while dragging the mouse.

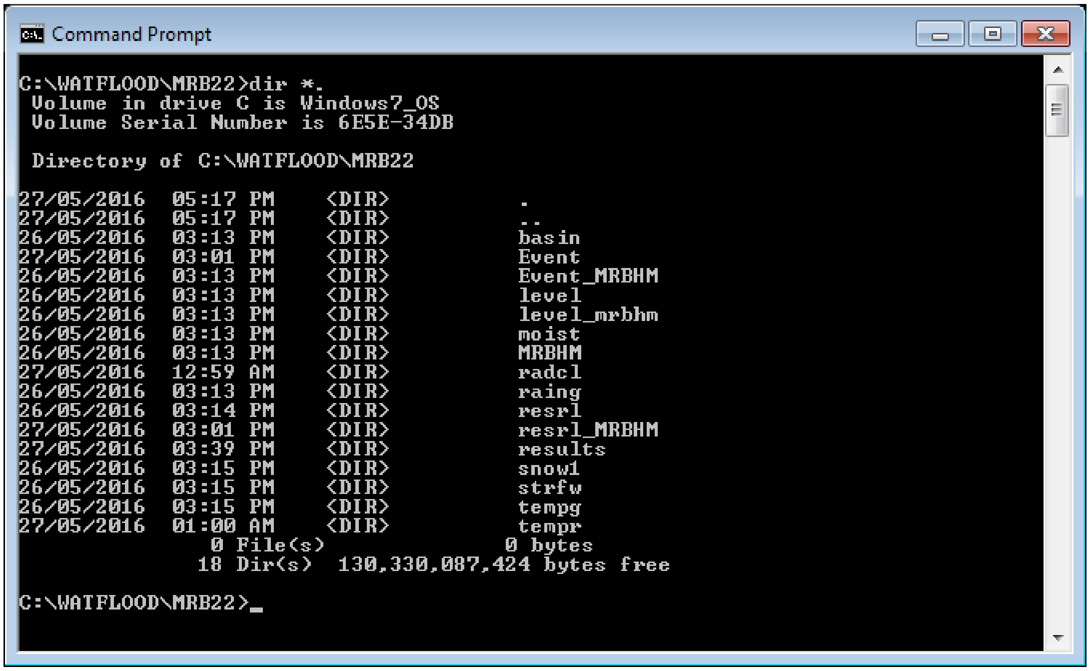
n. There seems to be a problem at gauge # 50 – the flow bypasses the gauge!!!!! Good trouble shooting in GK Can be fixed by rerouting the flow through the grid. Wrong flows at this station probably did not help the optimization for the Smoky.
o. Drag **Weighted SWE** into the 2D view, right click on this and then on **animate**
p. Repeat step (c).
q. Fix the colour scale as in (g) above with increments of 10 and 40 levels.
r. Extract time series as in (h) above and open a new 1D view, Drag the time series into the 1D View(2)
s. repeat step (j) above & animate (Note: Snow course data can be read in by CHARM and file with observed & computed SWE for each snow course is produced for further analysis)
t. Can this be real ? – Show DEM (make the **SWE** & **GridOutflow** invisible); Double click on DEM and then click on **ColourScale**, set colour scale to min = 500, interval = 50, **linear** mode Note headwaters in mountains & outlet in lowlands. Answer: certainly possible.
u. Drag **Cumulative Precipitation** into the 2D view, right click on this and then on **animate**
v. Then **animate** to the end of the time series to the double arrow
w. Double click on **Cumulative Precipitation**, then **Colour Scale** and then check **Show Legend,** and **Apply**
x. Check that there is precip everywhere in the Smoky watershed
y. Extract a time series for the highest & lowest precip, open a new 1D view and drag both time series into the 1D view – the largest one first. This is a good check on the precip. Flat spots mean missing data at nearby stations & radius of influence too small.
z. Drag **WeightedCumm ET** into the 2D view, right click on this and then on **animate**
aa. Then animate to the end of the time series to the double arrow
bb. Double click on **WeightedCumm ET**, then **Colour Scale** and then check off **Show Legend**
cc. Note: Highest ET where the lowest Precip - Lowest ET where the highest Precip!!!!
dd. Done with GK for now. Leave window open.
ee. Open an EXEL spreadsheet and load **c:\watflood\smoky\results\spl.csv** (= text file)
ff. In the file **c:\watflood\smoky\flow_station_location.xyz** are the obs./comp. plotting columns for each station. #52 = cz & da # 51 = cx & cy #50 – cv & cw # 49 = ct& cu # 48 = cr & cs
gg. So go to cols **cz** & **da** and select these 2, then **insert** a double line continuous curve and expand the graph.
    i. Note: There are 2 columns for each flow station – all the stations for the Mackenzie river basin are in the file. When running a sub-basin, the same str file can be used. Stations outside the sub-watershed just do not have computed flows.
hh. Close Excel
ii. **Done this part.**

Mackenzie River watershed model for the MRBHM – set up for 2 years

jj. Open a **DOS** window & do the following commands:
kk. **cd c:\↵** will put you in the root (or if to another drive – e.g. **d:↵**)

ll. **cd watflood\mrb22↵** will put you in the **MRB22** working directory

mm. **dir *.↵** will show a list of directories in **MRB22** as follows

nn. 

```
Command Prompt
C:\WATFLOOD\MRB22>dir *.
 Volume in drive C is Windows7_OS
 Volume Serial Number is 6E5E-34DB

 Directory of C:\WATFLOOD\MRB22

27/05/2016  05:17 PM    <DIR>          .
27/05/2016  05:17 PM    <DIR>          ..
26/05/2016  03:13 PM    <DIR>          basin
27/05/2016  03:01 PM    <DIR>          Event
26/05/2016  03:13 PM    <DIR>          Event_MRBHM
26/05/2016  03:13 PM    <DIR>          level
26/05/2016  03:13 PM    <DIR>          level_mrbhm
26/05/2016  03:13 PM    <DIR>          moist
26/05/2016  03:13 PM    <DIR>          MRBHM
27/05/2016  12:59 AM    <DIR>          radcl
26/05/2016  03:13 PM    <DIR>          raing
26/05/2016  03:14 PM    <DIR>          resrl
27/05/2016  03:01 PM    <DIR>          resrl_MRBHM
27/05/2016  03:39 PM    <DIR>          results
26/05/2016  03:15 PM    <DIR>          snow1
26/05/2016  03:15 PM    <DIR>          strfw
26/05/2016  03:15 PM    <DIR>          tempg
27/05/2016  01:00 AM    <DIR>          tempr
               0 File(s)              0 bytes
              18 Dir(s)  130,330,087,424 bytes free

C:\WATFLOOD\MRB22>_
```

oo. To create the master inflow file, all recorded flow files (strfw), precip (raing & radcl), temperatures (tempg & tempr) as well as the initial soil moisture (moist) and SWE (snow1) are common with running a normal WATFLOOD model (i.e. with WATFLOOD routing). However, **event, level & resrl** files are different for creating a master inflow file. So there are 2 directories for each of these with the appropriate files. We will now look at these files: open your favourite text editor. **Wordpad** if you don't have one.

pp. Open the files **c:\watflood\mrb22\event\1960.evt** & **c:\watflood\mrb22\event\1960_mrbhm.evt** (make sure you don't get the backup)

  i. Note: <u>both</u> of these are in the **mrb22\event** folder

  ii. Note the latter has **routeflg = q** to tell **CHARM** to write the master inflow file and **nudgeflg = 1** to tell it to use the **strfw\nudge_flags.xyz**

  iii. Note: the **strfw\nudge_flags.xyz** can be opened in GK so the values in col 3 can he shown in the 2D view. This is a way of checking that the proper stations are nudged.

  iv. Note that the **lvl, ill & rel** file names are different. This is only because there are 24 lakes (reaches) in the regular MRB model & 124 more for the MRBHM (2 are common – Lake Athabaska & Great Slave lake)

  v. Note: these event files are "config" files really.

  vi. Note the list of events to be run in succession at the bottom of the evt file.

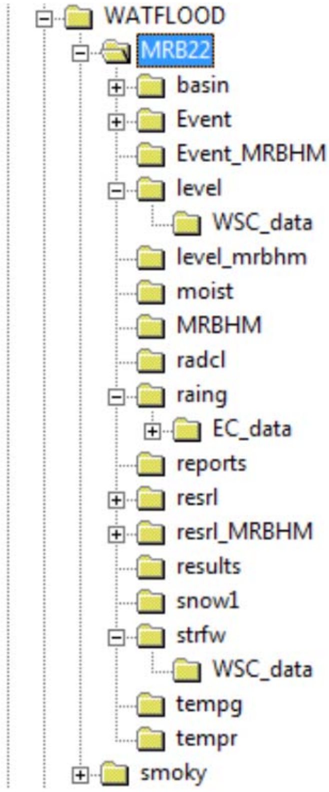
qq. In **1960_mrbhm.evt** set the **kenueflg = a** and save as **event.evt** This will write a default **results\watflood.wfo** file

rr. In **1960_mrbhm.evt** change :**noeventstofollow** from **55** to **1** This means we will run the model for only 2 years (to get done today)

ss. <u>Save as</u> **event.evt** <u>This makes this the active event file</u>. event\event.evt is the default file

11. Updating data files files for WATFLOOD from Env. Can. data

a. Note the extra data folders **WSC_data** in the **level** & **strfw** folder and **EC_data** in the **raing** folder **:**

b. 

c. The raw downloaded data is put in these **data** folders and processed there as follows:

d. Look in each of the folders **raing\EC_data**, **strfw\WSC_data** & **level\WSC_data**

e. **cd c:\\↵** will put you in the root - then **cd \watflood\mrb22\raing\EC_data OR**

f. if already in **MRB22** then just **cd raing\EC_data**

g. **..\\..\\..\ECmet↵ OR c:\watflood\ECmet↵** Do 1960 – 1961 Will create the **raing\yyyymmdd_rag.tb0** & **tempg\yyyymmdd_tag.tb0** files for **RAGMET.exe** & **TMP.exe**

   i. use **..\\..\\..** if execs not in PATH OR enter the whole path.

   ii. Note: leave out **..\\..\\..** if execs are in the path

h. **cd c:\\↵** will put you in the root

i. **cd \watflood\mrb22\strfw\WSC_data**

j. **..\\..\\..\ECflw↵** Answer "**y**" for natural flows. Enter 1958 – 1959, let it start and then hit **Ctrl C↵** !!!!!! Takes too long but will create the **strfw\yyyymmdd_str.tb0** files from HYDAT & provisional flow data. Would take 10 – 20 minutes to read in 120 HYDAT files.

k. **..\\..\\..\ECrel↵** Do 1960 – 1961 Answer "**n**" to insert reservoir releases into the rel files. Will create the **resrl\yyyymmdd_rel.tb0 & level\yyyymmdd_ill.pt2** files 1 Answer **2** to do the rel files for the MRBHM option

l. **cd c:\\↵** will put you in the root

m. **cd \watflood\mrb22\level\WSC_data**

n. **..\..\..\EClvl↵** Do 1960 – 1961 Will create the **level\yyyymmdd_lvl.tb0** files

12. **Run the model:** it is set to run just 2 years (in the event file)

a. In **DOS** window be in the **watflood\mrb22** directory

b. Execute the watflood programs in the dos window. If execs are in **Dr:\WATFLOOD:**

c. **..\snw64↵** < 1 sec. **if in the path:** **snw64↵**

d. **..\moist64↵** < 1 sec. **moist64↵**

e. **..\ragmet64x↵** ~ 1 min. **ragmet64x↵**

f. **..\tmp64x↵** ~ 1 min. **tmp64x↵**

g. **..\charm64x↵** ~ 10 min. **charm64x↵**

13. Open the **watflood\mrb22\mrbhm\MRB_MASTER_INFLOWS.tb0** file and have a look

a. Note: Some stations need to be renamed

i. 32_1097 must be 32_1097.5

ii. 31_66.1 must be 31_-66.1

iii. 42_325 must be 42_325.05341

14. Go back to GK window.

a. Delete **watflood.wfo** in the current GK window

b. **Open watflood\ MRB22\results\watflood.wfo**

c. Zoom way out to show the whole Mackenzie watershed

d. Drag **Grid Outflow i**nto 2D view and zoom out

e. Right click in **Grid Outflow** and **animate**

f. Double click on **Grid Outflow,** change **min** to **0, levels** to **40, and linear** to **NLog,** hit **Apply** and fix the colour scale

g. Drag **Channels, Flow station location** and **cities** to the top of the 2D view

h. So I forgot to make a watershed outline for the Mackenzie River basin. Click on **Channels** in the workspace window – it will be highlighted. Now double click in the river outline just below Arctic Red River. Zoom in first. The Right click & **add basin**. Call it **Mackenzie**.

i. Click on **File**, then **Save Copy As** - go to **mrb22\basin\i3s_files** - and hit **save**

j. Change the colour of the line to red and make the line width 3

k. Note: Flows in the Athabaska, Peace, Slave & Mackenzie are missing as they were written to the master inflow file and not routed.

l. Extract a time series for the **Liard** near Fort Simpson.

m. Close all 1D views and open a new one

n. Drag the **Liard** time series into the 1D view (in the workspace bar)

o. Click on the 1D view window and then **View** and **Select Sync View**, and pick **2D view (1)**

p. Hit the **play** button You can rewind, step through forward of backward. Try it.

15. NK show other files. rag, met, tag, tem, str, rel, ill

16.Q & A ☺

Appendix F – Alternative Lake Athabasca Rule

Q_out = c * k *[abs(Z_LA – Z_P)]^n * [max(Z_1, Z_P, Z_LA) –Z_1]^m

Where,

Z_P = (Q_PP/Q_ref)^a + Z_2

k = -1 when Z_P > Z_LA
k = +1 when Z_P <= Z_LA

Z_LA = elevation of Lake Athabasca (m)
Q_PP = Peace River flow at Peace Point (m3/s)
Q_out = outflow from Lake Athabasca (m3/s)

a, c, n, m, Z_1, Z_2, and Q_ref are calibrated parameters:

a = 1.0708
c = 632.404 (natural condition) or 701.036 (weir)
n = 0.9407 (natural condition) or 0.7818 (weir)
m = 0.2529
Z_1 = 204.000 m (natural condition) or 206.724 m (weir)
Z_2 = 205.209 m
Q_ref = 1741 m3/s