Deterministic Hydrological Prediction System (DHPS) v3.1.0

Technical Note

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Last update:
August 15, 2021
Version 3.1.0

REVISIONS			
Version	**Date**	**Author/changed by Auteur/changé par**	**Remarks/Remarques**
1.0.0	July 16, 2019	Étienne Gaborit, Dorothy Durnford	First draft
3.1.0	August 15, 2021	Étienne Gaborit, Dorothy Durnford, Vincent Fortin, Nathalie Gauthier, Silvia Innocenti	Updates for v3.1.0

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Nomenclature

Acronym	Definition
CaLDAS-Sat	Canadian Land Data Assimilation System based on Satellite data
CaPA	Canadian Precipitation Analysis
CMC	Canadian Meteorological Centre
CCMEP	Canadian Centre for Meteorological and Environmental Prediction
DHPS	Deterministic Hydrological Prediction System
ECCC	Environment and Climate Change Canada
GDPS	Global Deterministic Prediction System
HRDLPS	High Resolution Deterministic Land Prediction System
HRDPS	High Resolution Deterministic Prediction System
HREPA	High Resolution Ensemble Precipitation System
IC-3	Innovation Cycle 3
NHS	National Hydrological Service
NSRPS	Surface and River Prediction System
LZS	Lower Zone Storage
MRD	Meteorological Research Division
RDPS	Regional Deterministic Prediction System
SHOP	Operational Hydrodynamic Prediction System
SVS	Soil, Vegetation and Snow
WCPS	Water Cycle Prediction System

Summary

This technical note describes the Deterministic Hydrologic Prediction System (DHPS) v3.1.0. DHPS is a component of the National Surface and River Prediction System (NSRPS). In this document, we describe NSRPS, present the WATROUTE model used in DHPS and the evaluation of the final cycles for DHPS v3.1.0. Environment and Climate Change Canada's (ECCC) CPOP accepted DHPS v3.1.0 for implementation in Operations on June 22, 2021.

1. System Overview

Environment and Climate Change Canada's (ECCC) Canadian Meteorological Centre (CMC) implemented the new National Surface and River Prediction System (NSRPS; also known as GEM-Hydro) as an experimental system in 2019. CMC includes scientists from the Meteorological Research Division (MRD) and the Canadian Centre for Meteorological and Environmental Prediction (CCMEP). NSRPS aims to provide the best possible representation of the current and future states of the land surface, as well as the movement of water over and through the soil column and through the lake and river networks.

NSRPS currently contains five components to represent analysed precipitation and the current and future states of the land and the rivers. The Deterministic Hydrological Prediction System (DHPS) is the one-dimensional, river discharge routing component of NSRPS. DHPS is currently implemented at a 1-km resolution over six river basins representing ~50% of Canada. These domains are presented in Fig. 1. Products from DHPS are of interest to multiple levels of government, academia, water managers, hydro-electric producers, and the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

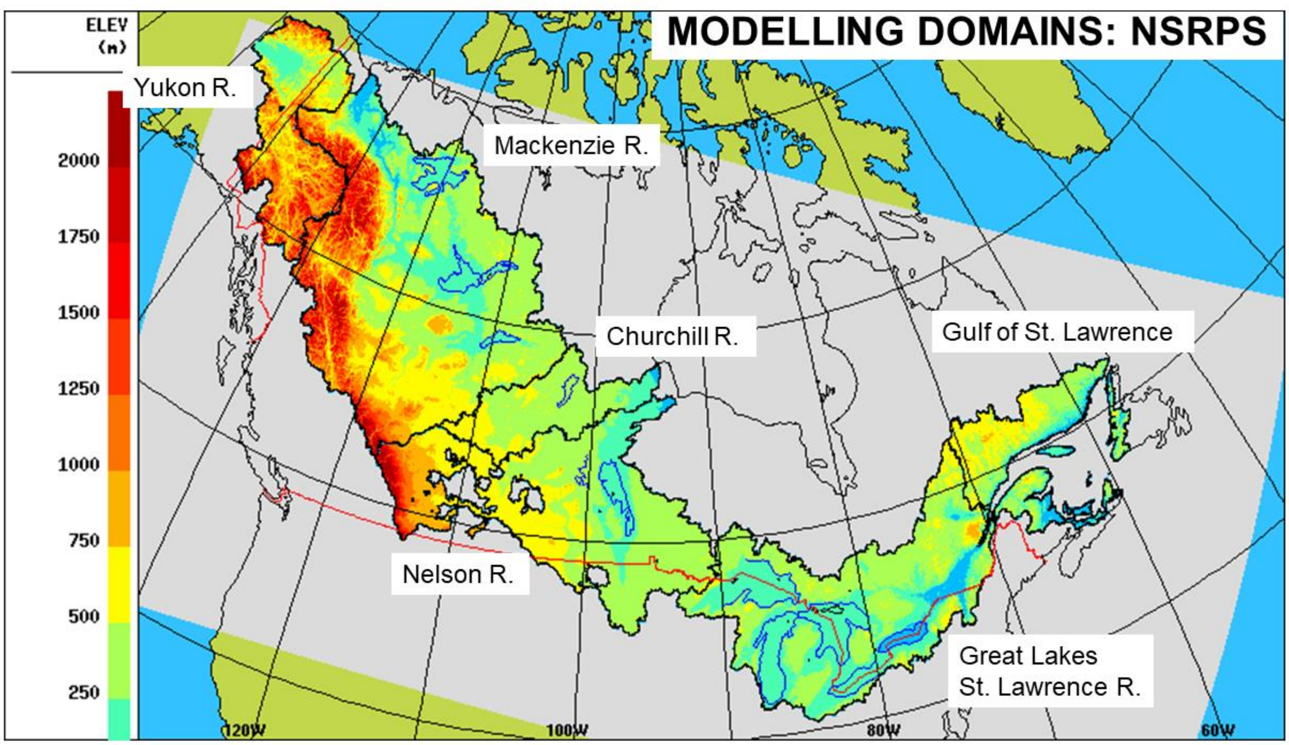

Fig. 1. The six domains represented by DHPS v3.1.0. The colours represent terrain elevation (m) and the solid black lines the boundaries of the river basins. The grey rectangle is the national domain used by NSRPS for precipitation analyses and for analyses and forecasts of the near-surface atmosphere, the land surface and the soil column.

DHPS produces hourly estimates, both analysed and forecast, of river discharge, the volume of water stored in the river channel or at the outlet of an explicitly represented natural lake or regulated reservoir, and the depth of the water in the subterranean reservoir. DHPS also provides 12-hourly estimates of analysed and forecast lakewide average precipitation, evaporation and terrestrial runoff for specified large lakes. This technical note describes DHPS v3.1.0.

In the remainder of the note, Section 2 gives a more detailed description of NSRPS and DHPS, the piloting of DHPS by NSRPS, and the innovations in and products of the current version of DHPS. Section 3 presents the WATROUTE model used in DHPS. In Section 4, we discuss the method used in DHPS to assimilate observations of river discharge. Section 5 provides technical specifications for the river basins included in the current implementation. Section 6 presents the evaluation of the final cycles. Finally, references and appendices are provided at the end of the document.

2. System description

2.1 System components

NSRPS is an integrated chain of numerical prediction systems. Together, the component systems provide analyses of precipitation, and analyses and forecasts of near-surface, surface and sub-surface variables, streamflows, and water levels and velocities. The component models of NSRPS, which have been documented in the scientific literature, include the High Resolution Ensemble Precipitation Analysis (HREPA; Khedhaouiria et al. 2020), the Canadian Land Data Assimilation System based on Satellite data (CaLDAS-Sat; Carrera et al. 2015), the High-Resolution Deterministic Land Prediction System (HRDLPS; Deacu and Bélair 2019), the Deterministic Hydrologic Prediction System (DHPS), and the Operational Hydrodynamic Prediction System (OHPS, also known as SHOP; Morin and Champoux 2006, Matte et al. 2017a, 2017b.

CaLDAS-Sat provides analyses of near-surface, surface and sub-surface variables such as snow depth, 2-m atmospheric temperature, skin (land surface) temperature and soil moisture over most of Canada at a 2.5-km resolution. The analyses are constructed by assimilating observations for these variables, relying on satellite data for soil moisture retrievals and snow cover extent. It also produces continuous simulations between successive analyses of surface processes, using the Surface Prediction System (SPS; also known as GEM-surf; Bernier et al. 2011) with the Soil, Vegetation and Snow (SVS; Alavi. et al. 2016, Fortin et al. 2016, Husain et al. 2016) land-surface scheme for terrestrial surfaces. CaLDAS-Sat is piloted by atmospheric fields from the High Resolution Deterministic Prediction System (HRDPS) and precipitation from HREPA.

HRDLPS predicts the future state of the land surface. It is initialized twice daily with a CaLDAS-Sat analysis and subsequently predicts near-surface, surface and sub-surface variables at 2.5-km resolution for the next six days. Like CaLDAS-Sat, HRDLPS uses SPS with SVS. It is piloted by HRDPS for the first two days, and by the Global Deterministic Prediction System (GDPS) for days 3-6.

DHPS is the river routing component of NSRPS. It provides both analyses and forecasts, routing water from CaLDAS-Sat and HRDLPS, respectively, through a river basin’s lakes and rivers at a 1-km grid resolution. It simulates lake levels for defined lakes or reservoirs and streamflow at all other points in a domain. Twice a day, launching at 00 and 12 UTC, DHPS performs a 12-h data assimilation cycle followed by a 6-day forecast. The data assimilation cycle provides initial conditions for both the following forecast and for the next assimilation cycle that is launched 12 hours later (see Figs. 2, 3 and Table 1). The data assimilation cycle and the forecast are both piloted by three fluxes of water produced by the surface systems (CaLDAS-Sat and HRDLPS): accumulated hourly surface runoff aggregated over all surface types represented in SPS, and accumulated total lateral flow and drainage from the regions covered by land (i.e. soil or rock). DHPS also ingests hourly precipitation and accumulated hourly evaporation aggregated over all surface types in order to estimate the terms of the water budget of large specified bodies of water. This calculation is performed in DHPS v3.1.0 for the five Laurentian Great Lakes, Lake Champlain, Lake Athabasca, Great Slave Lake and Great Bear Lake. While the data assimilation cycle of DHPS is piloted by water fluxes from CaLDAS-Sat and its forecast is piloted by fluxes from HRDLPS, DHPS does not, in the current implementation, feed any information back to CaLDAS-Sat or HRDLPS; the coupling is one-way.

DHPS assimilates streamflow observations during the data assimilation cycle. Currently, DHPS assimilates observations from ECCC's Water Survey of Canada, USGS, and the provincial networks of river gauges in Quebec and Alberta. The assimilation of streamflow data consists, for DHPS v3.1.0, of insertion plus upstream propagation (see Sect. 4).

2.2 Coupling between DHPS and the surface components

Since DHPS is a deterministic system while CaLDAS-Sat is an ensemble of 24 members (which have all benefitted from data assimilation), a single value for each of the three fluxes is calculated at each grid point from the 24-member ensemble trial run of CaLDAS-Sat. For each grid point, the member for which the 6-h accumulation of the sum of surface runoff and lateral flow is closest to the median of the 24 members is used to force DHPS over the corresponding 6-h period and for the considered grid point. All forcing variables are taken from the same member for a given grid point and over a given 6-hour period.

Table 1. The coupling of DHPS with the other components of NSRPS

Source model : destination model	Variables passed from source to destination model	Exchange frequency	Exchange method
CaLDAS: DHPS	Accumulated hourly surface runoff aggregated over all surface tiles Accumulated hourly total lateral flow from the top six layers (2m) of the soil column Accumulated hourly drainage from the sixth soil layer (2m) Hourly precipitation Accumulated hourly evaporation aggregated over all surface types	Hourly	Offline
HRDLPS: DHPS	Same variables as those from CaLDAS	Hourly	Offline

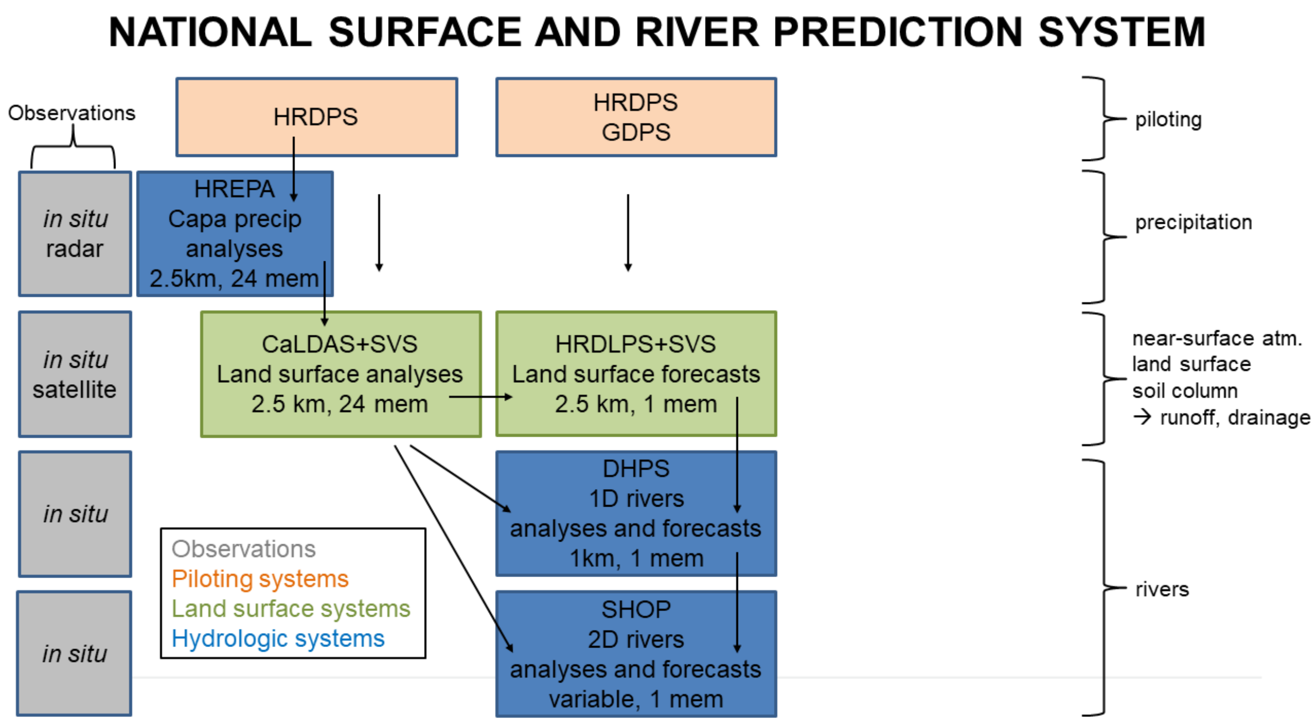

Fig. 2. Schematic of the National Surface and River Prediction System with the interactions between the five component systems (HREPA, CaLDAS-Sat, HRDLPS, DHPS and SHOP), and the piloting models. The types of observations assimilated are also indicated.

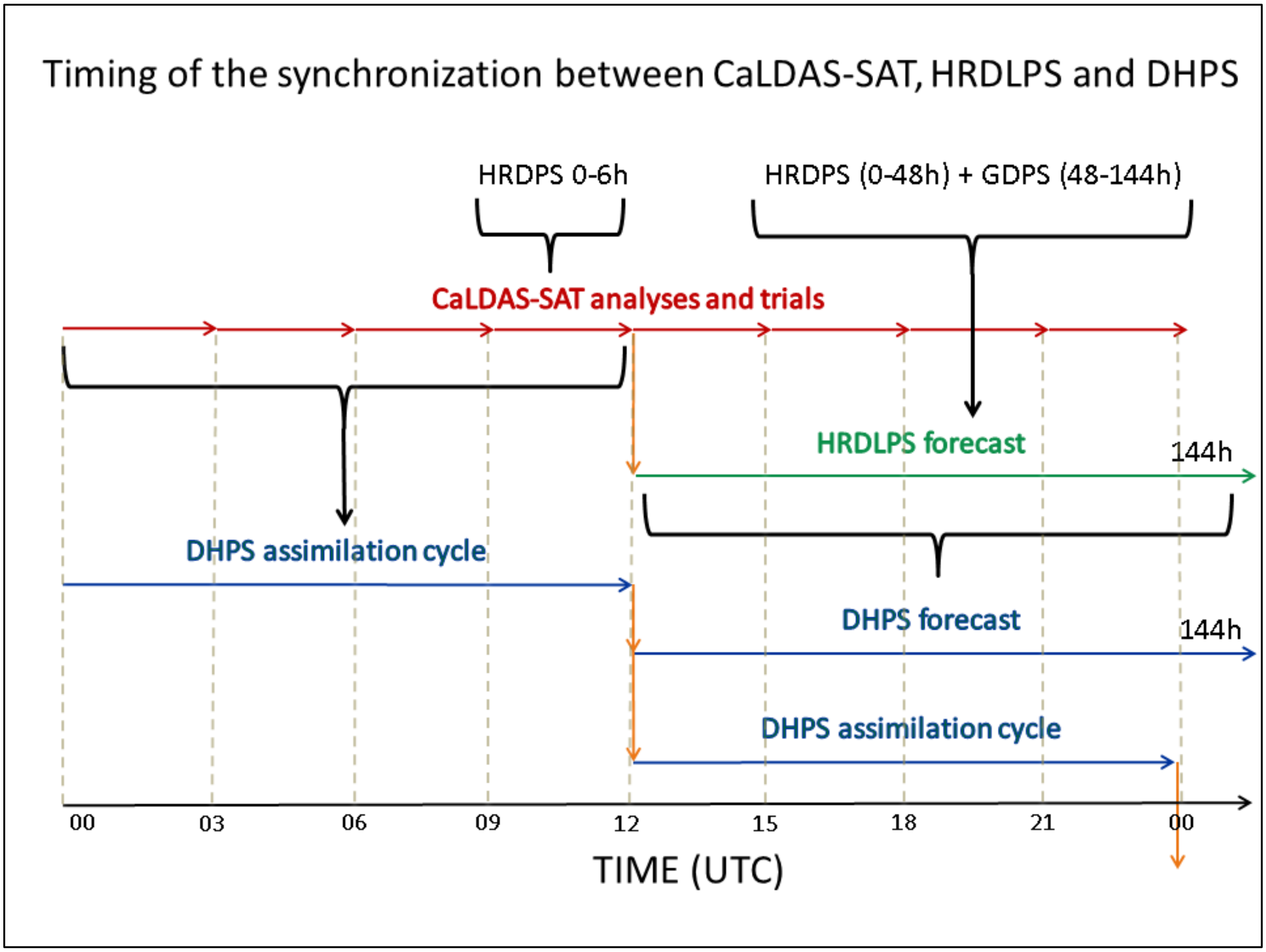

Fig. 3. Timing of the synchronization between CaLDAS-Sat, HRDLPS and DHPS over a sample 24-h period.

2.3 Updates for Innovation Cycle 3

Given the connections between CCMEP'S numerical prediction systems, the systems are updated periodically as a group during what is referred to as an innovation cycle. The innovations added to DHPS for Innovation Cycle 3 (IC-3) are presented in Table 2. These innovations impact all aspects of the modelling prediction system. This includes the coupling within NSRPS, the observations assimilated, the method of assimilating the observations, facets of the river routing model, WATROUTE, and the Maestro suite, a sequencer, that underlies DHPS.

Table 2. Innovations introduced to DHPS for Innovation Cycle 3

Aspect of DHPS	Innovations
Coupling with CaLDAS[1]	• Uses the median of water fluxes (see Sect. 2.2) from the 24 members of CaLDAS to pilot the data assimilation cycle of DHPS in all seasons instead of using the control member during the cool season and the median in the warm season
River routing model: WATROUTE	• Addition of a bugfix for the representation of inflows to explicitly defined lakes and reservoirs • Implementation of the Dynamically Zoned Target Release (DZTR) model (Yassin et al. 2019) to represent management rules of regulated reservoirs[2]
Data assimilation[3]	• Adjustment of water level of explicitly-defined natural lakes during upstream propagation of observation-derived information • Limiting of the upstream propagation when artificial structures (diversions, reservoirs) are encountered
Observations of river discharge[4]	• Added new networks river gauges from USGS, and the provincial networks of Alberta and Quebec
Maestro suite	• Processes the new observation networks • Processes SQLite3-formatted files of observations • Divides the simulation into 24-hour periods • Represents a diversion from Lake Champlain via the Chambly canal that is either open, closed, or that opens automatically if the forecast water level of Lake Champlain passes a specified threshold

[1]Described in Sect. 2.2 ; [2]Described in Sect. 3.6.2; [3]Described in Sect. 4 ; [4]Described in Sects. 5 and 6.3

2.4 Products from DHPS

DHPS produces analyses in near real-time and forecasts over the next six days. From the analyses and forecasts, DHPS provides hourly estimates of river discharge, the volume of water stored in the river channel or at the outlet of an explicitly represented natural lake or regulated reservoir, and the depth of the water in the subterranean reservoir (see Table 3). DHPS also provides analyses and forecasts of precipitation, evaporation and terrestrial runoff averaged over the surface of specified large lakes during successive 12-hour periods. As a reference for users, we also provide three constant fields, the flow directions underlying the river network of DHPS, the drainage area of each grid point, and the natural lakes and regulated reservoirs that are represented explicitly in DHPS.

These products from DHPS are of interest to a wide variety of users. This includes decision makers at multiple levels of government, including federal departments outside of ECCC and partners at the provinces and territories. Also interested are water managers and planners as well as other industries such as hydro-electric power producers who require knowledge of the state of the hydrologic cycle. Finally, partners in academia and other research institutions find the products useful.

At CMC, the simulated discharge of DHPS is of interest as lateral boundary conditions for 2- and 3-dimensional ocean, lake and river models. These models provide tools and numerical guidance for navigation, emergency response in reaction to spills of pollutants, and public safety activities. The simulated discharge of DHPS also provides valuable feedback for CCMEP's atmospheric prediction systems by informing them of the skill of their precipitation forecasts in data sparse regions.

Elsewhere at ECCC, the products from DHPS will support the National Hydrological Service (NHS) with advanced information on the current and predicted state of river networks. This information will help to improve the efficiency, safety and effectiveness of the hydrometric monitoring program. Additionally, as coverage from DHPS extends seamlessly across both international and provincial borders, the products are of interest for transboundary water management activities. For example, simulated river discharge is used by the International Joint Commission's Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

Currently, products from DHPS are shared informally with federal ministries, the province of Quebec, and academia. The formal dissemination of products from DHPS is expected to start in Fall 2021 via the beta versions of Datamart and GeoMet. NSRPS, is expected to be promoted from experimental to operational status in Fall 2022. As a system with operational status, dissemination would be via the operational versions of Datamart and GeoMet.

In Canada, flood forecasting is the responsibility of the provinces and territories. This stems from the Constitution Act of 1867 and subsequent pieces of legislation. Therefore, real-time predictions of river discharge from DHPS will not be made available to the public. They will be shared privately with departments of the federal government, the provinces and territories, and other permitted groups.

Table 3. Products from DHPS to be disseminated from Datamart and GeoMet

Variable Name	Frequency: Analysis/Forecast	Description
DISC	1h/1h	Mean hourly river discharge (m3/s)
STOR	12h/24h	Volume of water stored in the river channel or outlet of an explicitly represented natural lake or regulated reservoir (m3)
LZS	12h/24h	Depth of water in the lower zone storage or subterranean reservoir (kg/m2)
PRWM[1]	12h/12h	Precipitation averaged over a lake's surface (see note below): 5 Great Lakes, Lake Champlain, Great Slave and Bear Lakes, Lake Athabasca
EVWM[1]	12h/12h	Evaporation averaged over a lake's surface (see note below): 5 Great Lakes, Lake Champlain, Great Slave and Bear Lakes, Lake Athabasca
RUNF[1]	12h/12h	Terrestrial runoff averaged over a lake's surface (see note below): 5 Great Lakes, Lake Champlain, Great Slave and Bear Lakes, Lake Athabasca
DIRF	constant	Flow directions used to calculate the river network
DA	constant	The area of the terrain draining to each grid cell (km2)
REAC	constant	Explicitly represented natural lake or regulated reservoir (none)

[1]Currently two estimates are provided per day for PRWM, EVWM and RUNF. The units are mm/day. Each estimate is based on input from the previous 12h. The average of the two estimates from a given day provides the daily value. This Fall, we plan to provide the value of PRWM, EVWM and RUNF accumulated from the start of the forecast. The units will be mm.

3. Description of WATROUTE

3.1 Overview

WATROUTE (Kouwen 2018) uses a 1-D routing scheme based on the Manning-Strickler equation (Manning, 1891) to estimate streamflow. The channel's geophysical parameters (e.g. slope, cross-section shape, Manning coefficients) and the information used to route water from one pixel to its downstream neighbour are derived from gridded flow directions and terrain elevations. These static geophysical parameters are stored in the "shed file". Additional information about a modelling domain is passed to Watroute via the event file (see Appendix E). Figure 4 presents a diagram of flow directions and the river network derived, as well as the river network produced for a modelling domain.

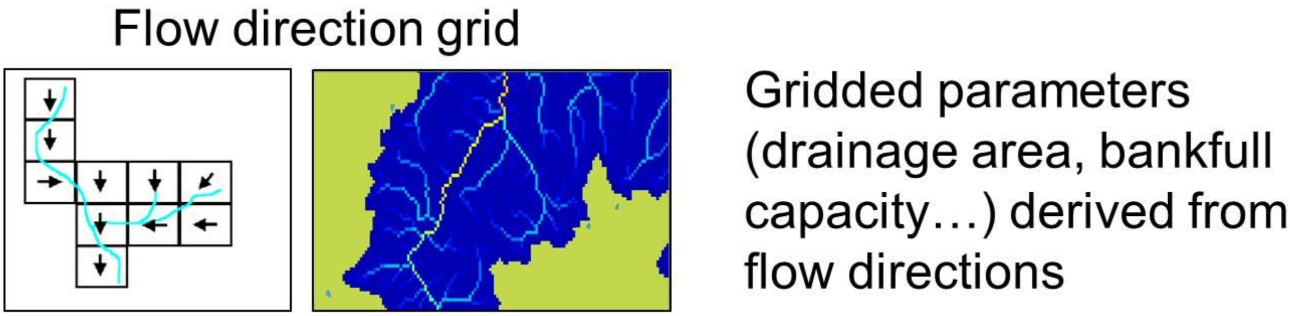

Fig. 4. Illustration of WATROUTE flow directions (left) and the channel drainage area (right).

The original version of WATROUTE is documented here as part of the Watflood manual (Kouwen 2018). However, many modifications have been made at ECCC's CMC to the original WATROUTE code. This section describes the version of WATROUTE used at CMC.

3.2 Shed file parameters for WATROUTE

3.2.1 Calculation of geophysical fields

The computation of the shed file parameters for a WATROUTE domain is based on flow directions, topographical elevations, the land/water mask, and vegetation classes. We list the databases used in Table 4. From the flow direction data and the elevation data we derive the stream network, delineate the watershed boundaries, and compute model parameters such as river shape and slope, and the drainage area of each grid cell. The land/water mask is used to determine the extent of lakes explicitly represented in the model. The vegetation classes are used to compute the fraction of the grid cell covered with low, high, or no vegetation.

Table 4. Geophysical databases used to create the shed file

Fields	Database	Resolution
Flow directions and elevations	primary source: HydroSHEDS secondary source: GTOPO30 Hydro1k	30 arc-seconds or ~ 1 km at the Equator
Topography	GMTED 2010	1 km
Land-water mask	CCI-LC 2015	300 m
Vegetation	CCI-LC 2015	300 m

Since the initial flow directions are not entirely accurate, manual intervention is required to correct obvious errors in the automatically-generated river networks. The corrections are guided by shapefiles of subwatersheds and independent databases and documentation. Regions where the river network and land/water mask are out of alignment are also corrected.

This process produces, for each grid point within the watershed of the specified outlet, numerous geophysical fields including: the area draining into each grid point (*DA*; km^2); the order in which to process the grid points (from the grid point with the smallest drainage area to the grid point with the largest; *RANK*); the rank of the grid point downstream of the current grid point (*NEXT*); the rank of the grid points upstream of the current grid point (BACK); the length of the channel within a grid cell assuming a straight line across the cell (*CLEN*; m); and the slope of the channel within a grid cell (*CSLP*; $m\ m^{-1}$). Reaches for specified lakes and reservoirs and their watersheds are also defined.

3.2.2 Channel and overbank cross-section areas

A channel in WATROUTE has two parts: a main channel part and an "overbank" part (i.e., the part above and to the sides of the main channel cross-section, which corresponds to the floodplain). The overbank (or floodplain) part has an infinite maximum area, with a fixed slope of 1:100 (100 m in the horizontal direction for 1 m in the vertical). The main channel cross-section has a rectangular shape with a width-to-depth ratio set to 20. The total cross-sectional area of the main channel is calculated using Eq. 1 or 2:

If *AA4* > 0:

$$CHAR_{i,j} = AA2 + AA3\ x\ {DA_{i,j}}^{AA4} \tag{1}$$

Otherwise:

$$CHAR_{i,j} = 10.0^{AA2\ x\ log10\left(DA_{i,j}\right)+AA3} \tag{2}$$

where $CHAR_{i,j}$ is the main channel cross-sectional area (m^2), $DA_{i,j}$ is the grid point's drainage area (km^2), and *AA2*, *AA3* and *AA4* are coefficients specified by the user and constant over the whole WATROUTE domain. For DHPS v3.1.0, the values for *AA2*, *AA3* and *AA4* are, respectively, 1.1, 0.043 and 1.0.

3.2.3 Degree of channel meandering

The actual length of the channel is the channel length calculated as a straight line across the grid cell (see Section 3.2.1) multiplied by a spatially-varying meandering factor, *MNDR*. The meandering factor increases the channel length. *MNDR* is calculated from the drainage area and slope of the grid cell channel following Eq. 3:

$$MNDR_{i,j} = \left(DA_{i,j}\ x\ \frac{(1.1-1.0)}{(0.0-DAmax)} + 1.1\right) x \left(CSLP_{i,j}\ x\ \frac{(1.3-1.0)}{(0.0-CSLmax)} + 1.3\right) \tag{3}$$

where $DA_{i,j}$ the drainage area (km^2), $DAmax$ = 3000.0, $CSLP_{i,j}$ the channel slope ($m\ m^{-1}$), and $CSLmax$ = 0.5; $MNDR_{i,j}$ is constrained to remain between 1.0 and 1.6.

Eq. 3 is derived from the following assumptions:

- channels in steep terrain (large *CSLP*) in headwater areas (small *DA*) meander little
- channels in flatter terrain (low *CSLP*) in/near headwater areas (small *DA*) meander the most
- channels in flatter terrain (low *CSLP*) far from headwater areas (large *DA*) meander so slowly that the degree of meandering is minimal in a given grid cell

The maximum storage capacity of the main channel part (m^3) is defined as the main channel cross-section area (m^2), multiplied by the actual channel length (m). The overbank (floodplain) part of the channel has an infinite storage capacity (m^3) given its infinite cross-sectional area.

3.2.4 Manning coefficients

The Manning's n coefficient for roughness that is used in Manning's equation to calculate streamflow (see Sect. 3.4) varies in space and time. The coefficient is based on the drainage area of a given grid point and the fraction and type of vegetation (low/high) in the grid cell. The month of the year is used as a proxy for vegetation growth. In Winter, the Manning's n coefficient for ice is also a function of latitude. A detailed explanation of the calculation of the spatio-temporal form of the Manning's n coefficients for roughness are provided below.

3.2.4.1 Main channel flow

The Manning's roughness coefficient for main channel flow (*R2N*) combines the roughness of the channel's bottom and side surfaces (*R2NB*) and of the underneath of the overlying ice cover (*R2NI*). *R2NB* (s $m^{-1/3}$) varies spatially with drainage area (*DA*) and latitude, and temporally with month (mth) as per Eq. 4:

$$R2NB_{i,j} = DA_{i,j}\ x \left(\frac{(0.040-0.030)}{(0.0-DAmax)} + 0.040\right)\ x\ vegmth_{mth} \qquad (4)$$

where DA_{max} = 0.5 x (1.5x10^5 + 7.8x10^5) m^2, or the average of DA for the Ottawa and St. Lawrence rivers at their confluence. The multiplicative coefficient $vegmth$ represents the retardation of the flow due to the presence of vegetation. The base value of this coefficient ranges from 1.0 for November through April to 1.25 for July and August. Additionally, *vegmth* decreases with latitude polewards of 40 °N. Polewards of 60 °N, the coefficient is always unity: no retardation due to vegetation is represented. *R2NB* is constrained to remain between 0.030 and 0.050 s $m^{-1/3}$. This calculation is guided by Chow (1959).

R2NI is Manning's n roughness coefficient for the underside of the ice covering the channel. *R2NI* (s $m^{-1/3}$) varies spatially with the channel slope (*R2NIslp*; see Eq. 5) and also with latitude (*R2NIlat*; see Eq. 6), which acts as a proxy for temperature. Temporally, *R2NI* varies by month (see Eq. 7). The maximum value of *R2NI* is limited by drainage area. The calculation of *R2NI* was guided by Daly (2007) and observations of fractional ice cover from Water Survey Canada. The latitudinal and monthly variations of *R2NI* were guided by observations of fractional ice cover from Water Survey Canada.

$$R2NIslp_{i,j} = (R2NIminslp - R2NImax)\ x\ \frac{(log(CSLP_{i,j})-slpmin)}{(slpmax-slpmin)} + R2NImax \qquad (5)$$

where *R2NIminslp*=0.01, *R2NImax*=0.055, *CSLP* is the channel slope (m m^{-1}), *slpmin*=log(0.001), and *slpmax*=log(0.1). *R2NIslp* is constrained to remain between *R2NIminslp* and *R2NImax*.

$$R2NIlat_{i,j} = (R2NImax - R2NIminlat)\ x\ \frac{(lat_j-latmin)}{(latmax-latmin)} + R2NIminlat \qquad (6)$$

where *R2NImax*=0.055, *R2NIminlat*=0.0, lat_j is the latitude of the grid point (°N), *latmin*=40.0 °N, and *latmax*=60.0 °N. $R2NIlat_{i,j}$ is constrained to remain between *R2NIminlat* and *R2NImax*.

At a given grid point, if either *R2NIslp* or *R2NIlat* is zero-valued, *R2NI* is also zero-valued. Otherwise, the two components of the roughness coefficient are combined following Eq. 7:

$$R2NI_{i,j} = \left(wtlat\ x\ R2NIlat_{i,j} + (1.0 - wtlat)\ x\ R2NIslp_{i,j}\right) x\ icemth_{mth} \quad (7)$$

where $wtlat = 0.75$ and $icemth_{mth}$ represents the retardation influence on the flow from the underside of the channel's ice cover. *R2NI* is constrained to remain between 0.0 and *R2NImax*. *R2NI* is further constrained to be no greater than *R2NIdaI*; it is unlikely that small streams will have an ice cover 1.5-m thick even at high latitudes. *R2NIdaI* is itself constrained to lie between R2NImindaI and R2NImax (see Eq. 8):

$$R2NIdaI_{i,j} = (R2NImax - R2NImindaI)\ x\ \frac{\left(log10\left(DA_{i,j}\right) - daImin\right)}{(daImax - daImin)} + R2NImindaI \quad (8)$$

where *R2NImax*=0.055, *R2NImindaI*=0.01, *daImin*=log(1.0E2) and *daImax*=log(1.0E5).

R2NB and R2NI are combined to provide the Manning's n coefficient for channel flow, *R2N*, following Eq. 9:

$$R2N_{i,j} = \sqrt[2]{R2NB_{i,j}^2 + R2NI_{i,j}^2} \quad (9)$$

3.2.4.2 Overbank or floodplain flow

R1N is Manning's n roughness parameter for flood plain flow. *R1N* (s $m^{-1/3}$) varies spatially with vegetation type and latitude and temporally with month. Vegetation classes are divided into high (*VEGH*) and low (*VEGL*) vegetation.

$$R1N_{i,j} = \frac{\left(VEGL_{i,j}\ x\ wtvegL + VEGH_{i,j}\ x\ wtvegH\right)}{\left(VEGL_{i,j} + VEGH_{i,j}\right)}\ x\ vegmth_{mth} \quad (10)$$

where $VEGL_{i,j}$ is the fraction of the grid cell covered by low vegetation, *wtvegL*=0.035, $VEGH_{i,j}$ is the fraction of the grid cell covered by high vegetation, *wtvegH*=0.075 and $vegmth_{mth}$ the retardation influence of vegetation on the flow.

Grid cells covered entirely by water are included in *VEGH*; lakes have extremely rough banks (Vincent Fortin, personal communication). The multiplicative coefficient $vegmth$ represents the retardation of the flow due to the presence of vegetation. The base value of this coefficient ranges from 1.0 for November through April to 1.25 for July and August. Additionally, *vegmth* decreases with latitude polewards of 40 °N. Polewards of 60 °N, the coefficient is always unity: no retardation due to vegetation is represented. *R1N* is constrained to remain between 0.030 and 0.120 (s $m^{-1/3}$). This calculation is guided by Chow (1959).

3.2.4.3 Modification of calculated Manning's n coefficient

Once calculated, the spatio-temporally varying Manning coefficients are multiplied by a user-defined multiplicative coefficient, *MULN*. This permits the user to tune the response of a given watershed. A value for *MULN* of 1.0 leaves the original value of the Manning coefficients unchanged. Note that Manning values modified by the *MULN* coefficient are not constrained to any maximum or minimum value.

All the computations of the Manning n coefficients that are described above occur during the preparation of the shed file. In WATROUTE, prior to the simulation of river flows, a linear interpolation between the values of the Manning's n coefficient for the two neighbouring months provides a coefficient value for the day being processed. Finally, during the simulation by WATROUTE of both channel and floodplain flows, the Manning's n coefficient is multiplied by the coefficient *RLAK*. *RLAK* represents a delay factor for streamflow that is caused by water surfaces in general. This includes the natural lakes that are not explicitly represented in the shed file. The *RLAK* coefficient varies between 1.0 and 3.0. *RLAK* is calculated using Eq. 11:

$$RLAK_{i,j} = \left(1.0 - MG2_{i,j}\right) x\ 2.0 + 1.0 \qquad (11)$$

where $MG2_{i,j}$ is the fraction of the grid point that is occupied by land. Note that the Manning coefficients are not constrained by any maximum or minimum value after their modification by the *RLAK* coefficient.

3.3 Water balance for a grid point

In WATROUTE, each grid point in a domain that is not part of a defined lake or reservoir (see Sect. 3.6) contains one channel or stream. For this channel, there are three input sources (see Fig. 5). Firstly, the piloting model's estimate of surface runoff and subsurface lateral flow are delivered immediately to the channel in the collocated grid point. Secondly, the piloting field of drainage, or the water exiting vertically through the bottom of the soil column, is provided to the subterranean reservoir called the Lower Zone Storage (LZS) in the collocated grid point (see Sect 3.8). Baseflow is released from the grid point's LZS to the channel. Finally, inflow is delivered to the channel from all upstream grid points. All of these input sources to a channel are always positive. If surface runoff from the piloting model is negative, which may happen, for example, over lakes or marine ice when evaporation exceeds precipitation, the negative value is removed from the grid cell's LZS to preserve the water balance. If the LZS becomes negative, it ceases to output any baseflow (see Sect. 3.8).

The output of the channel in a given grid point is the channel outflow ($m^3\ s^{-1}$). It is computed using the Manning equation (see Sect. 3.4; Manning 1891), assuming a subcritical flow regime with stable conditions at all times in WATROUTE. The water depth in a channel is calculated based on the channel's water storage (m^3) and its cross-section area.

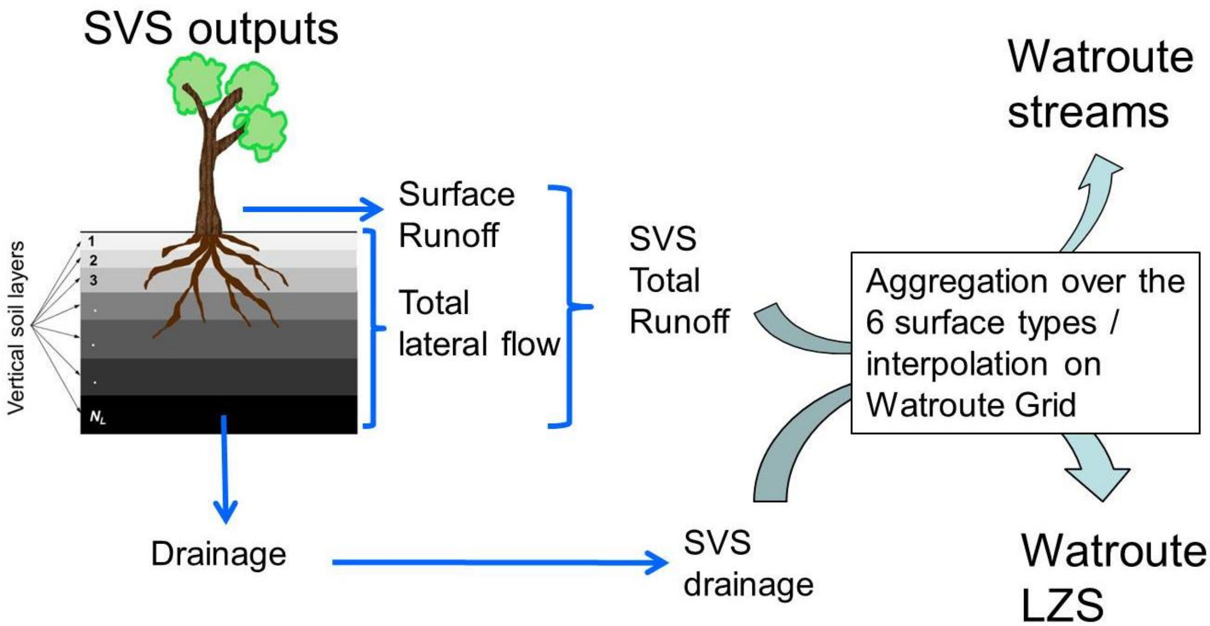

Fig. 5. Coupling between WATROUTE and the Surface Prediction System (SPS) within CaLDAS-Sat and HRDLPS. SVS is the acronym for the Soil, Vegetation and Snow land surface scheme. SPS has a total of six possible surface types.

In WATROUTE, lakes or reservoirs that are defined by the user during the generation of a domain's shed file are referred to as "reaches". A reach can include many grid points. However, water provided by the piloting model or by incoming tributaries to any grid point within the reach other than the outlet is added immediately to the reach's total water storage at its outlet. Thus, the total water storage of a reach is located at its outlet point; no outflow is computed for any other point within the reach.

A reach's storage capacity is considered infinite. However, the storage may be negative as, over water and marine ice, surface runoff is defined as precipitation minus evaporation. Negative surface runoff provided to a reach is directly removed from its storage to represent evaporation loss. Thus, if the flow from incoming tributaries is lower than evaporation losses, the reach's storage can become negative. A negative storage indicates that the water level in the reach is below the zero-flow level. Consequently, there is no flow through the outlet. However, since WATROUTE only represents the storage above the reach's zero-flow level (see Sect. 3.6), a reach with a negative storage may still contain water. Outflow from a reach is computed using a storage-discharge relationship (see Sect. 3.6).

3.4 Streamflow computation

For a grid point which is not part of a reservoir (see Sect. 3.6), the streamflow is computed following the Manning-Strickler equation (Eq. 12; Manning, 1891):

$$Q = \left(\frac{1}{n}\right) A R^{\frac{2}{3}} S^{\frac{1}{2}} \tag{12}$$

where Q is the flow rate ($m^3\ s^{-1}$), A is the cross-sectional area of the flow (m^2), n is the Manning's roughness coefficient, R is the hydraulic radius (m), and S is the channel slope ($m\ m^{-1}$). The flow area and hydraulic radius (and the water depth) in a channel are calculated based on the channel water storage (in m^3), and the shape of the channel (see Sect. 3.2), always assuming a subcritical flow regime (stable conditions).

3.5 Channel flow

When calculating flow within a channel (i.e., not within a lake or reservoir), WATROUTE processes each hour of a simulation period (an "event"). For a given hour, WATROUTE processes all grid points within a domain moving from upstream to downstream points. The length of a WATROUTE event is 12 hours for the data assimilation cycle and 6 days for the forecast. Information is output for the entire domain every hour of the event.

For a given event, WATROUTE needs input files with hourly data for streamflows, diversions and reservoirs (see the associated sections below). These input files are prepared automatically by DHPS, using a set of prepared template files together with a database of observed flow values available in near real-time. The template files (see Appendices A-E) contain the names, locations and coefficient values for the observation stations, diversions, and reservoirs.

3.5.1 Numerical solver

Numerical instabilities were noted in streamflow analyses and forecasts of DHPS. These were caused by the implicit solver described for DHPS v1.0.0 by Gaborit and Durnford 2021. The instabilities generated by the solver led to oscillations in streamflow that grew as flood waves travelled downstream. With the new numerical scheme that is used in DHPS V3.1.0, the oscillations disappeared.

During a model time step, WATROUTE processes all grid points progressing from upstream to downstream points. The solver is called for each grid point that is not a reservoir. Inputs to the solver include the geometry of the channel, the duration of the time step, the storage in the channel at the beginning of the time step (store1), the inflows into the channel from upstream grid points at the beginning (Qi1) and the end of the time step (Qi2), and the inflow during the time step coming from runoff and baseflow of the current grid point (Qr). The solver estimates the storage at the end of the time step (store2), the outflow at the end of the time step (Qo2), and the mean outflow during the time step (Avr_Qo2).

It is worth noting a few points before describing the solver itself:

- When the solver is called for a given grid point, the inflows at the end of the time step are known because upstream grid points are processed before downstream points. In DHPS v1.0.0, the inflows were assumed to be constant for the duration of the time step and were computed as the average of the inflows at the start and end of the time step. This is inconsistent with the implicit solver of DHPS v1.0.0, which assumes that inflows vary linearly during the time step (see Eq. 14 of Gaborit and Durnford 2021). In contrast, the solver of DHPS v3.1.0, or the new solver, does not assume that outflows vary linearly during a model time step.
- The outflow at the beginning of the time step (Qo1) is not used by the solver of DHPS v3.1.0. It has become a diagnostic variable. The new solver uses the kinematic wave assumption and works in water depth space rather than in flow space. Thus, not only is it possible to derive the outflow purely from the storage and the geometry of the channel, it is easier to back-calculate water depth from storage than from flow.
- Because the new solver works in water depth space rather than in flow space, the convergence criterion, *TOL*, is based on water depth, and is expressed in meters. Previously, convergence was assessed based on a relative precision criterion for storage.

The new solver relies on four known relationships:

- The geometry of the channel cross-section is known: the main channel is assumed to be rectangular, and the flood plain is assumed to be trapezoidal. All parameters defining the geometry of the channel cross-section are assumed to be constant over the length of the channel.
- The relationship between water depth (w) and storage (S) in the channel of Eq. 13 is completely determined by the geometry of the channel and is independent of time and flow velocity. The function f is bijective and can be easily inverted to obtain water depth from storage following Eq. 14. The derivative of $f(w)$ with respect to w is also known and is easy to compute.

$$S = f(w) \tag{13}$$

$$w = f^{-1}(S) \tag{14}$$

- The relationship between water flow and water depth, $Q=g(w)$, is also completely determined by the geometry of the channel and is time-independent. The function g is also a bijective function. This function does not need to be inverted.
- Conservation of mass implies that the time-derivative of storage is equal to the difference of inflows and outflows following Eq. 15:

$$\frac{dS}{dt} = I - O \tag{15}$$

From the chain rule, we obtain Eq. 16:

$$\frac{dw}{dt} = \left(\frac{dS}{dt}\right) x \left(\frac{dS}{dw}\right)^{-1} = \left(\frac{dS}{dt}\right)\Big/ f'(w) \tag{16}$$

Hence, at the start of the time step:

- The water depth w_t is known as it is obtained from store1.
- The rate of change of water depth with respect to time, dw/dt, can be computed for any value of w and t.
- the water depth at the end of the time step, $w_{t+\Delta t}$, is an unknown quantity from which storage at the end of the time step (store2) and outflow at the end of the time step (Qo2) can be readily computed.

This is a standard initial problem value to which standard numerical methods for ordinary differential equations can be applied. We chose to implement the well-known Bogacki-Shampine method, also known as the ode23 method. See Bogacki and Shampine (1989) as well as the Wikipedia page on this method for more details. The Bogacki and Shampine method belongs to the Runge-Kutta family of methods. It is also an adaptive time-step method. Based on three evaluations of dw/dt, for different values of w and t, it proposes two different solutions for $w_{t+\Delta t}$: a second-order solution $w^{(2)}$, and a third-order solution $w^{(3)}$. The two solutions are compared to the convergence criterion (*TOL*) to assess whether the model time step was small enough for the solution $w^{(3)}$ to be accurate and trusted. For DHPS v3.1.0, *TOL* equals 0.01 m. If the difference between the solutions is greater than *TOL*, the difference is used to determine, following Eq. 17, a multiplicative factor, *mult*, by which to multiply the model time step in order to reattempt to obtain two solutions, $w^{(2)}$ and $w^{(3)}$, within the desired level of agreement.

$$mult = \left(TOL/\left|w^{(2)} - w^{(3)}\right|\right)^{0.25} \tag{17}$$

mult is constrained to be at least 0.25%. The solver is re-launched with the smaller time step, integrating over a fraction of the total model time step. If the difference between the two solutions is still too large, the same process is used to reduce the model time step again. When the two solutions agree to within the specified level of tolerance, the model time step is increased, again based on Eq. 17, and integration in time continues until the entire time step has been processed.

In some cases, oscillations continued to be observed with the new solver. These occur mainly when using longer model time steps. Consequently, we also require that the Courant number never exceed unity at the initial time. The Courant criterion is defined by Eq. 18:

$$C = v\,\Delta t/\Delta x \tag{18}$$

Where C is the Courant number, v is the wave celerity (obtained by dividing the streamflow by the wetted area of the river cross-section), Δt is the model time step, and Δx is the length of the channel. If C is above unity at initial time, the time step is then reduced from its current value following Eq. 19.

$$Time\ step_{t+1} = \frac{C\Delta x}{(v+0.001)} \tag{19}$$

If the algorithm requires more than a maximum of 1000 iterations for a given grid cell, then WATROUTE will restart the whole hour of simulation with a smaller time step over all grid points of the domain, from upstream to downstream. In other words, the new numerical solver described here will first try to adapt the current WATROUTE time step for the current grid point. If convergence is still not achieved after 1000 iterations of decreasing the time step, then WATROUTE will restart the whole hour with a smaller time step than before, for all grid points. The default WATROUTE time step is one hour (3600s). The minimum WATROUTE time step value is 30 s. In the very unlikely event that convergence can still not be achieved by the numerical solver for a given grid point, after 1000 iterations when starting from the minimal WATROUTE time step of 30 s, then WATROUTE will start removing water for the current grid point. Indeed, not being able to achieve convergence with the minimum WATROUTE time step has only been noticed in very rare occasions where erroneous (abnormally high) flows were assimilated in the model due to ice jams. Removing water from the system is not desirable in theory because it breaks the water balance, but in the context of operational forecasting, the alternative solution of having a model crash is not acceptable. Therefore, to avoid any model crash, the flag “nocrashflg” is set to “yes” in the event template file (see Table 5 in Sect. 5 and Appendix E). The effect of this flag, when set to yes, is that if convergence cannot be obtained for a given grid cell after 1000 solver iterations and with the minimum WATROUTE time step of 30 s, water is removed both from Qi and from the storage of the current grid cell by halving them and restarting the numerical solver for the current point. This is done in an iterative manner until convergence is achieved, imposing minimum values of 0.001 $m^3 s^{-1}$ for flow and of 10 m^3 for storage. In this case, a warning is printed on the screen to warn the user that the water balance has not been preserved.

3.6 Lakes and reservoirs

In WATROUTE, lakes or reservoirs (referred to as “reaches”) of a domain are defined explicitly to represent their impact on streamflow and to simulate the mean water level of the reach. Reaches are defined during the creation of the shed file by specifying a point inside the reach. The location of the reach’s outlet and additional parameters that vary by reach are provided in the domain’s reservoir release template files (see Appendix B).

In general, lakes and reservoirs with large surface areas and also reservoirs with smaller surface areas but with the capacity to store water are represented; these bodies of water have a significant impact on streamflow. The extent of the reach is automatically generated based on the land/water mask. Manual intervention refines the initial version by assuring that rivers that enter a reach stay within the reach until the outlet. Note that the variable RLAK (see Section 3.2.4.3) of the shed file is used to represent the impact on streamflow of bodies of water that are not explicitly defined.

All points within a reach are part of the same reach. All inflows during a given time step to grid points within the reach are added immediately to the reach’s outlet (see Sect. 3.3). The outlet in WATROUTE contains the storage of all the water in the entire reach. If evaporation exceeds precipitation over the water tile of the surface model, a negative value of surface runoff is given to the Watroute grid points located inside this water body. If the Watroute grid points of this area are located inside a reach, then this negative runoff is added to the reach’s storage. This represents the removal of water from the reach due to evaporation. If the grid points located within the surface model's body of water are not located within a reach that is explicitly represented in WATROUTE, then this negative runoff is added to WATROUTE's lower zone storage to preserve the water balance (see Sect. 3.3).

Two different options are available in DHPS to simulate a reach: a natural lake model or the Dynamically Zoned Target Release (DZTR) reservoir model (Yassin et al. 2019). DZTR is used to simulate the management rules of regulated reservoirs. WATROUTE applies the natural lake model to a given reach when the variable "ColumnModel" for the reach is set to something other than "DZTR" in the main lakes template file (see Appendix B). In DHPS, we assign the term "LAKE" to this variable. When ColumnModel is set to "DZTR", the reach is treated as a regulated reservoir. Finally, to activate DZTR, resumflg in the event template file is set to "y". We describe the natural lake model in Sect. 3.6.1 and DZTR in Sect. 3.6.2.

If flow observations are available for the outflow of a lake or regulated reservoir, then these gauges may have been included in the streamflow template files of Appendix A. For such gauges, the location is situated one grid cell downstream of the outlet in WATROUTE. Observations from these gauges are then assimilated as per Sect. 4. and can be compared to the lake's simulated outflow. In DHPS v3.1.0, we no longer prescribe observed values as the outflow of a lake or reservoir.

3.6.1 Natural lake model

The natural lake model assumes a fixed surface area for the lake. The water level is equal to the lake storage divided by its surface area. The reach outflow is computed based on a storage-discharge relationship. The total water volume of a reach is much greater and much more stable than the water storage of a grid point's channel. Furthermore, the storage-discharge relationship of most reaches releases water more smoothly than the outflow from a grid cell. Thus, unlike for channel grid points where convergence is sought (see Sect. 3.5), a similar process is not required to determine the outflow from a reach. To preserve the water balance, if a reach's storage becomes negative, then the outflow becomes zero-valued and the negative value of storage is remembered for the next time step.

To activate the natural lake model in WATROUTE, the user defines five coefficients in the reservoir release template file (see Appendix B). Non-zero values must be provided for at least coefficient 1 or 2. If non-zero values are provided only for the first two coefficients, then the storage-discharge relationship is based on an exponential function following Eq. 20:

$$Q = Coeff1 \, x \, STOR^{Coeff2} \tag{20}$$

where Q is the reach outflow in $m^3\ s^{-1}$, and *STOR* is the reach water volume (m^3) above the zero-flow level (see below).

If non-zero values are specified for coefficients 1-3, 1-4 or 1-5, then the storage-discharge relationship is a polynomial function (see Eq. 21). To ensure a realistic behavior of outflow from the reach, the storage-discharge relationship must be a monotonically increasing function of the outflow as a function of the storage.

$$Q = Coeff1\, x\, STOR + Coeff2\, x\, STOR^2 + Coeff3\, x\, STOR^3 + Coeff4\, x\, STOR^4 + Coeff5\, x\, STOR^5 \quad (21)$$

The parameters Coeff6 and Coeff7 also participate in the calculation of outflow from the reach. Coeff6 is the reach area in square meters. Coeff7 is the zero-flow level (m) or the water level below which the outflow is zero and the reach storage is negative. WATROUTE only simulates the evolution of the water storage above the zero-flow level; the value of *STOR* used in the storage-discharge relationship (Eq. 20 or 21) is the "active" storage. To reconstruct the full water level, the zero-flow level is added as constant value to WATROUTE's simulated water level.

If both coefficients 1 and 2 are zero-valued, then WATROUTE will use prescribed hourly values as the reach's outflow. This mechanism can be applied to reaches that have observed streamflows at their outlet. In this case, WATROUTE will use the observed value as the reach outflow value, but only if it is positive. If an observation is missing for a given hour or is not positive, the most recent positive observation within the past two weeks is used. In forecast mode, the most recent observed value from the last 2 weeks is used and persisted throughout the forecast. If no positive observed value is found over the previous two weeks, then WATROUTE sets the reservoir outflow to zero. In order to avoid this issue, all reaches in DHPS v3.1.0 are either represented by the natural lake model or the DZTR model. When observed outflows are available at the outlet of the reach they are assimilated during the data assimilation cycle. Otherwise, including in forecast mode, the natural lake or DZTR model calculates the reach's outflow.

3.6.2 Dynamically Zoned Target Release reservoir model

DHPS uses the Dynamically Zoned Target Release (DZTR) model to represent management rules of regulated reservoirs. DZTR has been implemented on reservoirs in the Mackenzie and Nelson River domains, in the Great Lakes St. Lawrence River domain and in the Gulf of St. Lawrence domain. The distribution of these reservoirs is presented in Fig. 6.

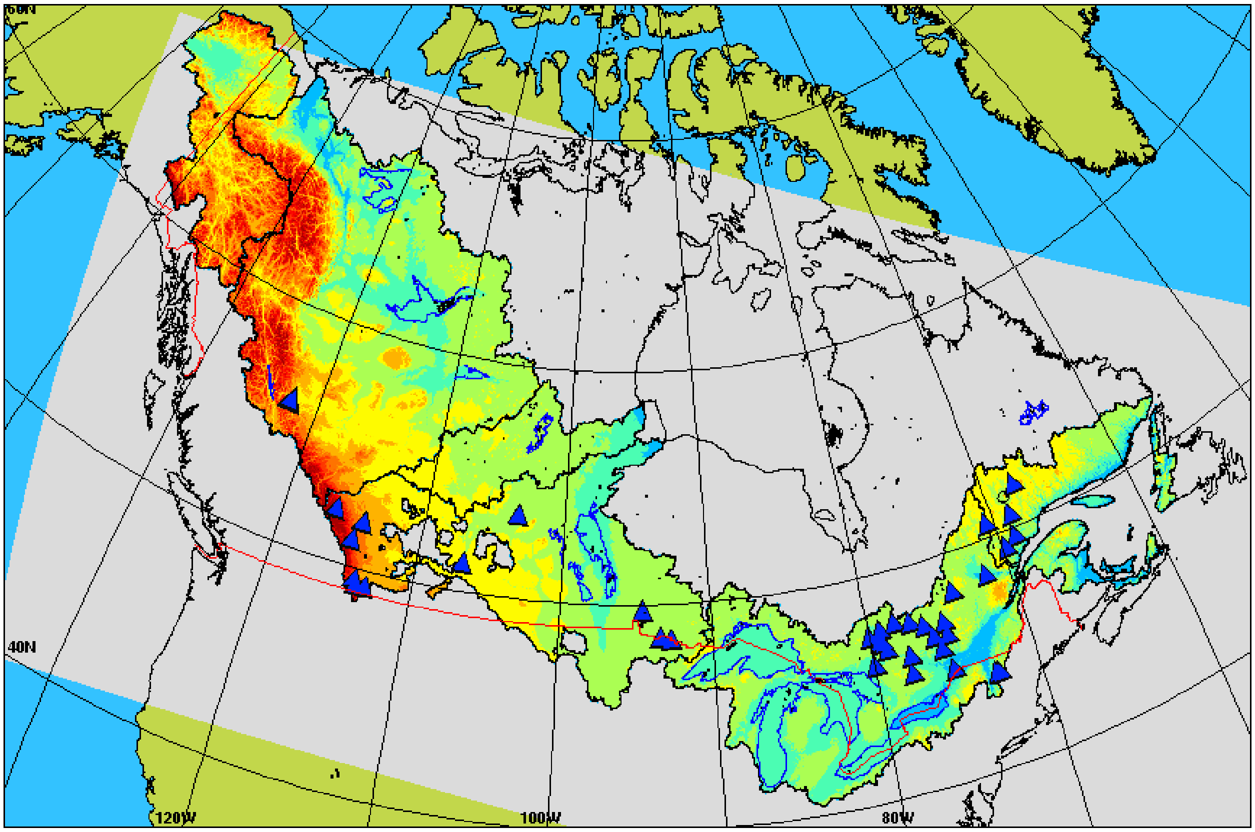

Fig. 6. The regulated reservoirs where DZTR has been implemented in DHPS are indicated by the blue triangles. The background colors and solid black lines are as per Fig. 1.

3.6.2.1 Model description

The reader is referred to Yassin et al. (2019) for a comprehensive description of the DZTR reservoir model. In summary, DZTR is a simple reservoir model that tries to reproduce the main management strategies for a given reservoir, in order to achieve satisfactory storage and outflow simulations capable of following the main trends of actual reservoir operations. The model is based on the overall concept that if storage exceeds (is below) a defined target, the management rules will tend to lower (increase) it by increasing (reducing) reservoir outflows. To do so, the reservoir is divided into five main zones or layers in the model, which are defined based on different storage and associated outflow thresholds. A specific set of equations governing the reservoir outflow is associated with each storage zone. These storage and outflow thresholds, which represent the main parameters of the model, vary according to the month of the year to try to capture the seasonal change in management operations, and should be defined for each reservoir based on observed storage and outflow statistics. Although they vary for each month of the year, these parameters are fixed from one year to another in the model. This is a main limitation of the model, which is built upon “climatological” parameters instead of actual management rules, but this is what actually allows it be implemented at large-scale (for many dams), because dams’ actual management rules are rarely available in practice. Therefore, a long period (ideally more than ten years in the near past) of observed data is needed to avoid building parameters which will be specific to a given year instead of being more general. This need for such data is actually the main drawback of the DZTR model, as stated by Yassin et al. (2019). However, a recent study by Gaborit et al. (submitted) has shown that DZTR can improve over the natural lake model even with a limited degree of available data, justifying the use of DZTR for representing regulated reservoirs in the large-scale NSRPS system implemented over Canada.

While the original DZTR model proposed by Yassin et al. (2019) relies on monthly values for some parameters (see the parameter files of Appendix C), a slight modification was brought to the DZTR model used in DHPS at ECCC, in order to use daily values for the three storage and the three outflow threshold (or target) parameter values, as explained in Gaborit et al. (Submitted). To do so, each monthly parameter value derived during the DZTR implementation is assumed to be valid on the 15th of a given month. Then, for each day of the simulation period, a daily value is derived by linearly interpolating between two monthly values. However, only monthly parameter values are still needed as input to the model, with this modification, since the interpolation is performed inside of the DZTR model directly. More precisely, during simulation, if the day of a given month is before the 15th of the Month, then the monthly parameter values are linearly interpolated (based on the distance in days) between the value of the previous month and the value of the current month, each monthly value being assumed to be valid on the 15th of the month. Otherwise, if the day of a given month is after or on the 15th of the month, then the monthly parameter values are linearly interpolated (based on the distance in days) between the value of the current month and the value of the next month.

3.6.2.2 Model parameters

To enable DHPS to implement the DZTR model on a given reservoir, we provide a set of parameters for each reservoir. The name and location of the reservoir are provided in the template file for reservoir release (see Sect. 3.6.1 and Appendix B). The parameter file for DZTR (see Appendix C) identifies the name of each of the reservoirs on which DZTR has been implemented. For each reservoir, the parameter file specifies its type as multi-year or intra-year. The parameter file also provides a considerable amount of information on the reservoir's storage and outflow, and on their relationship. More specifically, estimates are provided in the parameter file of the storage-elevation relationship to convert between these two parameters, the reservoir's maximum capacity, its area, volume and maximum depth under normal conditions, the maximum storage level with physical meaning, the maximum elevation at the dam, the minimum storage level allowed, and the dead storage fraction. For the outflow, the parameter file specifies the capacity of the downstream channel. Finally, monthly values are provided for the storage thresholds for the three main storage zones and the outflow thresholds associated with the three main storage zones. Note that, since the name of the regulated reservoirs are provided in a given domain's DZTR parameter file (see Appendix C), the order of the reservoirs defined in the parameter file does not need to be the same as the order of the DZTR reservoirs listed in the same domain's reservoir release template file (see Appendix B). However, the names themselves of the reservoirs need to match in the two files. More information on the methodology and available tools and databases to compute the DZTR parameters for a given reservoir can be found in Gaborit et al. (2021), or in an internal ECCC documentation (contact etienne.gaborit@ec.gc.ca).

3.7 Diversions

Flow diversions consist of adding flow to and removing flow from a model grid point. The spatial distribution of diversions represented in DHPS is presented in Fig. 7. Diversions are processed in order of their appearance in the input diversion template file (see Appendix D). Three types of diversions are represented:

- Type 1, both ends of the diversion are in the same watershed.
- Type 2, the start end of the diversion is inside the watershed but the end point is outside.
- Type 3, the start point of the diversion is outside the watershed but the end point is inside.

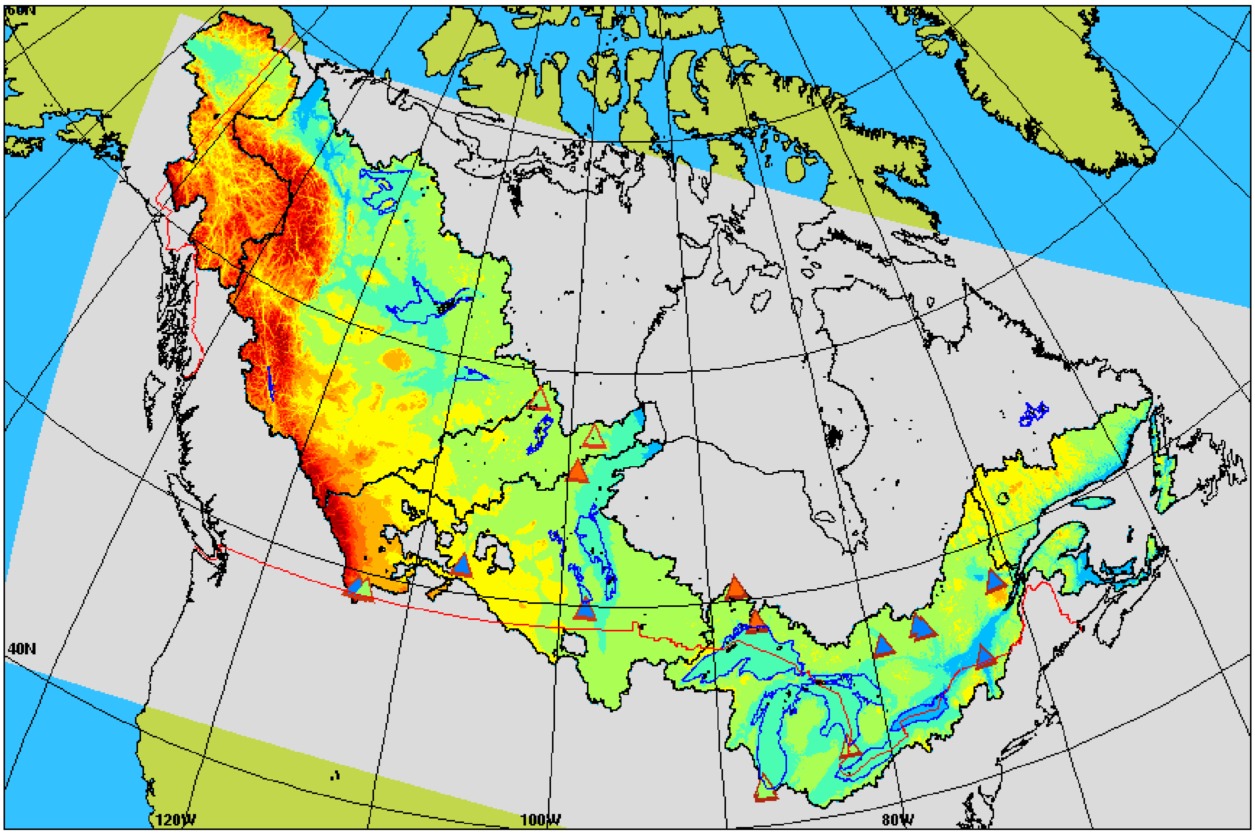

Fig. 7. The source end of diversions represented in DHPS v3.1.0 are indicated by the triangles. Diversions of type 1 are in blue, type 2 in yellow and type 3 in orange. The background colors and solid black lines are as per Fig. 1.

For channel flow, the outflow from a given grid point at the end of the time step (Qo2) is first calculated as described in Sect. 3.5. If an observation of discharge is available for the grid point, the observation is assimilated (see Sect. 4). Finally, flow that is to be diverted into or from the grid point modifies Qo2. For grid points within a reach, the first step is once again to calculate the outflow from the reach. Flow is then diverted into or from the reach's storage.

The base amount of flow to be diverted is provided to WATROUTE as a time-series of hourly values (see Sect. 3.5 for the definition of an event) over the duration of the event. These values may be observations. If no positive value is found for a given hour, then WATROUTE persists the last positive value from the beginning of the event. If no positive value of flow is found from the beginning of the event, then the simulated streamflow value (Qo2) at the diversion's source is used. If no positive value of flow is found and the source point of the diversion is not in the watershed, the model crashes.

Once the base amount of flow to be diverted has been determined, it is multiplied by a user-specified constant coefficient called "Value1" (see Appendix D). The resulting value is the actual flow that is to be diverted. Note that, at the source end of the diversion, no more water than the source grid cell contains will actually be diverted regardless of the calculated value of the flow to be diverted (more details follow at the end of this section).

If the flow to be diverted is to be based on an observed value, the name of the diversion in the diversion template file (see Appendix D) starts with a number; the name of the diversion must match the name of the observation station. Note that the diversion template file contain two lines of default flow values for each diversion. If the diversion name starts with a number (triggering DHPS to search for an observed value for this diversion), then the first default value must be negative. Indeed, if the first default value is positive, it means that a constant flow value is to be used for the diversion, which is incompatible with the fact that an observation is to be found.

During the data assimilation cycle, when, according to the diversion template file, a diversion is to be based on an observation, DHPS looks for an observed value from the indicated station for the hour being processed. If no valid observation is available, DHPS will look for the last valid observed value for the given station over the two weeks ending at the hour being processed. During the forecast phase, DHPS looks for the most recent observed value from the two weeks ending with the hour at the start of the forecast. The most recent observed value is then persisted throughout the entire forecast phase. For both the data assimilation cycle and the forecast, if no valid observed value is found in the two weeks searched, then the second default value provided in the diversion template file is used. The second default value represents a typical value for the station over a year. If a diversion based on an observation station is of type 3 where the source end is located outside of the watershed, a positive number must be prescribed as the second default value. If no flow observations are found and the default value is negative, then WATROUTE will look for the simulated flow at the source end of the diversion. Since it will be unable to find the simulated flow, WATROUTE will crash. In contrast, if the diversion type is 1 or 2 where the source end is within the watershed, then the second default flow value can be negative. In this case, if no valid flow observations were found over the previous two weeks, then the simulated flow value at the source end becomes the base value of flow to be diverted.

In both the data assimilation cycle and the forecast, if the diversion is not based on an observation (the diversion name does not start with a number), then DHPS will always use the first default value provided in the diversion template file; the second default value is not used. For simplicity, since a second default value must be provided in the template file, we set it to the same value as the first default value. For diversions not based on an observation, if the default value is positive, WATROUTE uses a constant flow equal to the first default value for this diversion. If the default value is negative, the simulated flow at the source end of the diversion becomes the base value of the flow to be diverted.

Once the base value of the flow to be diverted has been determined, either as observed at the hour of interest, observed during the previous two weeks, constant, or simulated, the base flow value will be multiplied by the "Value 1" coefficient of the diversion template file (see Appendix C). The value of this coefficient can be other than unity. When the flow to be diverted is based on the simulated flow at the source end of the diversion, the coefficient's value is often less than unity. Note that in all cases, and whatever the actual flow to be diverted will ultimately be, no more water than is available at the source point of the diversion will be diverted. If the source point of the diversion is a river, it means that no more flow than the flow of the grid cell at the source point will be diverted; the storage of the grid cell is not considered. If the source point of the diversion is in a reach (an explicitly represented body of water), then no more water than is contained in the reach's storage will be diverted during the current time step; the reach's inflow is not considered.

Note that there are two other special types of diversion that are represented in DHPS, namely a diversion corresponding to irrigation flows, and the diversion via the Chambly canal in the Lake Champlain/Richelieu River watershed. In the first case (irrigation), a constant flow value is provided for the diversion, and it will be spread over multiple grid cells to remove flow either from WATROUTE's lower zone storage, from lakes or from rivers in order to represent the main effects of irrigation in a given area. In the second case (Chambly Canal diversion), the diversion can be turned off, turned on, or activated when forecast water levels of Lake Champlain pass the prescribed threshold value. Since these last two special types of diversion have not been activated, we will not describe them in more detail here.

3.8 Lower Zone Storage

The Lower Zone Storage is an intermediate compartment in WATROUTE that represents the contribution of the aquifer at a grid point to the grid point's river channel or to the storage of a reach. Drainage from the surface model, which is the vertical flow of water through the bottom of the last hydrologically active layer of soil, is added to WATROUTE's lower zone storage. Outflow from the lower zone storage, or baseflow, contributes to the stream of the grid cell, or to the reach's storage if the grid cell is part of a reach. The baseflow is computed based on the stage-discharge relationship of Eq. 22:

$$Q = FLZ \; x \; LZS^{PWR} \qquad (22)$$

where Q ($m^3 \, s^{-1}$) is the baseflow from the lower zone storage for the grid point, *LZS* is the depth of the water (mm) of the lower zone storage, and *FLZ* and *PWR* are coefficients specified by the user. In DHPS v3.1.0, *FLZ* and *PWR* are constant over all grid points of a WATROUTE domain.

LZS can be negative. For grid points outside of a reach, any negative surface runoff is passed to the lower zone storage instead of directly to the river channel (see Sect. 3.3). If the grid point is part of a reach, all of the runoff (positive or negative) is added to the reach's storage (Sect. 3.3). When *LZS* is negative, the outflow from the lower zone storage is zero-valued. This arrangement preserves the water balance in WATROUTE. Unfortunately, the removal of surface water evaporation from the underground aquifer is not entirely relevant physically. This is an area of active research.

3.9 Irrigation

Irrigation is treated as a special type 2 diversion (see Sect. 3.7). Type 2 diversions represent irrigation if the name of the diversion starts with “irrig” or “Irrig”. Unlike with non-irrigation diversions, it is not possible to use an observation station to guide the total amount of water to be removed by irrigation.

With irrigation, flow is removed from both the lower zone storage (LZS) and the river channels. The area where the irrigation is active is the portion of the rectangle centred on the source end of the diversion that is within the watershed. The size of the rectangle is set in the diversion template file (see Appendix D) by specifying the number of points in the east-west and north-south directions. Value1 of the diversion template file indicates the fraction of the total amount of water that is to be removed from the LZS; the remainder is removed from the river channels or reach. The water to be removed from grid points within a reach is taken from the storage at the reach’s outlet. The total amount of water removed by irrigation is the sum of the water removed from each irrigated grid point, or the grid points within the defined rectangle that are also within the watershed. As mentioned in Sect. 3.7, only the available water can be removed from a river channel or a reservoir; there is a limit to removal of water by irrigation from these compartments. In contrast, the removal of water by irrigation from the LZS is not limited. However, if the LZS becomes highly negative, it may never recover from irrigation and may no longer contribute to baseflow. Note that, for grid points that are over water but that are not in a reach, water removed from the LZS has no impact on the simulation; the surface model only represents baseflow for areas covered by soil. Since areas covered by water always have zero-valued baseflow, recharge is always zero-valued; removing water from the LZS through irrigation does not further reduce an already zero-valued baseflow.

4. Data assimilation

In addition to the simple direct insertion of streamflow observations of DHPS v1.0.0, we have added the data assimilation method referred to as “upstream propagation” (see Fig. 8). Direct insertion consists of replacing the simulated value at the current grid point and time step with an observed value of river discharge. Then, the routing scheme propagates this information downstream from the insertion point as water moves through the river channel. Note that we use the same observed value for all time steps within a given hour.

For DHPS v3.1.0, the assimilation of streamflow data consists of first performing the direct insertion during the routing loop from upstream to downstream grid points for the current time step and then, in a second step, to apply the upstream propagation of the streamflow errors obtained at the measurement location (i.e. observation – simulation). Observations are assumed to be perfectly correct. Streamflow error is propagated upstream of the measurement location using a weight that decreases as a function of a measure of dissimilarity (section 4.1). Within the propagation loop of the current time step, the grid points are processed in reverse order, or from downstream to upstream, using the BACK variable of the shed file (see Sect. 3.2).

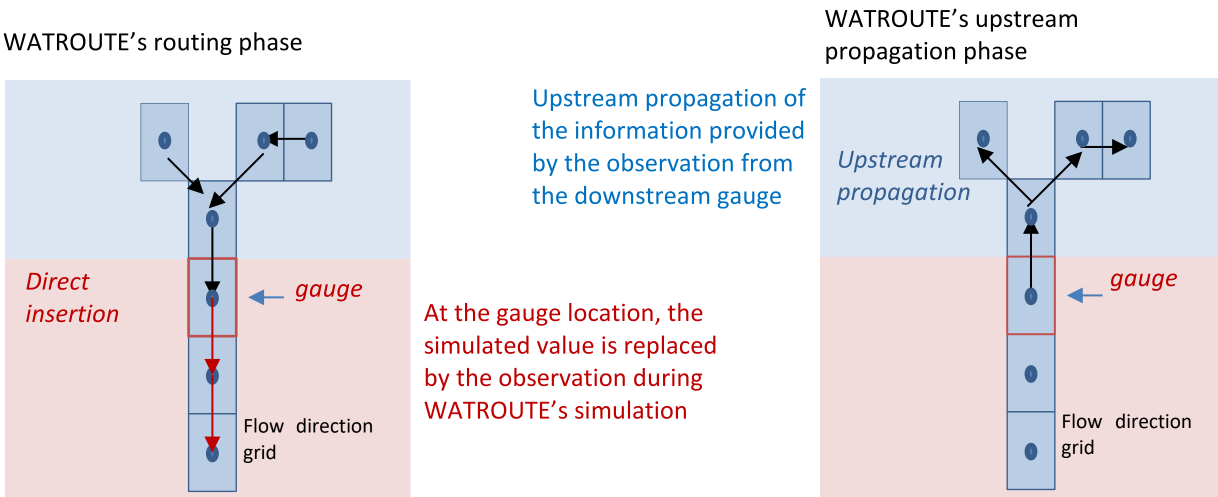

Fig. 8. Illustration of the mechanism of direct insertion (left) and upstream propagation (right).

If there are several observation stations on the same river, successive corrections are applied, starting from the station that is the farthest downstream. Propagation is applied upstream of the current grid point until it reaches the outlet of a regulated reservoir, or the start or end point of a diversion. When one of these points is encountered, the upstream propagation stops.

4.1 Upstream propagation

To propagate the error to the grid point *i* upstream of the measurement point *s*, we use a weight that decreases as a function of a measure of dissimilarity $f_{s,i}$ following Eqs. 23 and 24.

$$Qo_i^a = Qo_i^b + wRes_i\, f_{s,i}\,(Qo_s^{obs} - Qo_s^b) \tag{23}$$

$$f_{s,i} = A_i/A_s \tag{24}$$

where Qo_i^b is the simulated channel outflow before upstream propagation correction, Qo_s^{obs} the observed value and Qo_i^a the updated, or analysed, model outflow. A_i/A_s is the ratio of the drainage area at the grid point *i* to the drainage area at the measurement location *s*. There is no need to make the correction downstream because the routing model WATROUTE will propagate the correction downstream during the next time step (see Section 3.5). $wRes_i$ is an indicator to determine the extent to which a gauging station and the current grid point are influenced by regulated reservoirs upstream. See Sect. 4.2 for a detailed description of this indicator.

The final outflow, Qo_i^a, is obtained following Eq. 25 using a weighted value of the purely simulated flow (Qo_i^b) and the corrected flow from upstream propagation (Qo_i^a). As mentioned above, Qo_i^b is obtained during the routing process with direct insertion. An illustration of the scenario behind this calculation is provided in Fig. 9.

$$Qo_i^a = w_u Qo_i^a + w_d Qo_i^b \tag{25}$$

where the weights, w_u and w_d, are defined by Eqs. 26 and 27:

$$w_d(i) = \frac{\frac{\sum_{k=1}^{N} da(S_k)}{da(i)}}{\left[\frac{da(i)}{da(S)} + \frac{\sum_{k=1}^{N} da(S_k)}{da(i)}\right]} \tag{26}$$

$$w_u(i) = \frac{\frac{da(i)}{da(S)}}{\left[\frac{da(i)}{da(S)} + \frac{\sum_{k=1}^{N} da(S_k)}{da(i)}\right]} \tag{27}$$

where $\sum_{k=1}^{N} da(S_k)$ is the total drainage area of the upstream stations at all grid points k that influence the current grid point i, $da(S)$ the drainage area at the observation station downstream of the grid point and $da(i)$ the drainage area at the grid point.

In order to be able to perform the above calculations, the number of observation stations upstream that contributed to the simulated value at a given grid point, as well as the locations of those stations, are stored in memory for each grid point during the routing phase. The simulated value of the streamflow at the given point is also stored in memory for later use.

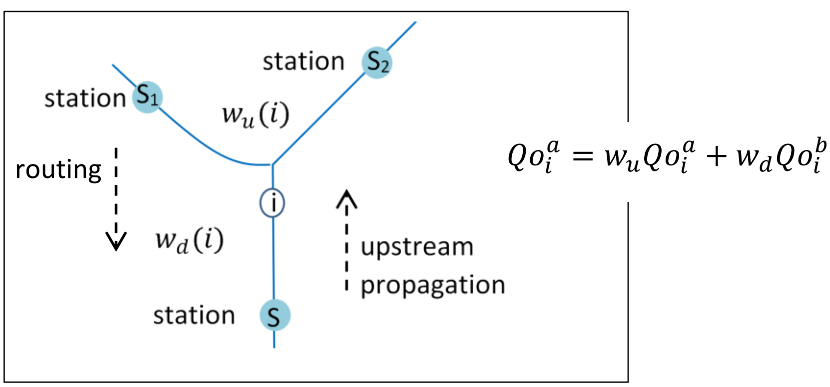

Fig. 9 Illustration of the calculation of the weighted final streamflow at the grid point *i* located between station *S*, and 2 upstream stations S_1 and S_2.

In addition to the process described above, to preserve the stability of WATROUTE, we adjust, for each grid point, the inflow into the channel from upstream grid points (Qi_i^a) and storage at the end of the time step (*store2*) to be coherent with the updated outflow (Qo_i^a). To calculate the volume of water associated with the difference between the simulated outflow before and after the correction, it is assumed that the difference is constant during the time step Δt. The updated channel storage for any grid-point is given by Eqs. 28 and 29:

At station locations:

$$store2_s = store2_s + \Delta\mathrm{t}(Qo_s^{obs} - Qo_s^b) \tag{28}$$

Otherwise:

$$store2_i = store2_i + \Delta\mathrm{t}\left(Qo_i^a - Qo_i^b\right) \tag{29}$$

The storage value is constrained by a minimum value of 1.0 m^3. Remember that Qo_s^{obs} is the observation at the station location, Qo_i^a is the corrected outflow from the data assimilation process and Qo_s^b and Qo_i^b is the outflow before any correction. No correction is applied to the channel inflow and storage for grid points at the head of a river branch because the upstream propagation process does not modify the inflow for these points.

The updated value for the inflow Qi^a is calculated from the sum of the updated outflows Qo^a of the grid points upstream that contribute to Qi^a. Finally, to these updated inflows, the local contribution of inflow from surface runoff and drainage (*Qr*) is added.

4.2 Regulated reservoirs

An indicator has been developed to determine to what extent a gauging station is influenced by regulated reservoirs upstream. The drainage area of all reservoirs located upstream of any point *i* in the network is first calculated (daR_i). In the case of cascading reservoirs, only the drainage area of the first reservoir upstream is retained. Then, we divide the reservoirs' drainage area by the drainage area of the grid point (da_i). This yields the fraction of the influence of the reservoirs (IFL_i; see Eq. 30a) at the point in the network *i*. An illustration of the scenario behind this calculation is provided in Fig. 10.

During the upstream propagation, we compare the fraction of influence of the reservoirs (IFL_s; see Eq. 30b) at the station grid point *s*, or the starting point of the upstream propagation, with the fraction of influence at the point *i* where we apply the streamflow correction. The developed indicator becomes a weight (see Eq. 30c) that multiplies the streamflow errors obtained at the measurement location. This weight decreases as the difference between the influence of the reservoirs at the grid point *i* and the influence at the station grid point *s* increases. This means that we gives less importance to the observations as we approach the reservoir.

$$IFL_i = daR_i/da_i \tag{30a}$$
$$IFL_s = daR_s/da_s \tag{30b}$$

$$\mathrm{wgtRES}_i = (1 - |IFL_i - IFL_s|)^{pow} \qquad pow \geq 1 \tag{30c}$$

where *pow* = 1.5. $daR = \sum_{R=1}^{N} da\,(R)$ is the sum of the drainage area of the *N* upstream reservoirs that influence a grid point. By increasing the power value (*pow*), we apply increasingly smaller increments as the fraction of influence changes during upstream propagation.

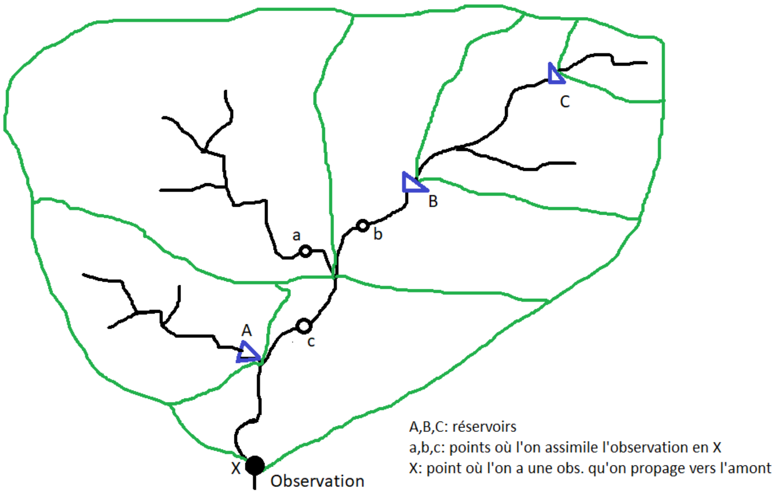

Fig. 10. Illustration of a simplified watershed with three regulated reservoirs at positions A, B and C. Point X is the location where we have an observation that we propagate upstream. The points, a, b and c are the locations where we assimilate information from the observation at X. In this example, it is assumed that the observation in X will be influenced by reservoirs A and B. Point a will not be influenced by any reservoir and point c will be influenced by reservoir B only.

4.3 Natural lakes

The adjustment during the data assimilation cycle of DHPS of the water level of natural lakes that are explicitly represented in DHPS (see Sect. 3.6) is based on observed flows downstream of the lake. In WATROUTE, the depth of the water above a lake's zero-flow level is the quotient of the lake's storage and its surface area. The surface area is considered constant. We modify the lake's storage (*store2*) by inverting the lake's storage-discharge relationship and along with the updated outflow (Qo^a) at the lake's outlet. If the storage-discharge relationship (see Eq. (20) of Sect. 3.6.1.) is based on an exponential function, the relation is directly inverted to get *store2*. If the storage-discharge relationship is a polynomial function as per Eq. (21), we use the Newton-Raphson method to invert the relationship and derive *store2*. Finally, WATROUTE computes the lake level during the next time step using the new value of *store2*.

4.4 Streamflow observations

Streamflow insertion plus upstream propagation occurs for all grid points containing a streamflow gauge when the hourly-averaged observed flow value is greater than zero. The name and location of the river gauges used by the data assimilation system are provided in the template files of Appendix A. The locations of the stations have been modified where necessary to ensure that they are on the appropriate river in the shed file and in the appropriate location on that river, for instance below or above the entrance of a tributary. We show the spatial distribution of the gauges used by DHPS in Fig. 11.

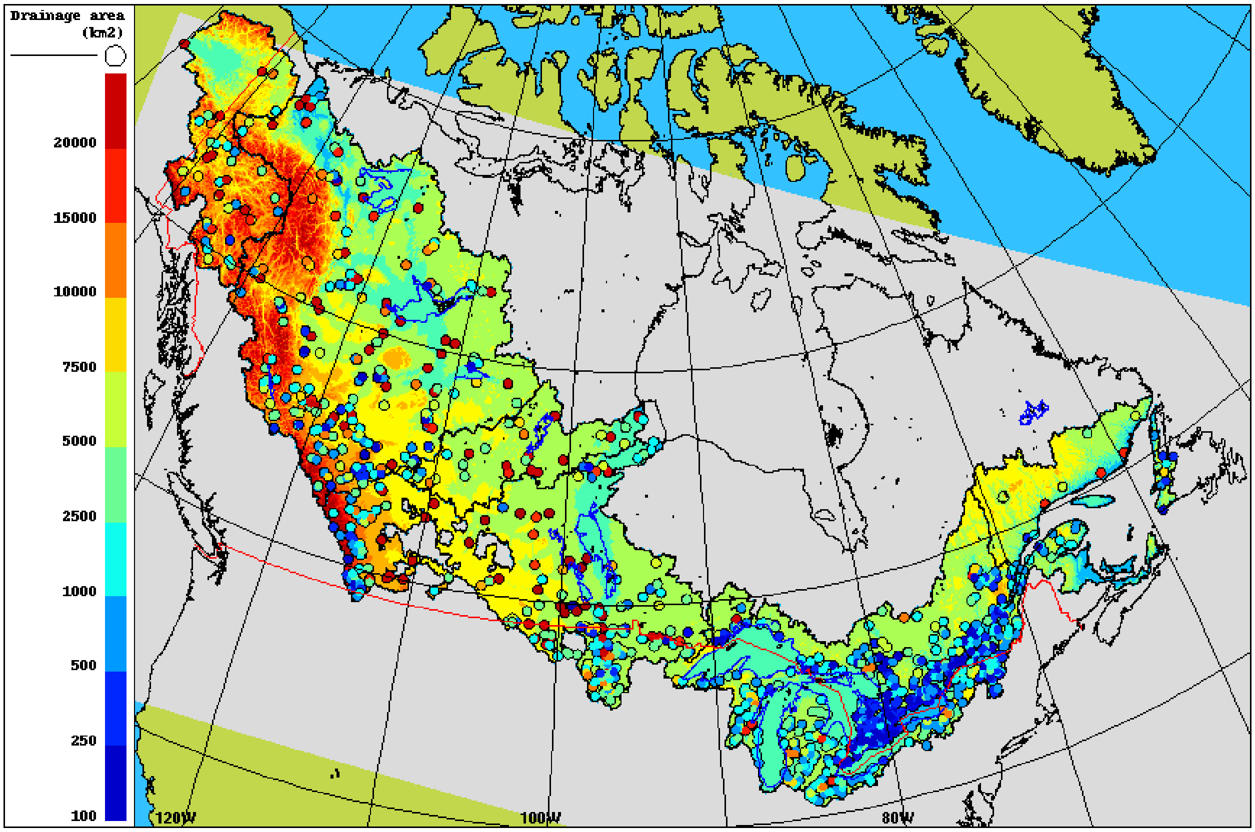

Fig. 11. Shown in circles is the spatial distribution of the stations processed by the data assimilation system of DHPS. The colours of the circles represent the size of the area that drains to a given gauge (km^2). The background colors and solid black lines are as per Fig. 1.

5. System Specifications

Tables 5-6 provide values of parameters used in DHPS. Table 7 summarizes the configuration of each domain. Detailed configuration files ingested by DHPS are provided in Appendices A -D.

Table 5. Parameters related to WATROUTE

Parameter	Value
Maximum length of time step	3600 s
Minimum length of time step	30 s
Convergence threshold	0.01 m
Initialize reservoir storage based on last level for a new event	yes
Spatially-varying Manning's roughness coefficient for channel flow	yes
Spatially-varying Manning's roughness coefficient for overbank flow	yes
Spatially-varying subgrid-scale meandering of rivers	yes
Spatially-varying implicit treatment of lakes	yes
Option to avoid model crash (nocrashflg)	yes

Table 6. Parameters common to all modelling domains

Parameter	Value
Grid type	latitude-longitude horizontal grid
Horizontal resolution	30 arcseconds (1 km at Equator)
Cross-sectional area of river channel	1.1 + 0.043*(drainage area)**1.0
Width-to-depth ratio of river channel	20
Manning multiplicative coefficient	0.75 (1.00 for Nelson)
LZS "FLZ" parameter	1.0E-6 (3.0E-8 for Nelson)
LZS "PWR" parameter	2.8 (2.6 for Nelson)
Maximum factor retarding flow in lakes treated implicitly	3.0

Table 7. Information related to specific modelling domains					
Domain	Abbreviated name of domain	Number of streamflow gauges processed by data assimilation system	Number of natural lakes defined explicitly	Number of reservoirs with DZTR implemented	Number of diversions represented
Yukon River	yuk	ECCC: 35 USGS: 6	10	0	0
Mackenzie River	mck	ECCC: 101 AEP[1]: 95	40	1	1
Churchill River	chu	ECCC: 22 AEP[1]: 5	38	0	2
Nelson River	nel	ECCC: 64 AEP[1]: 53 USGS: 88	43	11	6
Great Lakes St. Lawrence River	gls	ECCC: 251 USGS: 206 CEHQ[2]: 103	40	21	10
Gulf of St. Lawrence	gsl	ECCC: 9 CEHQ[2]: 21	13	4	0

[1]Alberta Environment and Parks, [2]Formerly the Centre d’Expertise Hydrique du Québec and now Ministère de l’Environnement et de la Lutte contre les changements climatiques

6. System evaluation

Section 6 describes how we evaluate the performance of DHPS. We present the experiments executed, the verification metrics and the observation stations used. Finally, the calculated scores are presented and discussed.

6.1 Experiments performed

For IC-3, we executed two experiments: a 12-month pre-final cycle and the two formal final cycles. We provide the description of these two experiments in Table 8. Also described in Table 8 is the 12-month reference or control run to which we compare the performance of the pre-final and final cycles. The 12-month runs are divided into four seasons for evaluation purposes. Although Fall and Spring are four months while Summer and Winter are two months, we separate the 12 months in this way so that the definitions of Summer and Winter coincide with the definition of the periods for the official final cycles.

Table 8. Experiments used to evaluate the impact of innovations introduced for Innovation Cycle 3 on the performance of DHPS

Experiment	Description	Periods evaluated
Control or 3.2	Operational version of WATROUTE new observations from USGS, Alberta and Quebec Maestro suite updated from v3.0.0 to v3.1.0[1] SSM package for Librmn updated from 19.5 to 19.7 SSM package for CMDS updated from 201910/01 to 202012/00 Fortran updated from v4.8-u1.rc5 to v4.8-u1.rc6	Summer 2019: 1 Jul – 31 Aug Fall 2019: 1 Sep – 31 Dec Winter 2020: 1 Jan – 29 Feb Spring 2020: 1 Mar – 30 Jun
Pre-Final or 3b.3	IC-3 version of DHPS, IC-3 version of NSRPS, Operational version of atmospheric piloting fields	Summer 2019: 1 Jul – 31 Aug Fall 2019: 1 Sep – 31 Dec Winter 2020: 1 Jan – 29 Feb Spring 2020: 1 Mar – 30 Jun
Final or 3b.4	IC-3 version of DHPS, IC-3 version of NSRPS, IC-3 version of atmospheric piloting fields	Summer 2019: 1 Jul – 31 Aug Winter 2020: 1 Jan – 29 Feb

[1]This update was necessary in order to be able to process the new observations. It is not expected that the new version of the suite impacted the results otherwise.

The reference run closely resembles the version of DHPS that is currently running in Operations. The primary difference between the version of DHPS that provided the reference run and the operational system is the inclusion in the reference version of the use of river gauges from USGS and the provincial networks of Alberta and Quebec. Unfortunately, this impacts the performance of DHPS at stations used in Operations where a gauge has been added upstream. Five out of the 495 stations used in Operations are impacted in this way. The benefit of using the new gauges in the reference version is that it greatly facilitates the comparison of the performances of the reference, pre-final and final experiments given the common set of stations used in data assimilation; the stations assimilated are also used for verification. Thus, we consider the appreciable benefit gained by the use of the new gauge networks in the reference experiment to outweigh the relatively minor cost in terms of the reference run not resembling the version of DHPS running in Operations quite as closely as it could. The distribution of the gauges from of ECCC’s Water Survey of Canada that are currently used in Operations is shown in Gaborit and Durnford (2021).

6.2 Verification metrics

We verify the quality of simulated river discharge by calculating the bias, standard error, root mean square error ("RMSE" or "rmse"), and median absolute deviation or error ("mad") of the analysed and forecast discharge. We calculate the score obtained at each gauge or observations station using 24-hour accumulations of discharge. The score presented is the mean of the scores obtained over all the stations. We discuss both the non-normalized scores and the mean scores obtained when the score at each station has been normalized by the drainage area of the gauge. Non-normalized scores emphasize the performance at stations with larger drainage areas. Scores normalized by drainage area increase the visibility of the performance at stations with small and medium-sized drainage areas. Note that, since the analysis is the 12th hour of a continuous data assimilation cycle, we use the terms "analysis" and "data assimilation cycle" interchangeably.

6.3 Verifying observations

As mentioned in Table 7 of Sect. 5, DHPS v3.1.0 assimilates observations from ECCC, USGS and the provincial networks of Alberta **and** Quebec. These are also the observations used to verify the performance of DHPS. The distribution of the gauges is shown in Fig. 12.

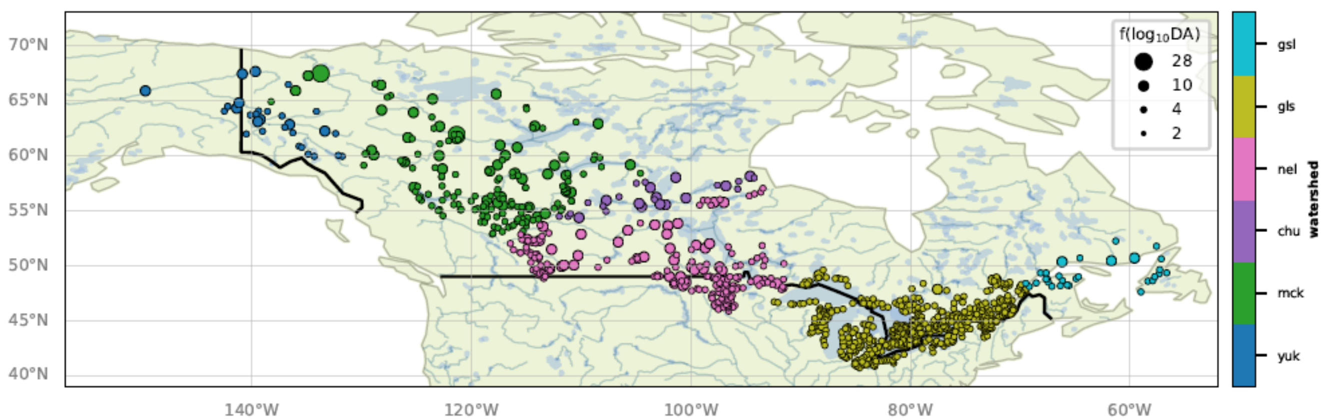

Fig. 12. The gauges providing the observations of river discharge that are assimilated by and used to verify the performance of DHPS are indicated by the circles. The colours of the circles represent the river basin in which the gauges are located. The size of the circles indicates the magnitude of the drainage area of each gauge.

In Table 9, we provide, for each domain, the distribution of gauges by size of drainage area. Small drainage areas are from 100 – 500 km^2, medium drainage areas are from 500 – 1000 km^2, and large drainage areas are upwards from 1000 km^2. It is evident in Table 9 that stations in all domains other than the Great Lakes St. Lawrence domain have primarily large drainage areas. The Great Lakes St. Lawrence domain has almost as many gauges with small drainage areas as with large drainage areas.

Table 9. For each domain and season: river gauges used during data assimilation and verification

Domains	Abbreviated name of domain	Number of stations assimilated by drainage area size group: small / medium / large (total)			
		Summer 2019	**Fall 2019[1]**	**Winter 2020**	**Spring 2020[1]**
Yukon River	yuk	0/2/28 (30)	0/2/27 (29)	0/3/25 (28)	0/3/28 (29)
Mackenzie River	mck	24/20/122 (166)	24/20/123 (167)	14/12/112 (138)	25/21/132 (178)
Churchill River	chu	0/1/25 (26)	0/1/25 (26)	0/0/25 (25)	0/1/25 (26)
Nelson River	nel	20/24/158 (202)	20/24/158 (202)	18/22/149 (189)[2]	20/24/159 (203)
Great Lakes St. Lawrence River	gsl	189/121/231 (547)[3]	189/121/230 (546)[3]	190/121/230 (547)[3]	191/120/230 (547)[3]
Gulf of St. Lawrence	gls	6/8/16 (30)	6/8/16 (30)	6/8/16 (30)	6/8/16 (30)

[1]Only in Control and Pre-Final suites; [2]190 stations in the Control suite; [3]6 more stations with drainage area <100 km^2 are available.

6.4 Results

In this Section, we present images of scores from Control, Pre-final and Final. In many of the figures, we summarize scores by considering the spatial and/or temporal means of the scores. We also provide hydrographs to show in a concrete way the impact of the innovations for specific locations and dates.

As a result of the data assimilation system, the analysed river discharge of DHPS is close to being error-free on rivers having a gauge. We will demonstrate this below. Moreover, the cancellation of positive and negative biases produces an overall bias that is even closer to zero. Consequently, the relative differences between Control and Final should be treated with caution; the degradation in normalized bias of 600% for the Great Lakes St. Lawrence River domain very likely reflects division by a number close to zero rather than an important degradation. Thus, the scorecards of Fig. 13 probably have little meaning. In future, scorecards will not be shown for analysed discharge from DHPS. However, we can say that there is generally a reduction of errors in analysed flows for Final versus Control and that the degradation seen is mainly in biases of smaller rivers (bottom row of Fig. 13).

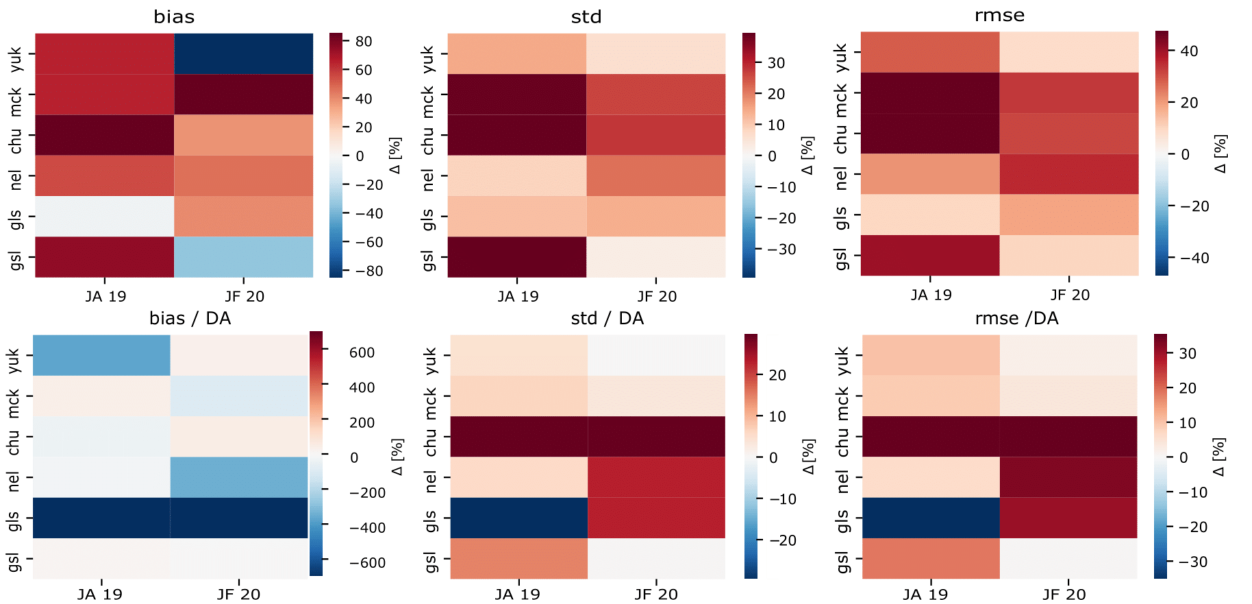

Fig. 13. This figure presents scorecards for bias, standard error ("std") and rmse that summarize the difference in performance (%) between the analysed river discharge of Control and Final (Control – Final). Warm and cool colours represent, respectively, improvement and degradation in the performance of Final versus Control. On the top row are the non-normalized scores and on the bottom row the scores normalized by drainage area. The left and right columns of a given scorecard show the comparison for Summer 2019 and Winter 2020, respectively. Moving from the top row to the bottom, the domains progress from the northwest (Yukon) to the east (Gulf of St. Lawrence). The abbreviated domain names are defined in Table 9.

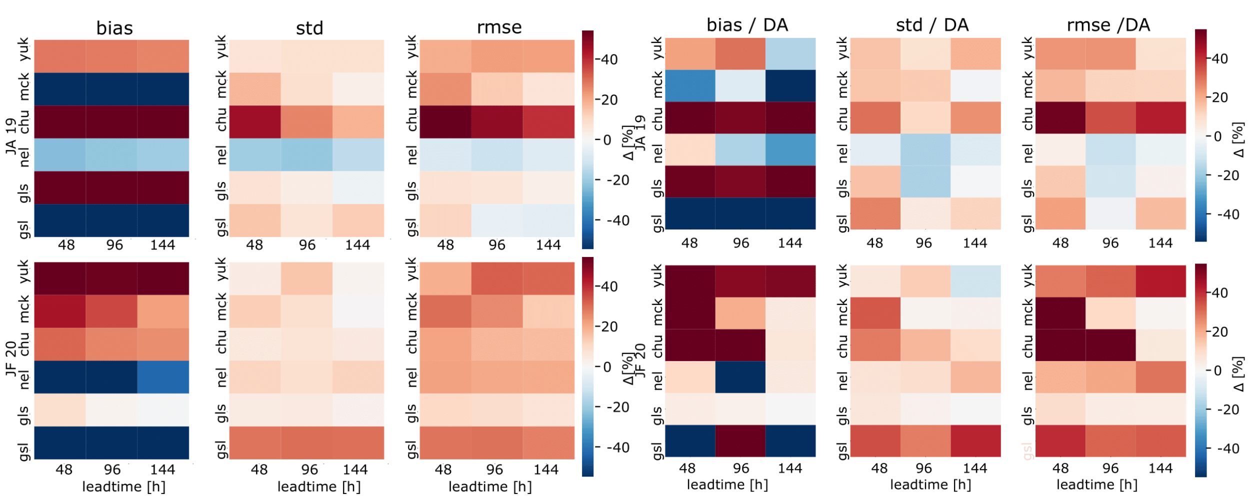

Fig. 14. As per Fig. 13 but for the forecasts of Control and Final (Control – Final). Additionally, the comparison of the scores for Summer 2019 are presented in the top panel while the scores for Winter 2020 are in the bottom row. The columns of a given scorecard provides the comparison for Days 2, 4 and 6.

The quality of predicted river discharge has improved for the standard error and RMSE for nearly all domains in both seasons from Control to Final (see Fig. 14). For the Nelson domain in

Summer, there are some instances of no change and some with a small amount of degradation. However, the primary degradation is in the bias of the Mackenzie (Summer) and Gulf of St. Lawrence domains (Summer and Winter). We will investigate this degradation further below.

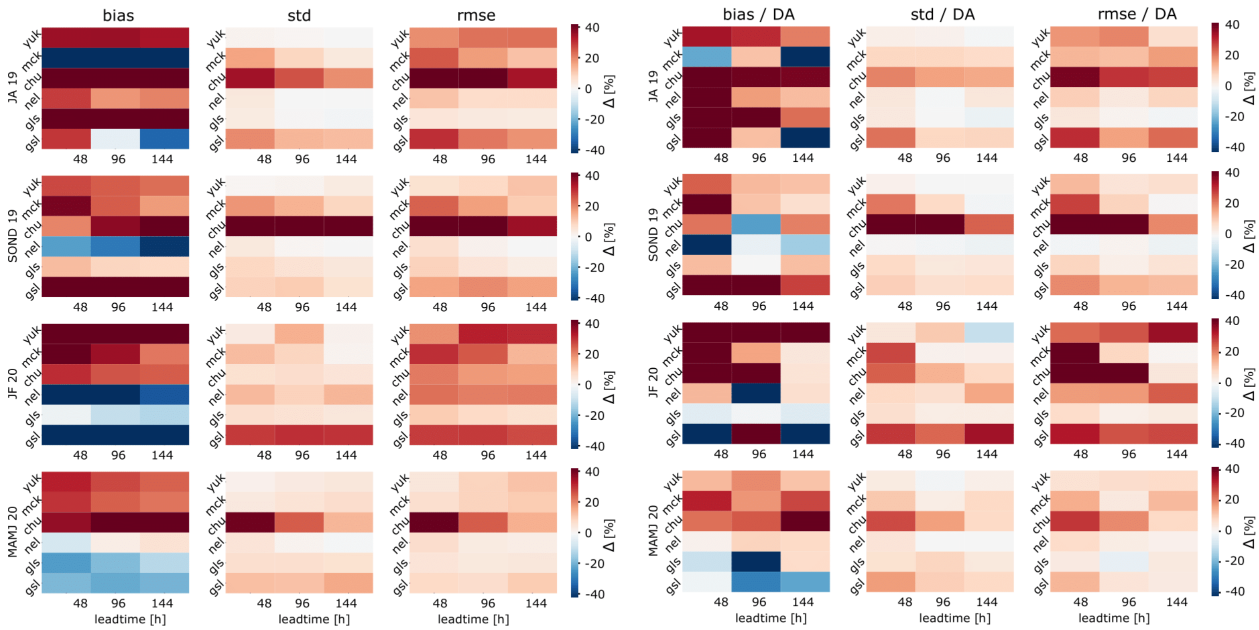

Fig. 15. This figure is similar to Fig. 14 except that it is the forecasts of Control and Pre-final that are compared (Control – Pre-Final). Additionally, progressing from the top to the bottom row, the seasons evaluated are Summer 2019, Fall 2019, Winter 2020 and Spring 2020.

Figure 15 shows the impact on the quality of the predicted river discharge of the innovations introduced for NSRPS; both Control and Pre-final use piloting fields from the operational version of the atmospheric prediction systems (see Table 8). The improvement in the standard error and RMSE is even stronger in Fig. 15 than in Fig. 14. Unfortunately, moving from the operational to the IC-3 version of the piloting atmospheric prediction systems appears to have weakened the improvements introduced by the innovations of NSRPS. This will be invested below. For the bias, Fig. 15 shows degradation but with little consistency between seasons and domains. This lack of consistency is a symptom of uncertainty of the results. Hence, we investigated the spatial distribution of these differences (see Figs. 19, 21-24) to evaluate how the variability across the stations impacts the regional assessment of Fig. 15.

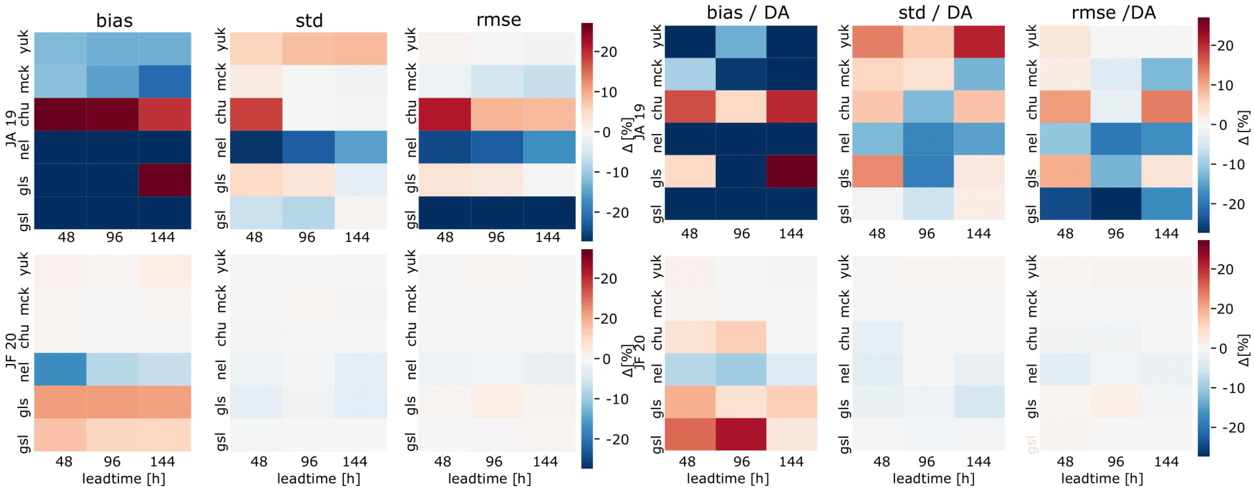

Fig. 16. This figure is similar to Fig. 14 except that it is the forecasts of Pre-final and Final that are compared (Pre-final – Final).

The innovations for IC-3 for the piloting atmospheric prediction systems have in general degraded the performance of DHPS. The degradation evident in Fig. 16 is greater in Summer than in Winter. Indeed, in Summer, there is more degradation than improvement. The degradation is strongest for the bias but also dominates the RMSE. The only fairly consistent improvement over all scores in Summer is for the Churchill domain. In contrast, the impact of the innovations for IC-3 for the piloting atmospheric prediction systems is weaker in Winter; the change in the standard error and RMSE is very close to neutral. Although the Nelson domain is characterized by a tendency to degradation, the bias has improved for Great Lakes and Gulf of St. Lawrence domains.

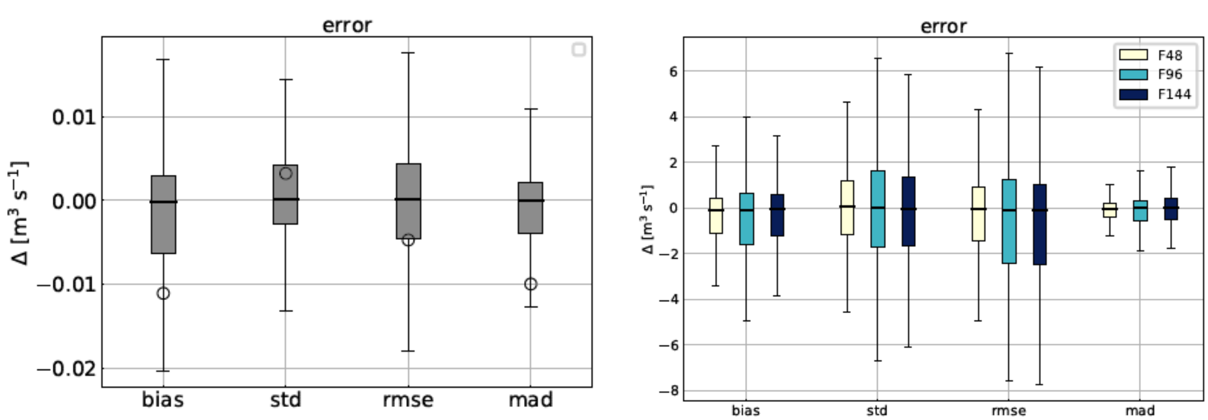

Fig. 17. For the forecast river discharge of Pre-final versus Final for Summer 2019, shown is the distribution over the stations of all domains of the difference (Pre-final – Final) of the non-normalized scores for the data assimilation cycle (left) and for Days 2 (yellow), 4 (green) and 6 (navy) of the forecast (right). The median absolute deviation is abbreviated to "mad".

Fig. 17 confirms that the differences in the analysed flows of Pre-final and Final are so small that they can be considered neutral. We find that this holds true regardless of the two experiments considered. This consistency in the quality of the analysed flows indicates the strong beneficial impact of the data assimilation method (see Sect. 4). Interestingly, for the forecasts, despite the degradation seen in the scorecard of Fig. 16, most stations appear to have similar biases and root mean square errors in Pre-final and Final in Fig. 17. It is possible that the scores of many stations are indeed almost unchanged. It is also possible that positive and negative score differences for a sizeable fraction of the stations are somewhat balanced. However, a clear degradation from Pre-final to Final from Day 2 to Day 4 is visible for a subset of stations. Note that the piloting of HRDLPS is by HRDPS for Days 1-2 while GPDS provides the piloting fields for Days 3-6.

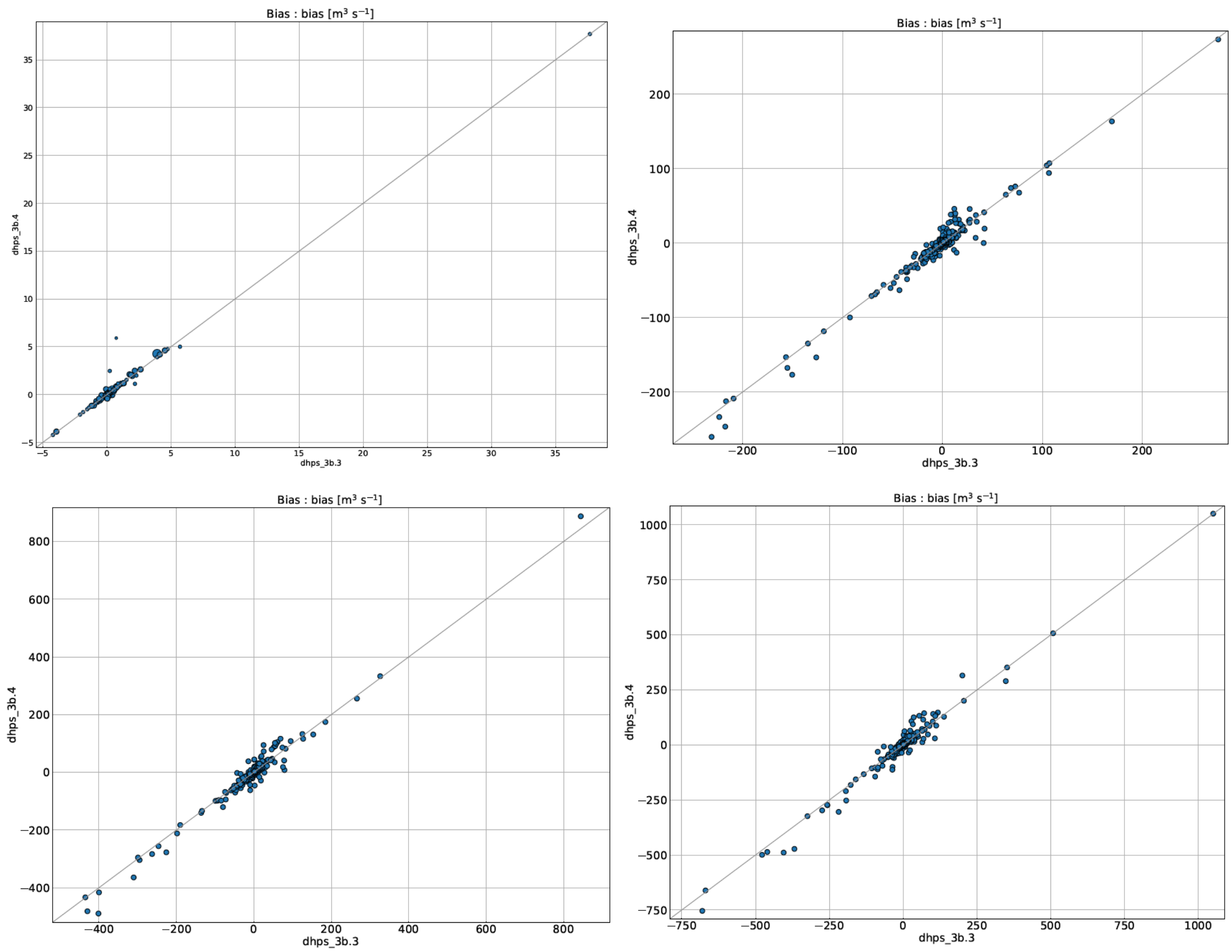

Fig. 18. For the forecast river discharge of Pre-final versus Final for Summer 2019, shown are the distributions of non-normalized bias For Final (ordinate or y-axis) versus Pre-final (abscissa or x-axis) for the data assimilation cycle (top left) and for Days 2 (top right), 4 (bottom left) and 6 (bottom right) of the forecast.

The non-normalized biases of analysed river discharge (see Fig. 18) are under 5 $m^3 s^{-1}$ apart from one outlier of over 35 $m^3 s^{-1}$. There is very little difference between the biases of Pre-final and Final. This indicates that the data assimilation system dominates the performance of the data assimilation cycle; the quality of the piloting fields for DHPS are secondary. However, differences appear between the biases of the two experiments during the forecast. On Day 2, a cluster of points is still centred around the origin. The stations with wet biases have comparable biases in both experiments given that they are located on the diagonal. However, several points have dropped below the diagonal in the region of the dry biases. This indicates that these stations have a greater dry bias in Final than in Pre-final: the existing dry bias has become drier. The same behaviours is apparent in Days 4 and 6: the wet biases of the wet stations are comparable for the two experiments but the dry biases in some stations are drier in Final than in Pre-final. Note, however, that the importance of the dry bias has greatly increased throughout the forecast from a maximum of 250 $m^3 s^{-1}$ on Day2 to 450 $m^3 s^{-1}$ on Day 4 and then to 700 $m^3 s^{-1}$ on Day 6. The box plots of Fig. 17 show the increase in dry bias from Day 2 to Day 4. On both these days, the cluster of points around the origin has remained centralized around the origin. In contrast, this cluster of points has shifted into wet bias territory on Day 6. It is possible that this shift has somewhat hidden in Fig. 17 the increase in the dry bias of some stations.

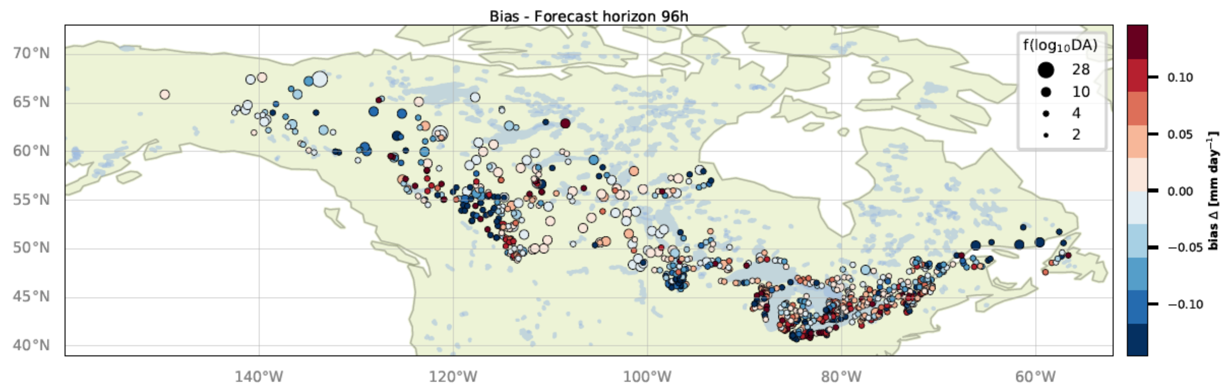

Fig. 19. For Pre-final versus Final for Summer 2019, shown is the spatial distribution of the difference (Pre-final – Final) of the bias in river discharge normalized by drainage area for Day 4 of the forecast. Warm colours indicate smaller biases in Final while cool colours indicate larger biases.

In the spatial distribution of the difference in normalized bias of Pre-final versus Final for Day 4 (see Fig. 19), we see clusters of improvement and degradation of the bias in different regions of the Rocky Mountains. In the Prairies, the difference is neutral or positive. The biases have no clear trends in the Great Lakes region. Most pronounced, however, is the degradation in bias in the northwest (Yukon Territory and northern region of Northwest Territory) and along the north shore of the Gulf of St. Lawrence. Note that Fig. 19, while clearly indicating a degradation in bias in these two regions, does not inform us of whether a dry bias has become drier or whether a wet bias has become wetter in Final compared to Pre-final.

Also important is the fact that the extensive degradation seen in Fig. 16 for bias in Summer for Final versus Pre-final is not as evident in Fig 19 as expected. Figures 17 and 18 indicate that a subset of stations accounts for the degradation of Fig. 16 and that it is not a widespread tendency. It is also possible, as mentioned above, that cancellations between biases of opposite signs lead to near-zero biases. If so, division by numbers near zero could alone account for the seemingly important degradation of Fig. 16.

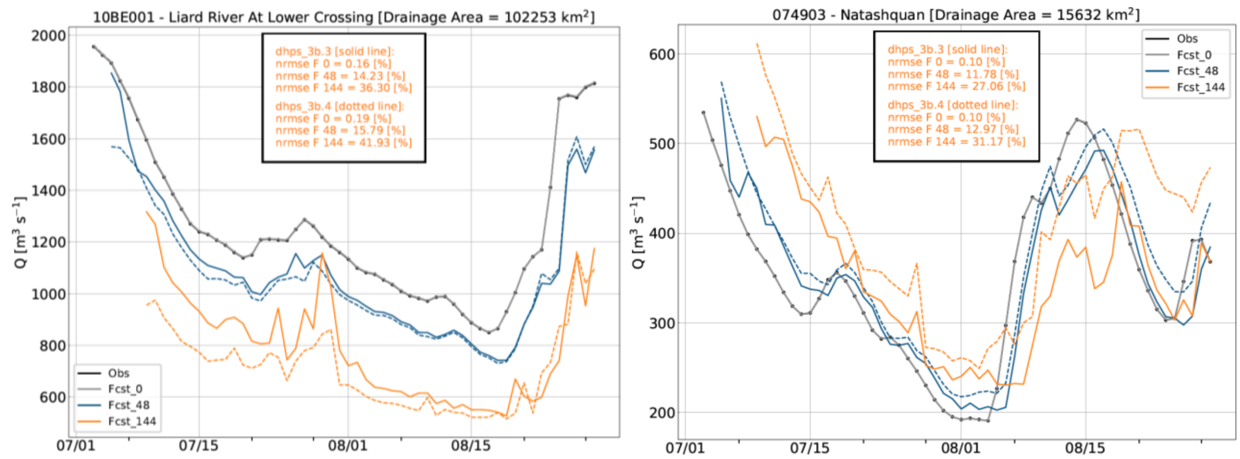

Fig. 20. Presented are hydrographs for Summer 2019 at Liard River at Lower Crossing, BC (10BE001; drainage area of 102,253 km^2; left) and at Natashquan (074903; drainage area of 15632 km^2; right). The observed discharge is in black, the analyses in grey, while Day 2 and Day 4 forecasts are in blue and orange, respectively. Forecasts from Pre-final are in solid lines while those of Final are dashed.

The Liard River starts in Yukon Territory, dips down into British Columbia where is constitutes the northern boundary of the Rocky Mountains, then flows north and east into Northwest Territory where it joins the Mackenzie River. For Liard River at Lower Crossing, the dry bias of Day 2 in Final tends to be slightly greater than in Pre-final (Fig. 20). However, on Day 6, the dry bias in Final is much more pronounced than in Pre-final from the beginning of July until mid-August. This hydrograph suggests that the degradation in bias in the northwest for Day 4 in Final versus Pre-final of Fig. 19 represents a dry bias in Pre-final that is drier in Final. This finding agrees with the scatter plots of Fig. 18. This suggests that the innovations introduced to HRDPS and GDPS for IC-3 have increased the under-generation of precipitation in this northwest region.

The situation at Natashquan, in the centre of the north shore of the Gulf of St. Lawrence is the opposite to that of the Liard River at Lower Crossing. At Natashquan, the overly wet period of Pre-final becomes wetter in Final in July. During the first two weeks of August, when Pre-final is overly dry, the wetter Final agrees more closely with the observations. Finally, in the last half of August, pre-Final matches the observations well while Final is again overly wet. Thus, Natashquan is likely one of the points above the diagonal in the wet zone of Fig. 18's scatter plots.

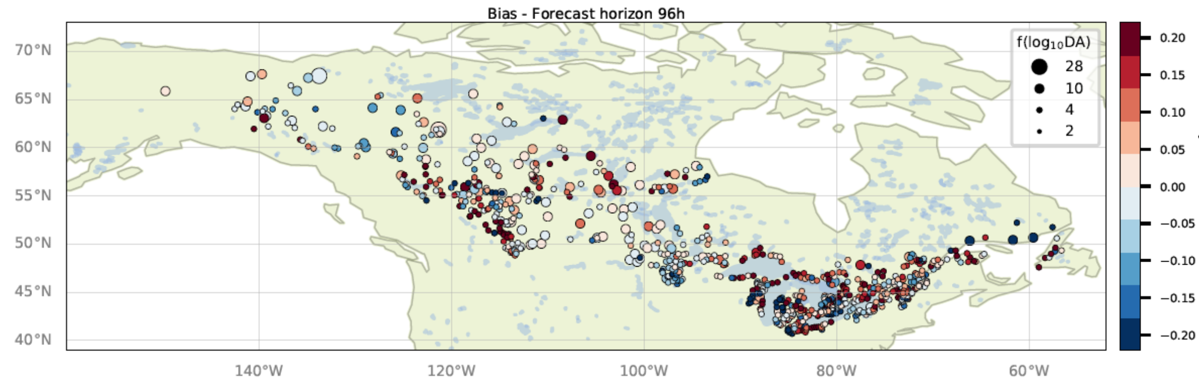

Fig. 21. As per Fig. 19 but for Control vs Final (Control – Final) and with a different scale.

Although it is important to understand the impact on DHPS of the innovations introduced for IC-3 in the piloting atmospheric prediction systems, in the end the comparison of greatest relevance is Final versus Control. The degradation of the bias in the northwest that is clearly visible in Fig. 19 is no longer a clear regional signal in Fig. 21. Thus, the innovations introduced to NSRPS are sufficiently beneficial that, despite the negative impact of the innovations introduced to the piloting atmospheric prediction systems, the biases of Final are comparable to those of Control in this region. Similarly, along the north shore of the Gulf of St. Lawrence, the biases of Final have been degraded at some stations but improved at others with respect to those of Control. Elsewhere, the biases have been improved at many stations in the Rocky Mountains, the Prairies and the Great Lakes region in Final versus Control.

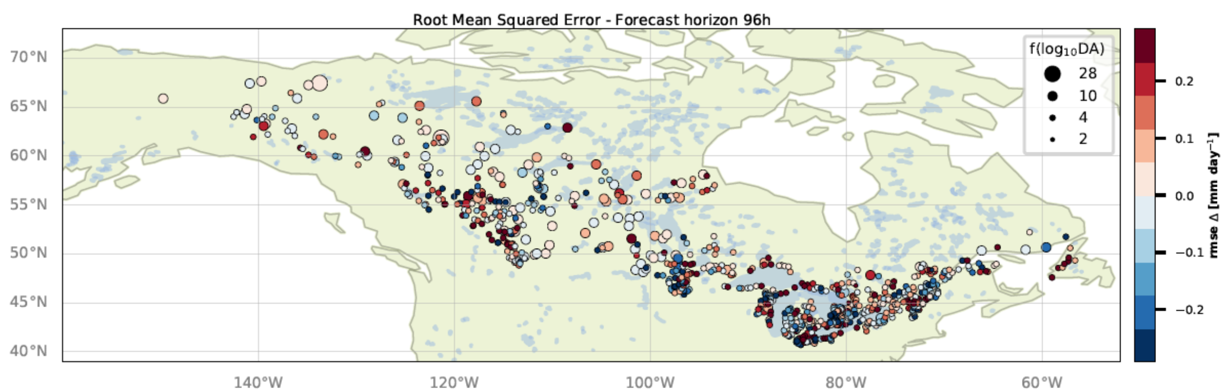

Fig. 22. As per Fig. 21 but for RMSE.

The difference in the RMSE of Final versus Control shows mainly mixed trends within regions. Some pockets in the Rocky Mountains show improvement while others show some degradation. In the Great Lakes region, the agricultural zones south of Lake Erie and in southwestern Ontario show some degradation while other regions have reduced errors. Errors in the Prairies tend to be unchanged or reduced.

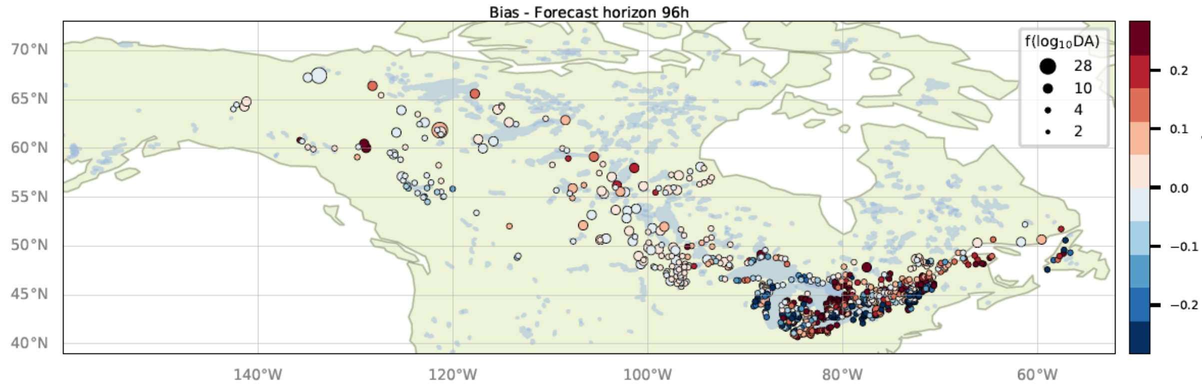

Fig. 23. As per Fig. 21 but for Winter 2020.

Once again, we see in the difference of the biases of Day 4 from winter (Fig. 23) that the biases of DHPS have improved at many stations from Control to Final. This is also generally true for the Great Lakes, St. Lawrence River and Gulf of St. Lawrence regions. However, to the west and north of Lakes Michigan and Huron, degradation of the bias is apparent at many of the stations.

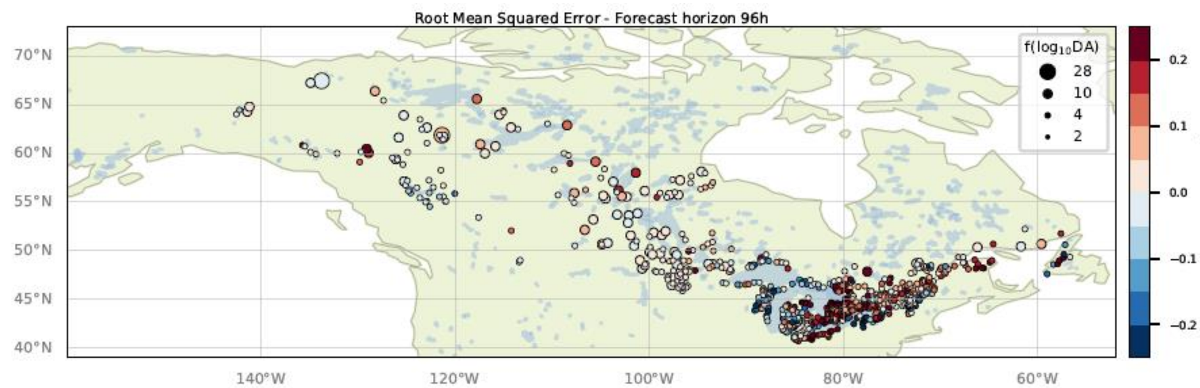

Fig. 24. As per Fig. 23 but for RMSE.

The differences in wintertime RMSE of Final versus Control (Fig. 24) resemble the differences in biases of Fig. 23. Thus, we see a reduction of the RMSE in the Prairies and at many stations in the Great Lakes and Gulf of St. Lawrence regions. Unfortunately, degradation of the RMSE is found to the west and north of Lakes Michigan and Huron.

With the series of hydrographs presented in Figs. 25-30, we investigate how the innovations introduced for IC-3 in both the piloting atmospheric prediction systems and in NSRPS itself impact the performance of DHPS at specific locations of interest. We have chosen a series of locations at key points across Canada; the accuracy of the simulated discharge at these locations was a secondary consideration. The series starts with locations in the northwest in the Yukon River domain and progresses towards the east, ending with the Gulf of St. Lawrence domain.

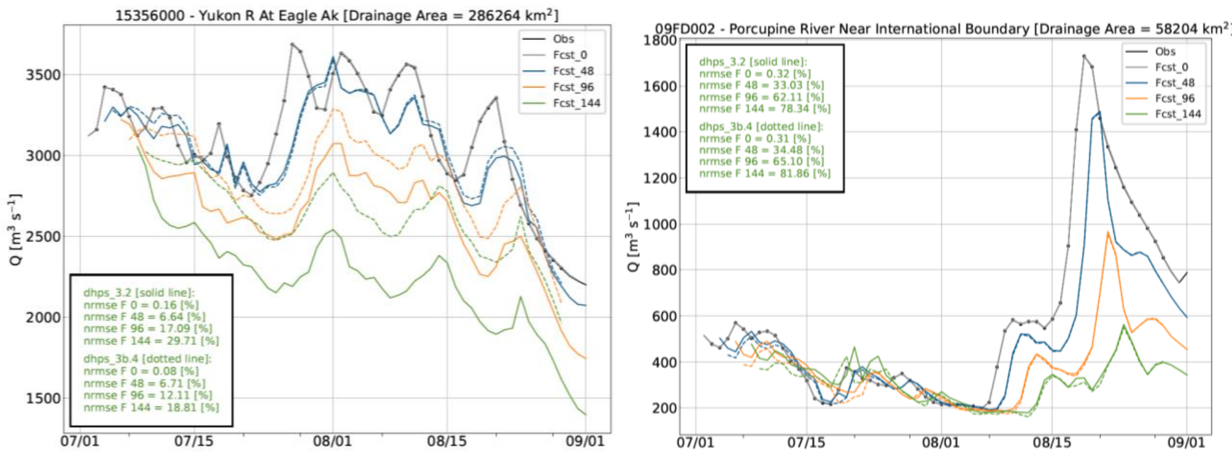

Fig. 25. Shown are hydrographs from Control and Final for Summer 2019 at Yukon River at Eagle, AK (15356000; drainage area of 286,264 km^2; left) and Porcupine River Near International Boundary, YT (09FD002; drainage area of 58,204 km^2; right). The observed discharge is in grey while Day 2, Day 4 and Day 6 forecasts are in blue, orange and green, respectively. Forecasts from Control are in solid lines while those of Final are dashed.

The two locations presented in Fig. 25 are the stations on the two major rivers in Yukon Territory that are closest to the border of Yukon Territory and Alaska. At Eagle, AK on the Yukon River, the analysed discharge of both experiments agrees perfectly with the observed values. This agreement is attributable to the data assimilation system. There is some gain in skill at Day 2 for Final versus Control. However, for both Day 4 and Day 6, DHPS has gained an impressive ~1-2 days in skill. In contrast, there is no gain in skill at Porcupine River near International boundary.

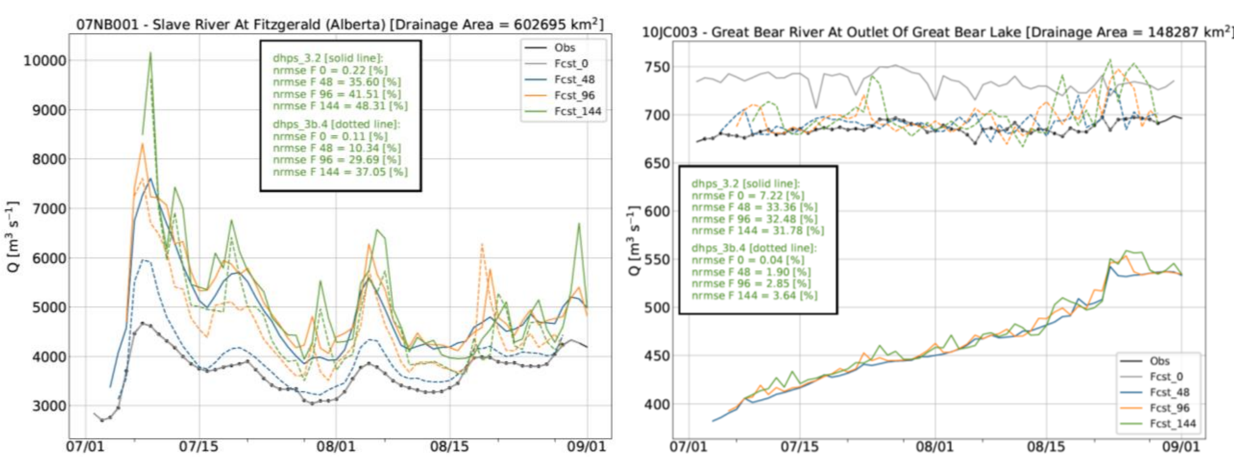

Fig. 26. As per Fig. 25 for Slave River at Fitzgerald, AB (07NB001; drainage area of 602,695 km^2; left) and Great Bear River at Outlet of Great Bear Lake, NT (10JC003; drainage area of 148,287 km^2; right).

In Fig. 26, we present two key locations in Northwest Territory: the station closest to Great Slave Lake on the Slave River, which is the largest river entering the lake, and at the outlet of Great Bear Lake. On the Slave River at Fitzgerald, the analysed and observed discharge agree perfectly for both Control and Final. For Days 2, 4 and 6 we see a gain in skill from Control to Final of ~1-2 days. On the Great Bear River, the analysed and simulated discharge agree perfectly for Final but not for control (solid grey line). The difference in performance reflects the innovation for IC-3 for DHPS where the data assimilation process adjusts the water level of explicitly represented lakes. An additional consequence of this update to the data assimilation system is the impressive gain in skill at Days 2, 4 and 6.

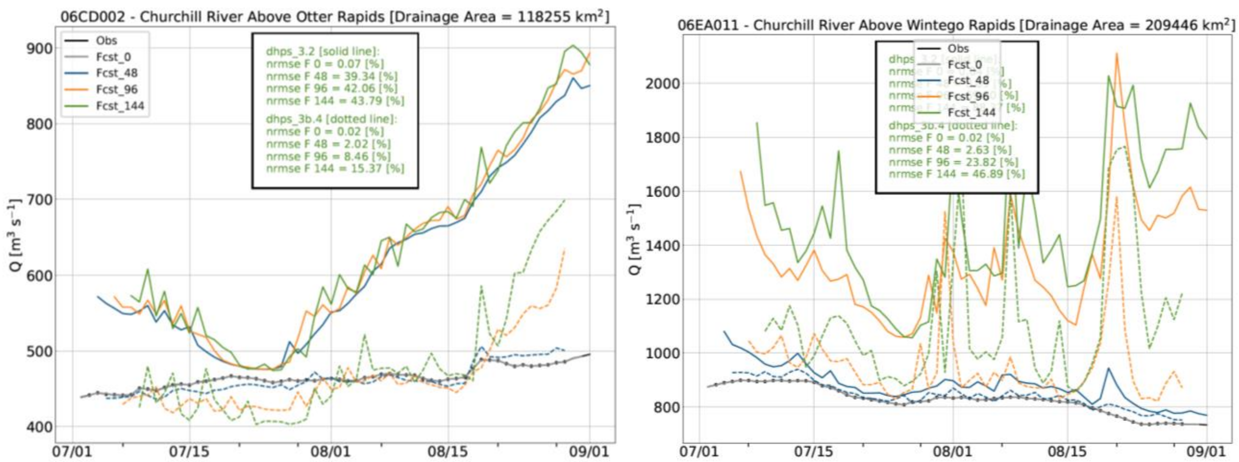

Fig. 27. As per Fig. 25 for Churchill River Above Otter Rapids, SK (06CD002; drainage area of 118,255 km^2; left) and Churchill River Above Wintego Rapids, SK (06EA011; drainage area of 209,446 km^2; right).

At the two locations on the Churchill River that are presented in Fig. 27, we see an impressive gain in skill in Final over Control. This is likely attributable to the adjustment of water levels of lakes by the data assimilation system; there are many lakes that are explicitly represented in the Churchill River domain. However, despite the notable gain in performance, there do remain some issues at both locations, particularly at Churchill River above Wintego Rapids.

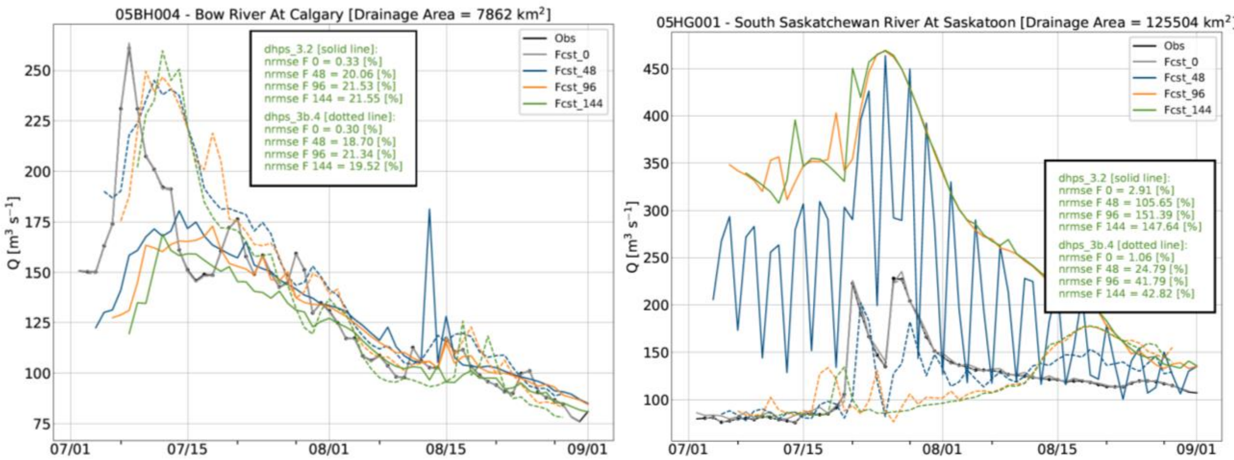

Fig. 28. As per Fig. 25 for Bow River at Calgary, AB (05BH004; drainage area of 7,862 km^2; left) and South Saskatchewan River at Saskatoon, SK (05HG001; drainage area of 125,504 km^2; right).

On the Bow River at Calgary, close to the Rocky Mountains, the skills of Control and Final are similar for most of the summer (Fig. 28). However, even though the timing is late, only Final represents the peak in discharge of early July. Furthermore, Final does not produce a spurious peak in mid-August whereas Control does. In contrast, there has been a significant gain in skill for the South Saskatchewan River at Saskatoon. Not only do the forecasts agree much more closely with the observed discharge in Final but the oscillations visible in Day 2 of the forecast from Control are also considerably quieter in Final.

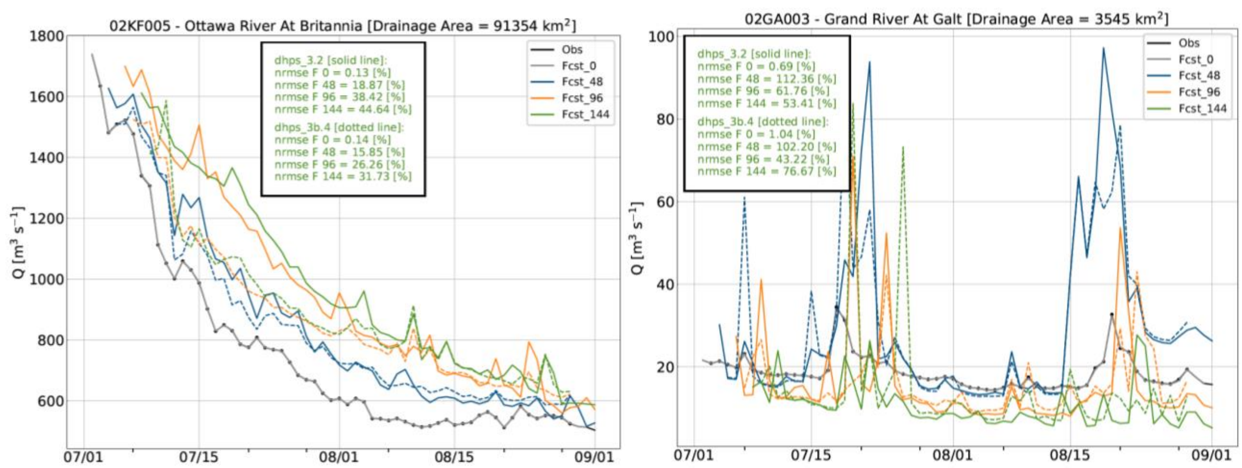

Fig. 29. As per Fig. 25 for Ottawa River at Britannia, ON (02KF005; drainage area of 91,354 km^2; left) and Grand River at Galt, ON (02GA003; drainage area of 3,545 km^2; right).

Near Ottawa on the Ottawa River (Fig. 29), DHPS has gained ~1 day of skill for Day 4 and Day 6. Of particular interest is the fact that Day 2 and Day4 of Final are able to reproduce the sharp decline in discharge over the first two weeks of July. This gain in performance is attributable to the implementation of DZTR on some 14 regulated reservoirs in the Ottawa River basin upstream of Ottawa. In contrast, the forecasts of Control and Final for the Grand

River at Galt show comparable skill between Control and Final. It is probable that the representation in DHPS of drainage tiles in the fields of the agricultural areas of this watershed needs to be improved.

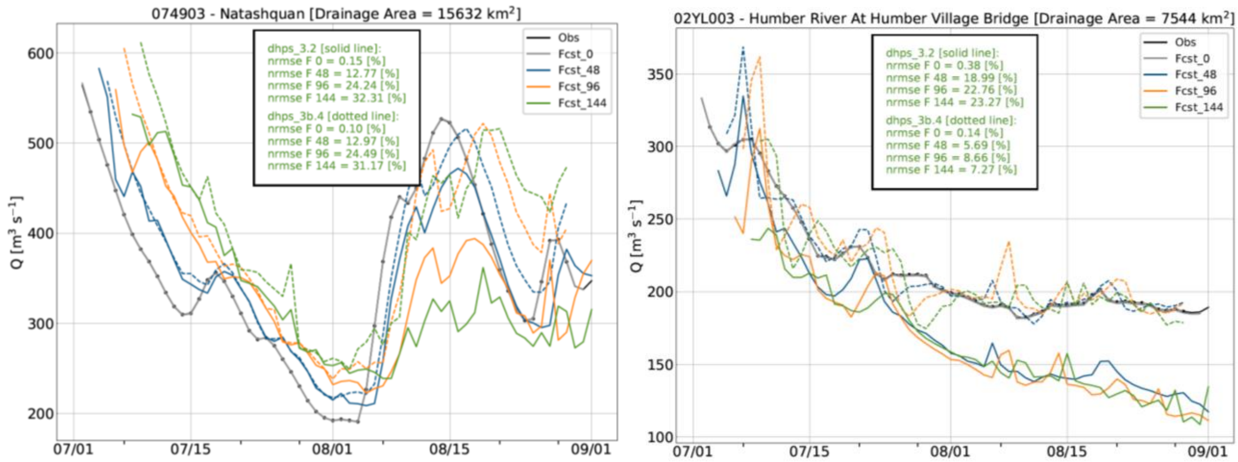

Fig. 30. As per Fig. 25 for Natashquan, QC (074903; drainage area of 15,632 km^2; left) and Humber River at Humber Village Bridge, NL (02YL003; drainage are of 7,544 km2; right).

Figure 30 presents hydrographs at two stations on the Gulf of St. Lawrence. At Natashquan in the centre of the North shore of the Gulf, the skill of Final is comparable to that of Control during July, considerably better than of Control during the second and third weeks of August, and then comparable once again at the end of August. In contrast, the performance of Final is clearly significantly better than that of Control for Humber River at Humber village bridge on the Gulf of St. Lawrence in Newfoundland.

6.5 Conclusions

The evaluation of the Control, Pre-final and Final experiments presented above leads to certain general conclusions. For the analyses produced by the data assimilation cycle, errors in discharge on gauged rivers are so small that changes in performance between experiments can be considered neutral.

For the forecasts, the innovations introduced for NSRPS (including DHPS) in the context of Innovation Cycle 3 generally reduce the cumulative errors, such as RMSE, found in Control. In contrast, biases seem frequently to have been degraded by the innovations. However, there is little consistency in the change in bias between seasons, domains, or size of drainage area. Interestingly, the spatial distributions of the computed biases for Day 4 highlight the existence of some stations where the forecast has been noticeably degraded but overall suggest a balance between stations with improved and degraded biases. Thus, it is possible that the appearance of a degradation in bias in the scorecards for Control versus either Pre-final (Fig. 15) or Final (Fig. 14) is an artifact produced by dividing by numbers close to zero when calculating the scorecard's differences. Since positive and negative biases cancel each other out in the calculations underlying the scorecards, division by a near-zero number is a realistic possibility.

Considering the effect on the performance of DHPS by the innovations introduced for IC-3 in the piloting atmospheric prediction systems, we find that the impact is generally neutral in Winter. There is some improvement in bias in the Great Lakes St. Lawrence River and the Gulf of St. Lawrence domains and some degradation in the Nelson River domain. However, in Summer, these innovations lead to some degradation as seen in the comparison of Final versus Pre-final. A jump in the degradation is visible in bias from Day 2 to Day 4. In the northwest region, the degradation is caused by increasing an existing dry bias. In contrast, along the north shore of the Gulf of St. Lawrence, we see an increase in the existing wet bias.

References

Alavi, N., Bélair, S., Fortin, V., Zhang, S., Husain, S. Z., Carrera, M. L., and Abrahamowicz, M.: Warm Season Evaluation of Soil Moisture Prediction in the Soil, Vegetation and Snow (SVS) Scheme, **J. Hydrometeorol.**, *17*, 2315–2332, https://doi.org/10.1175/JHM-D-15-0189.1, 2016.

Bernier, N. B., Bélair, S., Bilodeau, B., and Tong, L.: Near-surface and land surface forecast system of the Vancouver 2010 Winter Olympic and Paralympic Games, **J. Hydrometeorol.**, *12*, 508–530, https://doi.org/10.1175/2011JHM1250.1, 2011.

Bogacki, P., L. F. Shampine, 1989: A 3(2) pair of Runge–Kutta formulas. **Appl. Math. Lett.**, *2 (4)*, 321–325, doi:10.1016/0893-9659(89)90079-7, ISSN 0893-9659.

Carrera, M., S. Bélair, B. Bilodeau, 2015: The Canadian Land Data Assimilation System (CaLDAS): Description and Synthetic Evaluation Study. **J. Hydrometeor.**, *16*, 1293-1314, DOI:10.1175/JHM-D-14-0089.1.

Chow, V. T., 1959: Open-channel hydraulics: New York, McGraw-Hill Book Co., 680 pp. The table of roughness values can be accessed at: Modeling River Ice and River Ice Jams with HEC-RAS - ppt video online download (slideplayer.com) http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm.

Daly, S. F., 2007: Modeling River Ice and River Ice Jams with HEC-RAS. Available at Modeling River Ice and River Ice Jams with HEC-RAS - ppt video online download (slideplayer.com).

Deacu, D, and S. Bélair, 2019: The High Resolution Deterministic Land Surface Prediction System (HRDLPS) version 1.2.0 of the Meteorological Service of Canada (MSC). Tech. note Available at https://wiki.cmc.ec.gc.ca/images/e/e7/Tech_specificatio ns_HRDLPS_1.2.0_e_v1.0.pdf.

Fortin, M. Abrahamowicz, and N. Gauthier, 2016: The Multibudget Soil, Vegetation, and Snow (SVS) Scheme for Land Surface Parameterization: Offline Warm Season. **J. Hydrometeor.**, *17*, 2293-2313, DOI: 10.1175/JHM-D-15-0228.1.

Fortin, V., and Coauthors, 2017: An atmospheric, hydrological and hydrodynamic prediction system for the watershed of the Great Lakes and the Saint Lawrence. Canadian Centre for Meteorological and Environmental Prediction Extended Abstract, 33 pp., http://collaboration.cmc.ec.gc.ca/science/rpn/publications/pdf/20160212-CPOP-Seminaire-Vendredi-WaterCyclePredictionSystem_ExtendedAbstract.pdf.

Gaborit, É., V. Fortin, and D. Durnford, 2021: On the implementation of the Dynamically Zoned Target Release Reservoir Model in the GEM-Hydro streamflow forecasting system. Submitted to the Journal of Water Resources Planning and Management.

Gaborit, É., and D. Durnford, 2021: Deterministic Hydrological Prediction System (DHPS) version 1.0.0 of the Meteorological Service of Canada (MSC). Tech. note Available at Hydrology/DHPS project - Wiki.

Gaborit, É., Fortin, V., Xu, X. Y., Seglenieks, F., Tolson, B., Fry, L. M., ... & Gronewold, A. D. (2017). A hydrological prediction system based on the SVS land-surface scheme: efficient calibration of GEM-Hydro for streamflow simulation over the Lake Ontario basin. **Hydrol. Earth Syst. Sci.**, *21*, 4825–4839.

Husain, S.Z., N. Alavi, S. Bélair, M. Carrera, S. Zhang, V. Fortin, M. Abrahamowicz, and N. Gauthier, 2016: The Multibudget Soil, Vegetation, and Snow (SVS) Scheme for Land Surface Parameterization: Offline Warm Season. **J. Hydrometeor.**, *17*, 2293-2313, DOI: 10.1175/JHM-D-15-0228.1.

Khedhaouiria, D., S. Bélair, V. Fortin, G. Roy, and F. Lespinas, 2020: High-Resolution (2.5 km) Ensemble Precipitation Analysis across Canada. **J. Hydrometeor.**, *21*, 2023–2039, DOI:/10.1175/JHM-D-19-0282.1., DOI:10.1175/JHM-D-19-0282.1.

Kouwen, N., 2018: WATFLOOD® / CHARM® Canadian Hydrological And Routing Model. Department of Civil Engineering, University of Waterloo, Waterloo, ON. Available at Microsoft Word - manual_v16-04.docx (uwaterloo.ca).

Manning, R., « On the flow of water in open channels and pipes », Transactions of the Institution of Civil Engineers of Ireland, vol. 20, 1891, p. 161-207.Matte, P., Y. Secretan, and J. Morin, 2017a: Hydrodynamic Modeling of the St. Lawrence Fluvial Estuary. I: Model Setup, Calibration, and Validation. **J. Waterway, Port, Coastal, Ocean Eng.**, *143*, 4017010, DOI:10.1061/(ASCE)WW.1943-5460.0000397.

Matte, P., Y. Secretan, and J. Morin, 2017b: Hydrodynamic Modeling of the St. Lawrence Fluvial Estuary. II: Reproduction of Spatial and Temporal Patterns. **J. Waterway, Port, Coastal, Ocean Eng.**, *143*, 4017011, DOI:10.1061/(ASCE)WW.1943- 5460.0000394.

Morin, J., and O. Champoux, 2006: Integrated modelling of the physical processes and habitats of the St. Lawrence River, Water Availability Issues for the St. Lawrence River: An Environmental Synthesis, A. Talbot, Ed., Environment Canada, 24–39.

Yassin, F., Razavi, S., Elshamy, M., Davison, B., Sapriza-Azuri, G., and Wheater, H., 2019: Representation and improved parameterization of reservoir operation in hydrological and land-surface models, **Hydrol. Earth Syst. Sci.**, *23*, 3735–3764, DOI: 10.5194/hess-23-3735-2019.

Appendices

Appendix A: Template files for streamflow gauges

Provided below are the streamflow template files for the domains of the Yukon, Mackenzie, Churchill and Nelson rivers, the Great Lakes St. Lawrence River, and the terrain draining to the Gulf of St. Lawrence. The files provide the gauge ID, the latitude and longitude of the gauge in the model world, and the value of coefficients used by WATROUTE. For the gauge's location in the model, the gauge is placed on the appropriate river of the shed file and either below or above the entry of a tributary or other geographical feature as appropriate. Consequently, the model's location may not be identical to the data provider's location.

Note that the ten gauge IDs in the Great Lakes St. Lawrence domain that start with "02OT" were created at CMC to store historic observations that are not disseminated by Water Survey of Canada. No data from these gauges are assimilated in real-time. These gauges are included in the streamflow template file to facilitate the use of DHPS for both real-time simulations and for hindcasts.

Table A1: Gauges assimilated by the Yukon River (yuk) domain

:ColumnName	09AA012	09AA013	09AC001	09AC007	09AE003	09AE006	09AH003	09AH004	09BA001	09BC001	09BC004	09CA006	09CB001	09DB001	09DD003	09EA003	09EB003	09EB004
:ColumnLocationX	-134.8854	-134.3353	-135.7189	-135.4775	-131.7781	-132.1439	-137.0111	-136.2858	-132.3859	-136.5778	-133.3695	-139.0444	-140.5272	-134.1355	-139.2528	-139.4015	-139.6276	-140.1605
:ColumnLocationY	60.1354	59.9267	60.8522	60.7355	59.9272	60.0189	62.5691	62.0689	62.0021	62.8191	62.2277	62.2106	61.9609	64.0192	63.2944	64.0521	63.7773	63.6861
:Coeff1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Value1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

09FB002	09FC001	09FD002	09AA006	09AB001	09AD002	09AG001	09AH001	09AH005	09BB001	09BC002	09CA004	09CD001	09DA001	09DD004	09EA004	09EA005	15310002	15330000	15331000
-136.6938	-139.694	-140.8853	-133.8101	-135.0434	-133.0683	-134.8354	-136.2765	-134.4017	-130.5435	-132.4434	-139.1432	-139.4684	-131.4856	-137.2684	-138.5933	-137.5767	-142.5255	-142.2023	-142.2188
66.4601	67.6433	67.4267	59.5931	60.7442	60.7855	61.8859	62.1358	62.2109	62.9189	61.9943	61.3437	63.0859	63.3439	63.6022	64.0106	64.0106	64.035	64.4684	64.4684
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

15348000	15356000	15453500
-141.4006	-141.1839	-149.7188
64.3015	64.8015	65.8849
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

Table A2: Gauges assimilated by the Mackenzie River (mck) domain

:ColumnName	07AA001	07AA002	07AC001	07AC007	07AD002	07AF002	07AF013	07AG003	07AG004	07AG007	07AG008	07AH001	07AH002	07AH003	07BA001	07BB002	07BB004	07BB005
:ColumnLocationX	-118.1054	-118.055	-117.9464	-116.9624	-117.5877	-116.6297	-117.1959	-116.2713	-115.8378	-116.1626	-115.8376	-114.9042	-115.3376	-115.7799	-115.3214	-115.0045	-115.0541	-115.0211
:ColumnLocationY	52.8648	52.9151	53.5321	54.0142	53.4143	53.473	53.0809	53.6064	54.0151	53.6898	54.0314	54.3652	54.2314	54.2072	53.1314	53.6062	53.8985	53.9567
:Coeff1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Value1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07BB006	07BB011	07BC002	07BC007	07BE001	07BF001	07BF002	07BF010	07BF905	07BH003	07BJ001	07BJ003	07BK001	07BK009	07CA006	07CA012	07CA013	07CB002	07CD001	07CD004
-114.3959	-115.3642	-113.996	-113.9121	-113.2877	-116.3376	-116.4963	-116.3869	-116.2958	-115.7889	-115.4046	-115.4712	-114.7546	-114.7742	-112.4626	-111.7209	-111.8545	-112.1458	-111.2543	-111.3547
54.1149	53.8571	54.4479	54.215	54.7229	55.4222	55.4478	55.8151	55.5812	55.3481	55.3226	54.8063	55.3065	55.2727	55.1982	55.1732	55.0147	55.6483	56.6902	56.7064
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07CD005	07CE002	07CE003	07DA001	07DA006	07DA008	07DA018	07DB001	07DC001	07DD001	07DD002	07FA004	07FA005	07FB001	07FB008	07FC001	07FD001	07FD002	07FD003	07FD006
-110.929	-110.8633	-110.9138	-111.4041	-111.4123	-111.5624	-111.5709	-111.6962	-111.1963	-111.3885	-111.2459	-120.8139	-122.3545	-121.2125	-121.3624	-120.697	-120.5624	-120.6714	-118.605	-118.7048
56.6649	55.8393	55.8735	56.789	57.0068	57.1989	56.9402	57.2146	57.6484	58.1981	58.3634	56.1983	56.4623	55.7231	56.0988	56.2812	55.9643	56.1398	55.9223	55.6477
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07FD009	07FD010	07FD011	07GA001	07GA002	07GB001	07GB003	07GD001	07GD004	07GE001	07GE003	07GF001	07GF008	07GG001	07GG002	07GH002	07GJ001	07HA001	07HA003	07HA005
-119.6879	-120.0709	-118.2631	-119.1625	-118.8134	-118.9709	-118.5542	-119.4469	-119.704	-118.8047	-118.913	-118.1883	-117.7125	-117.2042	-117.1625	-117.1545	-117.622	-117.3046	-117.1299	-117.6726
56.3145	56.1151	56.3397	53.9484	53.9307	54.5227	54.4149	55.1897	55.0817	55.0734	55.3815	55.1395	54.4315	54.7566	54.7316	55.4565	55.7148	56.2398	56.057	56.5226
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07HC001	07HF001	07HF002	07JC001	07JC003	07JD002	07JD003	07JD004	07JF003	07JF005	07KC001	07KE001	07NB001	07OA001	07OB003	07OB004	07OC001	07EA004	07EA005	07EA007
-117.6212	-116.0308	-117.6294	-115.0965	-115.0706	-115.3873	-115.7462	-116.2538	-116.2708	-117.4793	-112.4383	-113.0628	-111.5958	-118.4799	-117.6295	-117.1968	-118.3293	-125.1134	-125.2464	-124.9124
56.9232	58.39	57.7481	57.0737	57.0813	57.8818	58.1899	58.1485	58.4732	57.9483	59.1233	58.3227	59.8648	58.5899	59.1483	59.5815	58.5982	56.7318	57.1301	57.1898
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07EB002	07EC002	07EC003	07EC004	07ED003	07EE007	07EE009	07EE010	07EF004	07FA003	07FA006	07FB002	07FB003	07FB006	07FB009	07FC003	07FD007	07LB002	07LE002	07MA003
-123.9377	-124.5706	-124.6464	-124.7963	-123.629	-122.9129	-122.6117	-123.0378	-122.6543	-122.2466	-121.6211	-121.2046	-121.6207	-121.0125	-120.9372	-121.2207	-120.0295	-104.6133	-105.5375	-109.8044
56.4801	55.9233	56.2476	56.1309	55.4314	55.0808	54.5307	54.9972	55.9479	56.5142	56.2564	55.556	55.5405	55.0649	55.0895	56.6816	55.8649	58.3896	59.1565	58.3229
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07MB001	07OB001	07OB008	07QC005	07QC006	07QC007	07QC008	07QD007	07RD001	07SA002	07SA004	07SA008	07SB002	07SB003	07SB010	07SB013	07SC001	07SC002	07SC004	07SC005
-108.1707	-115.8464	-116.9292	-108.7709	-108.3128	-110.6627	-108.8709	-111.5138	-108.4622	-115.4289	-115.0128	-114.9873	-114.2124	-114.2457	-113.5217	-114.4054	-113.154	-110.4788	-109.2211	-110.1626
58.9724	60.7395	60.0068	60.0059	59.7985	60.4145	59.6399	60.4645	62.8982	63.9816	64.3896	64.2316	62.557	62.6734	62.4897	62.5152	62.0552	63.0481	62.8729	62.9482
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

07TA001	07UC001	10AA001	10AA004	10AA005	10AB001	10AC005	10BD001	10BE001	10BE004	10BE007	10BE009	10BE013	10CA001	10CB001	10CD001	10CD003	10CD004	10CD005	10DA001
-116.9708	-117.4046	-128.9041	-129.5544	-129.7041	-129.1125	-129.8211	-124.8965	-126.0957	-125.3791	-125.9382	-126.2289	-126.4623	-121.4629	-122.6877	-122.6542	-123.3213	-122.7208	-122.7123	-122.9541
63.1068	60.9482	60.0568	60.2061	60.157	60.4733	59.1153	60.1224	59.4068	58.8568	59.34	59.4569	59.5484	58.2802	57.2398	58.7893	58.8987	58.0318	58.1073	59.9899
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

10EA003	10EB001	10ED001	10ED002	10ED003	10ED007	10ED009	10FA002	10FB001	10FB005	10FB006	10GA001	10GB006	10GC001	10GC003	10HA004	10HB005	10HC008	10JA002	10JB001
-125.4046	-125.805	-123.4628	-121.2129	-122.088	-122.8963	-121.4465	-119.8371	-117.5461	-121.238	-120.7874	-123.4372	-122.897	-121.3544	-121.6048	-128.1964	-125.2955	-123.6127	-117.754	-121.7454
61.523	61.6312	60.239	61.7399	61.3313	61.0647	61.4232	61.148	61.2732	61.4482	61.8231	62.4817	62.6568	61.8734	61.898	64.1399	63.9146	63.4983	65.5982	64.5729
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

10JC003	10JD002	10KA001	10KA007	10KA008	10KB001	10KC001	10LA002	10LB004	10LC003	10LC007	10LC014	10LD004	10MA001	10MA002	10MA003	10MC002	10MC022
-123.5535	-124.5794	-126.8458	-126.8793	-127.3713	-127.6795	-128.5542	-133.0877	-128.8039	-133.854	-133.4792	-133.7542	-128.255	-136.0373	-138.271	-138.2624	-134.8875	-134.6541
65.1398	65.7311	65.2815	65.3317	65.4479	65.2979	65.2317	66.7897	66.5152	67.7645	68.0902	67.4649	66.407	65.8983	65.381	64.8988	67.2566	67.6398
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A3: Gauges assimilated by the Churchill River (chu) domain

:ColumnName	06AA002	06AB001	06AB002	06AD006	06AF001	06AG002	06BA002	06BB003	06BB005	06BD001	06CB002	06CD002	06DA002	06DA004	06DA005	06DC001	06DD002	06DD003	06EA002	06EA006	06EA011	06FA001	06FB001	06FB002	06FC001	06FD001	06FD002
:ColumnLocationX	-112.0099	-111.1852	-110.9941	-110.2113	-109.8361	-107.7439	-109.3967	-107.719	-108.0186	-106.5609	-104.5023	-104.7358	-101.394	-104.1859	-104.9856	-103.7035	-103.1593	-103.3288	-102.3277	-100.4592	-102.8279	-97.5939	-96.8273	-95.6629	-95.7451	-94.6191	-94.2437
:ColumnLocationY	54.4735	54.4714	54.7151	54.3568	54.5652	54.9306	55.7144	55.9234	55.3989	56.2487	55.3571	55.6475	58.0071	57.5814	57.4819	57.0904	56.199	56.0069	55.5316	56.1475	55.5816	57.3059	57.2402	57.6571	56.9483	58.1232	57.974
:Coeff1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Value1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A4: Gauges assimilated by the Nelson River (nel) domain

:ColumnName	05AA008	05AA022	05AA024	05AA035	05AB021	05AC003	05AD003	05AD005	05AD007	05AD010	05AD028	05AD041	05AE002	05AE006	05AG006	05AJ001	05BA002	05BB001
:ColumnLocationX	-114.4084	-114.1499	-113.825	-114.0831	-113.7086	-113.1169	-113.8343	-113.692	-112.8669	-113.7922	-113.4834	-113.4832	-113.2926	-112.8418	-111.7917	-110.6749	-116.1751	-115.5666
:ColumnLocationY	49.6046	49.4877	49.5543	49.7295	50.021	50.1377	49.1127	49.104	49.7126	49.2957	49.4294	49.3541	49.2041	49.5712	49.9204	50.0461	51.4294	51.171
:Coeff1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Value1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

05BC001	05BG006	05BG010	05BH004	05BH015	05BJ001	05BJ004	05BJ010	05BL004	05BL012	05BL014	05BL022	05BL024	05BN012	05CA009	05CB001	05CB004	05CB007	05CC001	05CC002
-115.542	-114.8422	-114.9255	-114.05	-114.5675	-114.0837	-114.5753	-114.1666	-113.8748	-113.9751	-114.2418	-114.592	-113.8166	-111.5921	-115.017	-114.1418	-114.4754	-114.2089	-113.7919	-113.8083
51.1543	51.287	51.27	51.0542	51.1283	51.0128	50.9458	50.9958	50.5956	50.7212	50.6876	50.2793	50.7874	50.046	51.6459	52.0291	52.0876	52.0541	52.3542	52.2794
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

05CC007	05CE001	05CK004	05DA009	05DB002	05DB006	05DC001	05DC006	05DD009	05DF001	05EA005	05EF001	05FA001	05FA011	05FE004	05GG001	05HD036	05HD039	05HG001	05JE006
-114.3423	-112.7084	-110.2999	-116.4672	-114.9253	-114.8586	-114.9336	-115.4169	-115.5169	-113.4835	-113.7587	-109.617	-113.5836	-112.9588	-110.0172	-105.7667	-108.4759	-107.6589	-106.6423	-105.4004
52.3208	51.4714	50.9127	52.0039	52.2789	52.2541	52.3793	52.371	52.8204	53.5373	53.6622	53.5292	52.6621	52.9536	52.8536	53.2039	49.8454	50.496	52.1374	50.3955
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

05JF001	05JF005	05JK007	05JM001	05KD003	05KE010	05KH007	05KJ001	05LC001	05LH005	05LJ025	05LL002	05LL014	05LM001	05LM006	05MD004	05MD005	05MF001	05MH001	05MH005	05MJ001
-104.8668	-104.9004	-104.2835	-101.5588	-103.3004	-104.6177	-102.1003	-101.2085	-102.1918	-99.5421	-99.9671	-98.5839	-99.2086	-98.7088	-98.317	-101.9172	-101.3177	-99.9092	-99.9591	-98.8844	-97.4009
50.6538	50.6373	50.7868	50.4954	53.7042	53.8625	53.6202	53.8369	52.8623	51.8537	51.4539	50.1288	49.9041	51.5875	51.995	51.5624	50.9622	50.3624	49.8621	49.6955	49.8705
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

05NA003	05NB001	05NB021	05NB036	05ND010	05NG001	05NG024	05OB007	05OB016	05OB021	05OC001	05OC012	05OG001	05PA006	05PB014	05PB018	05PG001	05PH003	05QA004	05QC001	05QD006
-103.3506	-103.0089	-102.8421	-103.084	-102.1756	-99.6753	-101.4005	-98.2755	-98.6006	-98.4503	-97.2175	-97.1759	-97.4255	-92.167	-92.7173	-91.5841	-95.509	-95.9507	-91.5418	-93.4837	-93.4012
49.0039	49.1037	49.0373	49.1536	49.5288	49.5954	49.8454	49.0285	49.0206	48.9957	49.0039	49.5619	49.6791	48.3792	48.8453	48.7539	50.0371	49.9371	50.1701	50.8789	49.9624
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

05QE008	05QE009	05QE012	05RA001	05RB003	05RC001	05TD001	05TE002	05TF002	05TG001	05TG002	05TG003	05TG006	05UF004	05UG001	05UH001	05UH002	5017500	5020500	5030500	5046000	5046475
-93.2592	-94.4671	-93.9755	-96.2832	-96.6086	-93.5175	-97.0005	-99.2176	-98.8839	-97.8923	-98.1925	-97.3594	-98.4839	-94.692	-94.2172	-93.6337	-93.4511	-113.4175	-113.3004	-96.0173	-96.1839	-96.584
50.5125	50.3542	50.6873	51.1038	51.7037	51.8122	55.7373	55.4957	55.929	55.7455	55.4871	55.9957	55.9122	56.3369	56.512	56.6788	57.0203	48.8376	49.0123	46.371	46.2125	46.2704
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5050000	5051300	5051500	5051522	5051600	5052000	5052500	5053000	5054000	5054500	5055300	5055400	5056000	5057000	5057200	5058000	5058500	5058700	5059000	5059500	5059700	5059715
-96.5673	-96.576	-96.5924	-96.7925	-97.5093	-97.0095	-96.7256	-96.7842	-96.7759	-99.9423	-99.4174	-99.2757	-98.7173	-98.0259	-98.1259	-98.0842	-98.0087	-97.6845	-97.001	-96.9093	-97.5758	-97.4679
45.8623	46.154	46.2709	46.6625	46.0206	46.1707	46.3124	46.4706	46.8625	47.7041	47.904	47.8209	47.8042	47.4289	47.2291	47.0289	46.9208	46.4457	46.629	46.8873	46.6208	46.6872
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5060000	5060100	5060500	5061000	5061500	5062000	5062500	5063398	5064000	5064500	5065500	5066500	5067500	5069000	5070000	5074500	5075000	5076000	5078000	5078230	5078500	5079000
-97.1012	-97.051	-97.2096	-96.3258	-96.626	-96.6592	-96.2508	-96.3838	-96.7927	-96.8422	-97.4507	-97.0594	-96.7677	-96.8088	-96.9343	-95.276	-95.8089	-96.1675	-96.0423	-95.8591	-96.259	-96.6092
46.8624	46.9038	47.0122	46.8456	46.7795	46.9625	47.2708	47.1125	47.2706	47.354	47.5456	47.4123	47.4125	47.6125	47.7622	47.9623	48.0459	48.1873	47.9209	47.8457	47.8791	47.7706
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5080000	5082500	5082625	5084000	5085000	5085450	5087500	5090000	5092000	5094000	5099400	5099600	5100000	5101000	5104500	5106000	5107500	5112000	5113600	5114000	5116000
-96.8093	-97.0257	-97.509	-97.7256	-97.3672	-96.7174	-96.8175	-97.409	-97.1423	-96.6591	-98.0009	-97.9088	-97.5506	-97.7425	-95.7343	-95.6592	-95.9175	-96.4596	-103.0756	-101.9589	-101.5009
47.8036	47.929	47.9374	48.1959	48.2874	48.2124	48.3375	48.4291	48.5709	48.7373	48.8623	48.9127	48.9875	48.7791	48.7954	48.9959	48.9124	48.9791	48.9794	48.9954	48.379
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5116500	5120000	5120500	5122000	5123400	5123510	5124000	5124480	5125000	5126210	5127500	5129115	5129290	5129515	5131500	5132000	5133500	5134200
-101.5674	-100.7343	-100.5432	-100.4424	-100.443	-100.8601	-100.9595	-91.5346	-91.6926	-91.8009	-91.6511	-92.5675	-93.0263	-93.4424	-93.5427	-93.8096	-93.909	-94.5595
48.371	48.1622	48.1372	48.5042	48.5869	48.5868	48.9955	47.9204	47.8373	47.8457	48.079	48.2624	48.4706	48.5953	48.3955	48.196	48.6374	48.5377
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A5: Gauges assimilated by the Great Lakes St. Lawrence River (gls) domain

:ColumnName	02AB006	02AB008	02AB014	02AB017	02AB021	02AB023	02AC001	02AC002	02AD010	02AD012	02AE001	02BA003	02BA006	02BB003	02BB004	02BC006	02BC008	02BF001	02BF002	02BF014
:ColumnLocationX	-89.5929	-89.3017	-89.1683	-89.8019	-89.2356	-89.4102	-88.5351	-88.3683	-87.9601	-88.3524	-87.6852	-86.6027	-86.8606	-86.2941	-85.9016	-85.7189	-85.8929	-84.5103	-83.9686	-84.2767
:ColumnLocationY	48.532	48.3901	48.5238	48.2899	48.5646	48.3237	48.8233	48.9071	49.5981	49.1237	48.9318	48.8483	48.8154	48.7734	48.7066	48.1654	48.5899	47.0068	46.8568	46.7237
:Coeff1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Value1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02CA002	02CA007	02CB003	02CC005	02CC010	02CD001	02CD006	02CE002	02CF007	02CF008	02CF010	02CF011	02CF012	02CF014	02DB005	02DC004	02DC012	02DC013	02DD010	02DD012	02DD015	02DD024
-84.2769	-83.7104	-83.4106	-83.2769	-82.9609	-82.5104	-82.5941	-82.0601	-81.1941	-81.0192	-81.3771	-80.9937	-81.0935	-80.9524	-80.8354	-80.2518	-80.4604	-79.6527	-80.5684	-80.1186	-79.6019	-79.3019
46.5653	46.5316	46.9736	46.3981	46.5814	46.2151	46.5151	46.2154	46.5899	46.6146	46.5986	46.6899	46.4319	46.8154	46.3486	46.6399	46.9731	46.4317	46.0238	46.4151	45.9485	46.1735
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02DD026	02EA005	02EA010	02EA011	02EA018	02EB004	02EB008	02EB011	02EB012	02EB013	02EB014	02EC002	02EC008	02EC009	02EC011	02EC018	02EC019	02ED003	02ED007	02ED013	02ED014	02ED015
-80.2014	-79.3769	-79.3104	-80.4771	-79.2772	-79.2685	-79.1102	-79.7845	-79.768	-79.1521	-78.9854	-79.2768	-79.3354	-79.4775	-79.0601	-79.1853	-79.0354	-79.8187	-79.6351	-79.9021	-79.9525	-80.0691
46.0737	45.6735	45.7066	45.7739	45.5569	45.2073	45.1486	45.0652	45.0235	45.3984	45.3151	44.7152	44.2568	44.0899	44.3904	44.2651	44.9982	44.2493	44.6988	44.6484	44.1984	44.3067
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02ED024	02ED026	02ED027	02ED029	02ED032	02ED101	02ED102	02FA001	02FA004	02FB007	02FB009	02FB010	02FB012	02FB013	02FC001	02FC002	02FC011	02FC012	02FC015	02FC016	02FC020	02FC021
-79.5691	-79.9684	-79.9604	-79.7768	-79.7856	-79.8849	-79.8938	-81.2435	-81.1685	-80.9269	-80.4606	-80.6436	-80.4773	-80.5353	-81.3266	-81.1101	-81.0106	-80.9769	-81.2599	-80.7769	-81.2766	-80.9185
44.7651	44.0234	44.4819	44.1319	44.4648	44.1066	44.1568	44.6736	44.5319	44.5154	44.5151	44.5655	44.4649	44.3405	44.4569	44.1238	44.1073	44.0909	44.2737	44.1901	44.0069	44.1651
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02FD001	02FD003	02FE002	02FE005	02FE007	02FE008	02FE009	02FE010	02FE011	02FE013	02FE015	02FE016	02FF002	02FF007	02FF008	02FF009	02FF013	02GA003	02GA005	02GA006	02GA010	02GA014
-81.7097	-81.6178	-81.3101	-81.2513	-81.2434	-81.3017	-81.5353	-81.0687	-80.8854	-81.1184	-81.6188	-81.3933	-81.6512	-81.5769	-81.6271	-81.5016	-81.4349	-80.3102	-80.4352	-80.5516	-80.4439	-80.2684
44.0985	44.1737	43.8902	43.9151	43.8485	43.8067	43.6816	43.6733	43.9066	43.7151	43.7149	43.5816	43.0737	43.5486	43.1653	43.3653	43.1819	43.3569	43.7152	43.5404	43.1902	43.8656
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02GA015	02GA016	02GA018	02GA023	02GA028	02GA029	02GA034	02GA038	02GA039	02GA040	02GA047	02GA048	02GB001	02GB006	02GB007	02GB008	02GB010	02GC002	02GC007	02GC008	02GC010	02GC011
-80.2435	-80.3354	-80.7101	-80.5015	-80.6933	-80.1768	-80.4772	-80.8267	-80.6269	-80.2683	-80.3269	-80.4102	-80.2601	-80.5438	-80.1516	-80.3769	-79.9435	-81.2103	-80.5349	-80.2849	-80.7182	-80.4352
43.5321	43.7319	43.3817	43.5819	43.6571	43.5485	43.5903	43.4821	43.7815	43.6403	43.4237	43.4154	43.1318	43.1733	43.1489	43.1235	43.0401	42.7815	42.6905	42.8234	42.8568	42.9899
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02GC017	02GC018	02GC022	02GC026	02GC029	02GC030	02GC031	02GD001	02GD003	02GD004	02GD005	02GD008	02GD009	02GD010	02GD014	02GD015	02GD016	02GD021	02GD027	02GE002	02GE003	02GE005
-80.5354	-81.0521	-80.0681	-80.8351	-81.1268	-80.9765	-81.2682	-81.2019	-81.1767	-80.9933	-81.1429	-81.2769	-81.0932	-81.2349	-81.2014	-81.1848	-80.8767	-80.6849	-80.9519	-81.3262	-81.9598	-81.3431
42.9654	42.7483	42.8071	42.7144	42.8398	42.7735	42.7899	42.9735	43.0401	43.0574	43.2569	43.0152	43.2736	43.2233	43.4492	43.1483	43.0483	43.2157	42.9738	42.9649	42.5399	42.9321
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02GE006	02GE007	02GG002	02GG003	02GG005	02GG006	02GG009	02GG013	02GH002	02GH003	02HA006	02HA007	02HA020	02HB001	02HB004	02HB005	02HB007	02HB008	02HB011	02HB018	02HB022	02HB023
-81.5681	-82.0851	-81.8435	-82.0014	-81.6185	-82.1095	-82.2933	-82.2521	-82.6269	-83.0182	-79.3769	-79.6185	-79.5602	-80.0182	-79.7684	-79.8766	-79.9602	-79.8603	-79.8604	-79.9184	-79.9851	-80.0433
42.7318	42.3816	42.8319	42.6486	42.9566	42.9071	42.8152	42.7649	42.2149	42.1569	43.1325	43.0235	43.1153	43.8321	43.4984	43.5151	43.2654	43.6401	43.4404	43.7732	43.3906	43.2818
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02HB025	02HB029	02HC003	02HC009	02HC018	02HC022	02HC024	02HC025	02HC030	02HC031	02HC047	02HC049	02HD012	02HD019	02HE002	02HF002	02HF003	02HJ001	02HJ003	02HJ006	02HK003	02HK005
-79.8513	-79.7018	-79.5181	-79.5767	-78.9599	-79.2269	-79.3603	-79.6189	-79.5519	-79.6685	-79.8101	-79.0513	-78.3265	-78.1766	-77.3599	-78.8107	-78.6768	-78.3182	-78.0436	-78.3596	-77.6768	-77.9271
43.6481	43.5818	43.6981	43.7904	43.8734	43.8569	43.6901	43.8149	43.5987	43.7567	43.9317	43.8485	43.9904	43.9653	44.0234	44.7313	44.7072	44.3066	44.2984	44.3069	44.4815	44.8482
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

02HK006	02HK007	02HK017	02HL001	02HL003	02HL004	02HL005	02HL007	02HL008	02HM002	02HM003	02HM004	02HM005	02HM006	02HM007	02HM010	02JC008	02JE027	02JE028	02KA015	02KB001	02KC009
-77.6935	-77.7852	-77.6182	-77.4099	-77.3681	-77.3186	-77.6101	-77.3185	-77.2269	-76.7602	-77.2014	-76.8434	-76.6103	-76.7517	-76.8349	-76.9936	-79.8771	-78.8765	-79.7269	-78.4851	-77.3101	-76.5602
44.5318	44.1318	44.3403	44.2572	44.5403	44.5485	44.4985	44.4899	44.4815	44.4733	44.2067	44.2402	44.2569	44.2237	44.3319	44.4903	47.8912	46.0902	47.0814	46.2825	45.8897	45.4982
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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02KC015	02KC018	02KD002	02KD004	02KF001	02KF005	02KF006	02KF010	02KF011	02KF012	02KF013	02KF016	02KF017	02KF018	02KF019	02LA004	02LA006	02LA007	02LA024	02LB005	02LB007	02LB008
-77.1021	-77.1184	-77.8355	-77.5105	-76.2767	-75.7527	-76.1182	-76.3934	-76.1935	-76.2519	-76.6181	-77.1103	-76.9601	-76.4017	-76.5352	-75.6934	-75.6599	-75.7848	-76.2515	-74.9683	-75.5436	-75.1518
45.7984	45.8151	45.0567	45.3233	45.0566	45.4148	45.1737	45.0482	45.4155	45.2485	45.1403	44.8399	44.9737	44.9483	44.9733	45.3732	44.9903	45.2486	44.8985	45.5153	44.8409	45.4233
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02LB009	02LB018	02LB020	02LB022	02LB032	02MB006	02MC001	02MC026	02MC027	02MC036	02OJ007	02OT901	02OT908	02OT906	02OT907	02OT910	02OT912	02OT903	02OT904	02OT916	02OT905	4024000
-75.2265	-74.9437	-75.4099	-75.1018	-74.4349	-75.8018	-74.6348	-74.4847	-74.8686	-74.6021	-73.2513	-79.0929	-78.318	-79.2845	-80.0099	-77.6852	-77.7857	-76.4599	-75.9847	-75.6599	-77.3098	-92.4182
45.1068	45.3731	45.2237	45.1906	45.4902	44.5235	45.1569	45.2736	45.0818	45.3151	45.3988	46.7069	47.7821	47.5902	47.4153	46.1902	45.4148	47.3066	46.7148	46.1152	47.6153	46.6991
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4024430	4027000	4027500	4031000	4032000	4040000	4041500	4045500	4056500	4057510	4058100	4059000	4059500	4060993	4062000	4062011	4062500	4063000	4063500	4064500	4065106	4065650
-92.0931	-90.6849	-90.9017	-90.0678	-89.7677	-89.2022	-88.6602	-85.2672	-86.1512	-86.7013	-87.4933	-87.2099	-87.1929	-88.3097	-88.2599	-88.2093	-88.2182	-88.1847	-88.0764	-88.2186	-87.9766	-87.8346
46.6323	46.4824	46.499	46.5152	46.5405	46.7233	46.7233	46.5734	46.0402	45.9405	46.3148	45.9156	45.7568	45.9652	46.0067	45.9492	46.1163	45.9576	45.8743	45.849	45.7729	45.7736
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-87.8595	-87.7766	-87.8016	-87.9924	-87.693	-87.66	-88.3011	-87.7924	-87.7433	-88.2935	-87.9767	-89.1345	-88.9431	-88.7344	-88.7263	-88.7358	-88.8596	-88.993	-88.4183	-88.0103	-87.7094	-87.7427
45.7401	45.5905	45.4823	45.499	45.3911	45.3238	45.3821	45.1481	45.0481	44.8658	44.8653	43.8487	43.9576	45.1901	44.7234	44.3985	44.4155	44.3318	44.2486	44.5243	44.1072	43.7489
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4086600	4087000	4087240	4096405	4097500	4099000	4099750	4100500	4101000	4101500	4101800	4102500	4103500	4105000	4105500	4106000	4108660	4111000	4112500	4113000	4114000	4114498
-87.943	-87.9012	-87.8186	-85.076	-85.6266	-85.7514	-85.5764	-85.8428	-85.9778	-86.2528	-86.2096	-86.3596	-84.9592	-85.1428	-85.1926	-85.5095	-86.1024	-84.6348	-84.4685	-84.5431	-84.9016	-84.7594
43.282	43.0984	42.7487	42.1073	41.9402	41.8075	41.7486	41.5899	41.6903	41.8241	41.9155	42.1907	42.2653	42.3325	42.3238	42.2819	42.6483	42.5318	42.7321	42.7482	42.807	42.8321
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4115000	4116000	4117500	4118500	4119000	4119400	4121300	4121500	4121944	4121970	4122200	4122500	4124000	4124200	4125460	4125550	4133501	4136000	4136500	4136900	4137005	4137500
-84.6936	-85.0597	-85.2266	-85.5928	-85.677	-86.0183	-85.0342	-85.2605	-85.5848	-85.6685	-86.227	-86.2682	-85.6927	-85.809	-85.7596	-85.9348	-83.6265	-84.2848	-84.1265	-83.8354	-83.8022	-83.4268
43.115	42.9816	42.6156	43.0823	42.9648	43.0235	44.1989	43.8981	43.4312	43.4402	43.4647	43.9482	44.4405	44.3735	44.1898	44.2648	45.1234	44.6821	44.6654	44.6151	44.5649	44.432
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4142000	4146063	4147500	4148500	4151500	4154000	4155500	4156000	4157005	4159492	4161820	4164000	4164500	4165500	4166500	4172000	4174500	4176000	4176500	4178000	4180000	4180500
-84.0098	-83.3428	-83.5099	-83.7678	-83.7434	-84.7013	-84.3594	-84.2349	-83.9513	-82.6181	-83.0178	-82.9432	-82.8848	-82.9017	-83.2518	-83.7931	-83.7265	-83.9765	-83.5271	-84.7932	-85.068	-85.0762
44.0737	43.1573	43.1151	43.0402	43.332	43.6317	43.5656	43.6073	43.4238	43.1491	42.6072	42.5817	42.6319	42.5984	42.3738	42.474	42.2907	41.9066	41.9566	41.3976	41.2235	41.1654
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4180988	4181500	4182000	4183000	4184500	4185000	4186500	4188100	4188400	4189000	4189131	4189260	4191500	4192500	4193500	4195500	4195820	4196500	4196800	4197137	4198000	4199000
-84.6432	-84.9265	-85.1017	-85.0263	-84.2431	-84.4266	-84.2595	-84.2182	-83.5678	-83.6849	-83.9179	-84.0429	-84.4017	-84.2768	-83.7099	-83.3512	-83.2264	-83.2513	-83.3429	-83.1757	-83.1519	-82.602
40.7074	40.8483	40.9909	41.0907	41.657	41.5071	40.9568	40.9905	41.0401	41.0571	41.0151	41.0153	41.2401	41.2906	41.4985	41.4574	41.498	40.8569	40.9238	41.1155	41.3151	41.3071
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4199500	4200500	4201500	4206000	4206425	4208000	4209000	4212100	4213000	4213500	4218000	422016550	4221000	4223000	4227500	4228500	4229500	4230500	4231600	4232482	4232730	423406130
-82.3177	-82.1017	-81.8843	-81.5351	-81.5598	-81.6183	-81.4015	-81.227	-80.6016	-78.9264	-78.6093	-78.3096	-77.951	-78.0346	-77.8349	-77.7601	-77.5845	-77.7846	-77.6186	-76.9594	-76.7592	-76.735
41.3811	41.3822	41.4071	41.1322	41.2817	41.3902	41.6407	41.7148	41.9237	42.4658	43.0821	43.2983	42.1237	42.5659	42.7646	42.9154	42.9571	43.015	43.14	42.6824	42.94	42.9573
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4235000	4235440	4235600	4247000	4247055	4249000	4250200	4252500	4258000	4260500	4262000	4262500	4263000	4265432	4266500	4267500	4268000	4269000	4271500	4271815	4273700	4273800
-77.2347	-76.5597	-76.6349	-76.2107	-76.2766	-76.4936	-76.0349	-75.3014	-75.3928	-75.918	-75.0679	-75.3262	-75.3687	-75.0681	-74.5679	-74.8762	-74.9762	-74.7763	-73.5015	-73.418	-73.4846	-73.4842
42.9154	42.9409	43.0824	43.2147	43.2072	43.4484	43.5322	43.5155	43.8989	43.9909	44.2238	44.1904	44.5986	44.8483	44.2402	44.5153	44.8322	44.8653	44.9988	44.8991	44.6407	44.5992
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4274000	4275500	4276500	4280000	4280450	4282000	4282500	4282525	4282650	4282780	4282795	4283500	4284751	4285500	4286000	4287000	4288000	4288040	4289000	4290500	4292000	4292201
-73.9106	-73.6345	-73.3929	-73.3014	-73.2846	-73.0092	-73.1597	-73.168	-73.2432	-73.2264	-73.2095	-72.4344	-72.5428	-72.576	-72.5844	-72.6428	-72.7428	-72.7342	-72.7678	-73.1345	-72.6693	-72.8263
44.3147	44.4575	44.3659	43.6243	43.4658	43.6071	44.0065	44.066	44.1984	44.249	44.366	44.1578	44.2493	44.2995	44.2651	44.1828	44.2744	44.3245	44.3743	44.482	44.6238	44.6493
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4292500	4293000	4293500	4294000	4296000	4296280	4296500	22505	22507	22513	22601	22704	23004	23106	23303	23401	23402	23422	23427	23429	23432	23448
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44.6817	44.9743	44.9571	44.9154	44.8661	44.8658	44.9411	47.6495	47.6159	47.8242	47.5327	47.3825	46.8161	46.8243	46.6909	46.6576	46.5829	46.166	45.5742	46.0993	46.5411	45.9495
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23702	24003	24014	30101	30103	30106	30208	30215	30220	30225	30234	30278	30282	30284	30298	30302	30304	30309	30314	30316	30345	30348
-72.0926	-71.4508	-72.0926	-71.9592	-72.3007	-71.9843	-71.8927	-71.8927	-71.9675	-71.2843	-71.6509	-71.4012	-71.3847	-71.468	-71.4095	-72.9595	-72.9011	-72.6094	-72.7352	-72.8511	-72.943	-72.6344
46.5412	46.3079	46.2077	45.7909	46.0579	46.0743	45.4161	45.2911	45.2828	45.941	45.4661	45.7576	45.5826	45.6574	45.7494	45.2826	45.4992	45.4242	45.2152	45.9493	45.6244	45.5911
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30415	30421	30424	30905	30907	30919	30921	40110	40122	40129	40204	40238	40406	40619	40624	40627	40830	40840	40841	41902	42610	43003
-73.1844	-73.3679	-73.0428	-73.7593	-73.8177	-74.1679	-73.7512	-74.0011	-74.2425	-74.1095	-74.6759	-74.6011	-75.0926	-75.1425	-75.3178	-75.2426	-75.7432	-76.0596	-76.0428	-77.8093	-79.2678	-77.543
45.4909	45.391	45.1661	45.3328	45.1577	45.091	45.091	45.7911	46.0494	46.0994	45.733	46.1161	45.7912	47.1826	46.7826	46.6573	47.0825	46.0826	46.5911	46.3494	47.0408	47.8411
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43012	43030	46709	48603	50119	50135	50144	50304	50408	50409	50702	50801	50807	50904	51001	51005	51502	52212	52219	52228	52233	52401
-78.8512	-76.7093	-73.9681	-79.0351	-73.9019	-72.7344	-73.0426	-72.401	-71.8761	-71.8428	-71.8428	-71.5263	-71.6263	-71.3093	-71.1509	-71.1348	-70.2095	-73.7011	-73.4262	-73.6511	-73.4842	-73.3845
48.3658	47.7325	45.5655	46.7652	46.6816	47.766	47.6743	46.5909	46.8576	46.9826	46.7326	46.8911	46.866	46.8162	46.8994	47.2576	47.6993	46.041	46.0159	46.3412	45.8492	46.1575
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

52601	52606	52805	60102	60704	60901	61004	61020	61022	61024	61028	61029	61307	61502	61602	61801	61901	62102	62114	62701	62803	64101
-73.0929	-73.4513	-73.1762	-70.0347	-70.9929	-71.0346	-71.1931	-71.6427	-71.3764	-71.2847	-71.4429	-71.2684	-71.7102	-72.001	-72.2345	-72.0427	-72.4842	-72.2677	-72.1679	-70.9761	-69.9017	-72.3844
46.2989	46.4409	46.5993	48.091	48.2076	48.3981	48.3066	48.1826	47.9411	48.2408	48.3076	48.3735	48.3985	48.3744	48.2076	48.8162	48.6909	48.8909	48.9493	48.4911	48.2742	48.5829
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A6: Gauges assimilated by the Gulf of St. Lawrence (gsl) domain

:ColumnName	02XA003	02YC001	02YJ001	02YK002	02YK005	02YL001	02YL003	02YL008	02ZB001	10802	10902	11003	11204	11508	11509	20404	20602	21407	21601	21702
:ColumnLocationX	-61.3027	-57.1521	-58.3684	-57.9346	-56.6589	-57.3519	-57.7526	-57.2936	-59.01	-65.5513	-65.7354	-66.1684	-66.3511	-67.4433	-67.1273	-64.9201	-64.7013	-66.4688	-67.5346	-67.6606
:ColumnLocationY	52.2248	50.6078	48.5751	48.6246	49.3412	49.2497	48.9909	49.6249	47.6082	48.1915	48.2332	48.6333	48.1584	48.4912	48.1085	48.8077	48.9748	49.0407	48.7743	48.7664
:Coeff1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Coeff4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
:Value1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

22003	22301	70204	71203	71401	72301	73503	74903	75705	76601
-68.5517	-69.1933	-69.5023	-68.1516	-67.6538	-66.1943	-64.5688	-61.7022	-59.6017	-57.5941
48.4173	48.0915	48.3832	49.3249	49.3331	50.3499	50.6831	50.4329	50.6833	51.7583
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Appendix B: Template files for lakes and regulated reservoirs

Provided below are the reservoir template files for the Yukon, Mackenzie, Churchill and Nelson rivers, the Great Lakes St. Lawrence River, and the terrain draining to the Gulf of St. Lawrence. The files provide the name of the lake or reservoir that is explicitly represented by DHPS, the latitude and longitude of the outlet of the lake or reservoir in the model world, and the values of coefficients used by WATROUTE. See Sect. 3.6.1 for an explanation of the coefficients.

Table B1: Lakes and reservoirs modelled explicitly by the Yukon River (yuk) domain

:ColumnName	Laberge	Teslin	Atlin	Tagish	Kluane	Mayo	Kusawa	Marsh	Bennett	Schwatka
:ColumnModel	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
:ColumnLocationX	-135.2181	-133.2519	-133.8013	-134.2605	-139.0435	-135.3597	-136.1179	-134.5013	-134.7179	-135.0263
:ColumnLocationY	61.3856	60.4608	59.5942	60.2768	61.4356	63.7779	60.6026	60.5441	60.1691	60.6939
:Coeff1	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
:Coeff2	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
:Coeff3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff6	1.98E+08	3.56E+08	5.90E+08	3.52E+08	3.98E+08	9.90E+07	1.45E+08	9.95E+07	9.62E+07	2.10E+06
:Coeff7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B2: Lakes and reservoirs modelled explicitly by the Mackenzie River (mck) domain

:ColumnName	Artillery	Athabasca	Aylmer	Basler	BSpruceKwe	Bistcho	Black	Blackwater	Buffalo	Calling	Claire	ClntnColdn	Cree	Davy	Faber	Frnces	GBear	GSlave
:ColumnModel	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
:ColumnLocationX	-108.4048	-111.196	-107.9459	-116.0958	-115.9797	-119.1631	-105.538	-123.3212	-115.2545	-113.2042	-111.7045	-107.213	-106.2959	-108.1878	-117.4628	-129.2794	-123.5046	-117.4877
:ColumnLocationY	62.8982	58.7068	64.0648	63.7815	63.5229	59.7562	59.1482	63.9066	60.3564	55.2062	58.6315	63.7481	57.715	58.94	64.0232	61.2314	65.1399	61.265
:Coeff1	1.000E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-15	1.00E-12
:Coeff2	1.750E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
:Coeff3	0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff4	0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff5	0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff6	5.170E+08	7.53E+09	8.01E+08	9.90E+07	1.39E+08	4.12E+08	4.44E+08	2.16E+08	5.54E+08	1.39E+08	1.33E+09	5.96E+08	1.16E+09	1.12E+08	4.04E+08	1.02E+08	3.05E+10	2.67E+10
:Coeff7	0.000E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Hardisty	Hottah	Ingray	Kakisa	Keller	LBelot	LMartre	LSlave	Mackay	MarianRusl	McArthur	Nonacho	Porter	SambaaKe	Scott	Selwyn	Snare	Tathlina	Tazin	Utikuma
LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
-117.513	-118.2294	-116.229	-117.4212	-121.5125	-126.3207	-117.2626	-116.0959	-109.8293	-115.996	-107.221	-109.9295	-107.8966	-121.1378	-106.3965	-104.2045	-114.6958	-117.5298	-109.4052	-115.3878
64.7647	65.2319	64.1148	60.9401	64.0568	66.7568	63.1321	55.4898	64.1484	62.8062	61.823	61.6734	61.7977	60.7482	59.8645	59.8814	64.2236	60.6647	59.8312	55.9317
1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.30E+08	9.51E+08	1.20E+08	3.34E+08	3.92E+08	2.95E+08	1.68E+09	1.19E+09	9.67E+08	4.00E+08	4.30E+07	6.97E+08	1.01E+08	4.99E+08	5.34E+08	5.65E+08	1.72E+08	5.61E+08	3.67E+08	2.54E+08
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Williston	Winefred	PeaceDam
DZTR	LAKE	LAKE
-122.1962	-110.5045	-121.9961
56.0233	55.5898	55.9815
1.00E-12	1.00E-12	1.00E-12
1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00
1.72E+09	1.27E+08	8.60E+06
0.00E+00	0.00E+00	0.00E+00

Table B3: Lakes and reservoirs modelled explicitly by the Churchill River (chu) domain

:ColumnName	Baldock	Besnard	BlackBear	Churchill	Cold	Deception	Delaronde	Dore	Frobisher	Gauer	Granville	HighrockMB	HighrockSK	Kamuchawie	Kississing	LBrochet	LIleCrosse	LPlonge
:ColumnModel	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
:ColumnLocationX	-98.0439	-105.7106	-105.3768	-108.2521	-109.844	-104.3103	-107.1272	-107.5772	-108.2018	-97.5854	-100.019	-100.4768	-105.3605	-101.9017	-101.1934	-101.4103	-107.7354	-107.502
:ColumnLocationY	56.6398	55.5482	55.5897	55.7318	54.5647	56.6236	54.0816	54.7067	56.1653	57.1151	56.4985	55.9816	57.0569	56.3988	55.2986	58.5486	55.9315	55.1902
:Coeff1	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-13	1.00E-12	1.00E-12	1.00E-12
:Coeff2	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
:Coeff3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff6	1.38E+08	1.33E+08	1.77E+08	5.44E+08	3.47E+08	1.05E+08	1.24E+08	6.28E+08	4.27E+08	2.63E+08	4.20E+08	4.92E+08	9.30E+07	1.65E+08	2.77E+08	2.41E+08	4.71E+08	2.39E+08
:Coeff7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

LRonge	Montreal	Nemeiben	Nokomis	Oliver	PeterPond	Pinehouse	Primrose	Rat	Reindeer	Russell	Sisipuk	Smoothston	Sokatisewn	SIndian	Turnor	UpprFoster	Wasekamio	Wskaiowaka
LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
-104.5519	-105.5936	-105.2101	-103.2101	-103.3021	-108.4602	-106.2353	-109.6936	-99.5518	-103.1523	-101.2939	-101.6102	-106.7937	-102.3605	-98.1433	-108.4269	-105.3102	-108.6769	-96.252
55.3237	54.5402	55.3149	57.0399	56.9982	55.8401	55.7901	54.8485	56.2484	56.2398	56.3647	55.7731	54.7483	55.5146	57.3647	56.6237	56.7318	56.7151	56.6067
1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.30E+09	4.57E+08	1.64E+08	1.46E+08	1.31E+08	8.28E+08	4.04E+08	4.37E+08	2.47E+08	5.44E+09	1.56E+08	2.26E+08	2.78E+08	4.87E+07	2.31E+09	2.38E+08	1.07E+08	1.30E+08	2.00E+08
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Wollastn
LAKE
-102.7852
58.7985
1.00E-12
1.75E+00
0.00E+00
0.00E+00
0.00E+00
2.27E+09
0.00E+00

Table B4: Lakes and reservoirs modelled explicitly by the Nelson River (nel) domain

:ColumnName	BigHorn	Brazeau	Ghost	Dickson	Oldman	Gardiner	LastMntn	Campbell	Deschamblt	Amisk	Cumberland	LOTPrairie	Athapapskw	Winnipgsis	Swan	Cedar	Cormorant	Moose
:ColumnModel	DZTR	LAKE	DZTR	DZTR	DZTR	DZTR	LAKE	DZTR	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE
:ColumnLocationX	-116.3251	-115.5753	-114.7003	-114.2083	-113.9	-106.8666	-105.2167	-103.3999	-103.1499	-102.1667	-102.3749	-101.4082	-101.4583	-99.6417	-100.7499	-99.3333	-100.6085	-100.2751
:ColumnLocationY	52.3126	52.971	51.2204	52.0544	49.571	51.2796	51.3961	53.6629	54.8545	54.4462	53.9712	50.9713	54.5544	51.8963	52.6379	53.1542	54.2291	53.6958
:Coeff1	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	5.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-11	1.00E-11
:Coeff2	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
:Coeff3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff6	5.30E+07	4.00E+07	1.10E+07	1.80E+07	2.20E+07	4.30E+08	2.14E+08	2.00E+08	5.44E+08	3.44E+08	2.52E+08	6.15E+07	2.56E+08	5.04E+09	3.08E+08	2.51E+09	3.39E+08	1.31E+09
:Coeff7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Bruntwood	Dauphin	Waterhen	LManitoba	LWinnipeg	Setting	StMartin	Cross	Sipiwesk	Split	Family	RoughrockL	LOTWoods	Stephens	Umfreville	Trout	Eagle	Rainy	Seul	Namakan	Sturgeon
LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	DZTR	LAKE	LAKE	LAKE	LAKE	DZTR	LAKE	DZTR	LAKE
-100.1252	-99.9502	-99.5498	-98.7252	-97.8667	-98.3917	-98.3085	-97.8751	-97.2749	-95.8335	-95.559	-94.8677	-94.5168	-94.6335	-94.9749	-93.2421	-93.1837	-93.3586	-93.176	-92.675	-90.8172
55.3962	51.446	51.9296	51.5875	53.7131	55.1961	51.8293	54.7458	55.2213	56.2712	51.8544	50.1204	49.7713	56.3792	50.2544	51.1374	49.7462	48.6125	50.6293	48.496	50.0873
1.00E-12	5.84E-11	1.00E-25	2.34E-16	2.00E-15	1.00E-12	3.00E-14	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	8.00E-14	1.00E-12	1.00E-11	2.00E-12	2.00E-11	1.00E-12	5.00E-12	1.00E-12	5.00E-11
1.75E+00	1.50E+00	3.05E+00	1.87E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.30E+08	5.16E+08	1.61E+08	4.75E+09	2.39E+10	1.27E+08	3.32E+08	5.91E+08	5.14E+08	2.81E+08	1.45E+08	1.60E+07	3.47E+09	3.17E+08	2.15E+08	3.48E+08	3.09E+08	8.27E+08	1.25E+09	1.46E+08	2.43E+08
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

WnnpgOutlt	Red	Pelican	RedDeer	Namew	Clearwater	Reed	Wekuskoo	Candle	Dog	Talbot	Basswood	Waterton	laCroix	StMary
LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	DZTR	LAKE	DZTR
-98.0164	-95.2672	-100.3087	-101.2001	-102.017	-100.917	-100.2667	-99.6752	-105.1667	-98.5417	-99.8084	-91.6418	-113.6751	-92.1593	-113.1169
54.5294	47.9544	52.5708	52.8959	54.0876	54.1457	54.6625	54.8956	53.7709	51.1126	54.1368	48.1041	49.3209	48.3707	49.3629
1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.19E+09	1.14E+09	1.55E+08	2.61E+08	2.00E+08	2.84E+08	1.90E+08	1.76E+08	1.32E+08	1.14E+08	1.85E+08	9.80E+07	8.00E+06	1.16E+08	3.75E+07
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B5: Lakes and reservoirs modelled explicitly by the Great Lakes St. Lawrence River (gls) domain

:ColumnName	Kaministiq	WhiteLake	LNipissing	LMuskoka	MusquashR	Nipigon	Winnebago	Simcoe	Superior	Huron	StClair	Erie	Ontario	Timiskamng	Kipawa	Cabonga	Baskatong	StFrancois	StLMtlQue
:ColumnModel	LAKE	LAKE	DZTR	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	DZTR	DZTR	DZTR	DZTR	LAKE	LAKE
:ColumnLocationX	-89.6193	-85.7101	-80.0024	-79.6113	-79.7363	-88.3021	-88.4355	-79.3439	-84.353	-82.4188	-82.911	-79.0689	-74.794	-79.1027	-79.2607	-76.4689	-75.9857	-73.9105	-70.6941
:ColumnLocationY	48.4231	48.6651	46.1321	45.0149	45.0149	49.3155	44.1904	44.7399	46.5071	43.0072	42.3651	43.0818	45.0063	46.7151	47.0397	47.3153	46.7237	45.307	47.14
:Coeff1	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	8.00E-15	3.00E-18	9.00E-15	2.00E-16	2.00E-16	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
:Coeff2	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.50E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
:Coeff3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff6	2.80E+06	6.5000+07	8.73E+08	1.20E0+08	2.40E+06	4.51E+09	6.46E+08	7.68E+08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.95E+08	2.62E+08	4.35E+08	2.82E+08	2.97E+08	2.05E+09
:Coeff7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

LacStJean	Kenogami	Champlain	Bartlett	LPlacid	UnionFls	TaylorPd	ChazyLake	LGeorge	Chitenden	Waterbury	Wrightvle	Greenrvr	EBarre	Marshfield	Gouin	Dozois	Quinze	LadyEvelyn	Rapid7	Mitchinmcs
DZTR	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	DZTR	DZTR	LAKE	LAKE	LAKE	DZTR	DZTR	DZTR	DZTR	DZTR	DZTR
-71.6442	-71.2104	-73.2438	-74.2434	-73.9776	-73.919	-73.8516	-73.8024	-73.4269	-72.9101	-72.7608	-72.5687	-72.5273	-72.4192	-72.2857	-74.1237	-77.3021	-79.2768	-80.0183	-78.3102	-75.1766
48.5901	48.3151	45.3076	44.2654	44.3064	44.4985	44.4902	44.7652	43.8226	43.7318	44.3903	44.3234	44.6313	44.1899	44.3656	48.3737	47.6149	47.5817	47.4067	47.7733	47.215
1.00E-12	1.00E-12	5.91E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
1.75E+00	1.75E+00	1.50E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1.05E+09	5.90E+07	1.18E+09	2.00E+07	8.80E+06	6.90E+06	3.20E+06	6.50E+06	1.14E+08	2.60E+06	3.40E+06	8.00E+05	2.20E+06	2.80E+06	1.70E+06	1.32E+09	3.29E+08	1.45E+08	1.05E+08	2.00E+08	5.90E+07
0.00E+00	0.00E+00	2.80E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.62E-01	0.00E+00	1.00E-03	1.00E-03	0.00E+00	1.00E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

DesJoachms	Kiamika	BarkLake	Paugan	LwrNotch	Manouane	Peribonka	Kempt	Temagami	Rice	Panache	Dog	Seneca	Cayuga	Oneida	Onaman	Wanapitei	Chestervil	FanshaweL	LBelwood	PoissnBlnc
DZTR	DZTR	DZTR	LAKE	DZTR	DZTR	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	DZTR	LAKE	LAKE	DZTR
-77.6941	-75.1103	-77.7942	-75.9274	-79.4692	-70.5434	-71.2436	-74.1851	-80.0349	-78.2264	-81.5266	-89.6183	-76.9435	-76.7354	-76.1273	-87.4352	-80.6684	-75.2348	-81.1687	-80.3271	-75.6683
46.1815	46.6392	45.4151	45.8069	47.1399	50.6653	49.9149	47.5315	46.8656	44.1569	46.1735	48.7151	42.8649	42.9401	43.2398	50.0733	46.6736	45.0988	43.0481	43.7404	46.1146
1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8.64E+07	5.20E+07	4.88E+07	3.00E+07	1.34E+07	4.72E+08	2.78E+08	1.84E+08	2.34E+08	9.60E+07	8.19E+07	1.45E+08	1.74E+08	1.72E+08	2.07E+08	1.12E+08	1.34E+08	1.80E+06	2.61E+06	6.00E+06	8.52E+07
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table B6: Lakes and reservoirs modelled explicitly by the Gulf of St. Lawrence (gsl) domain

:ColumnName	GStLawrnce	Manicouagan	GrandLake	Pipmuacan	Outardes	Fleche	Pletipi	Romaine4	Romaine3	Romaine2	Romaine1	PetitMncgn	Magpie	Brule	Musquaro	Manicougn2	DenisPerrn
:ColumnModel	LAKE	DZTR	LAKE	DZTR	DZTR	LAKE	LAKE	LAKE	LAKE	LAKE	LAKE	DZTR	LAKE	LAKE	LAKE	LAKE	LAKE
:ColumnLocationX	-59.3421	-68.7257	-57.2586	-69.7588	-68.9008	-68.604	-70.0849	-63.5008	-63.4012	-63.1671	-63.2422	-67.7935	-64.5934	-63.7017	-61.1265	-68.3426	-66.7851
:ColumnLocationY	46.4765	50.6598	49.2013	49.3597	49.7094	49.756	51.8253	51.3763	51.1179	50.6346	50.3931	51.8324	50.7245	52.1501	50.4664	49.3249	50.7998
:Coeff1	1.00E-12	5.00E-14	4.00E-14	9.00E-14	6.50E-14	5.00E-14	6.50E-14	4.00E-14	4.00E-14	4.00E-14	4.00E-14	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12	1.00E-12
:Coeff2	1.75E+00	1.60E+00	1.75E+00	1.60E+00	1.62E+00	1.60E+00	1.62E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00	1.75E+00
:Coeff3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
:Coeff6	1.55E+11	1.80E+09	4.97E+08	7.91E+08	6.84E+08	2.36E+08	3.07E+08	1.42E+08	3.86E+07	8.58E+07	1.26E+07	2.15E+08	1.08E+08	8.90E+07	1.70E+08	1.25E+08	2.53E+08
:Coeff7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix C: Parameter files for regulated reservoirs

Provided below is an example of the parameter file used by the DZTR model for regulated reservoirs. The file provides the names of the reservoirs where DZTR has been implemented and the value of parameters used by WATROUTE. See Sect. 3.6.2 for an explanation of the parameters. Note that, in this sample file, all numbers provided are meaningless; the purpose of this file is to demonstrate the information that the file contains. We do not provide the parameter values used by DHPS as some of the data underlying the parameter values are provided to us privately and are not to be shared.

Table C1. Prototype file containing parameter values for the DZTR model

1	# Number of reservoirs represented with the DZTR model										
####### Note : line 02 - 14 reserved for the following comments											
#Model_parameters for each reservoir : one divider line with 7# and 10 lines of data											
#											
#line 1 : Reservoir name, max 12 chars (must be the same as the name defined in yyyymmdd_REL.tb0 file)											
#line 2 : coefficients of polynomia used for the Storage-Elevation relationship, higher precison possible (max degree = 6; 7 coefficients must be provided),											
Stor = A0 + A1 * lev + A2 * lev ^ 2 + A3 * lev ^ 3											
#line 3 : Model type reservoir (0 interyear; 1 multi-year)											
#line 4, col 1 : Max Reservoir capacity (m3) = max. allowed storage											
# col 2 : Max. level allowed to avoid unrealistic answers with Newton_Raphson (max. level with physical meaning)											
# col 3 : Min. level allowed to avoid non-increasing parts of the storage-elevation relationship											
# col 4 : D/s Channel capacity (m3/s) = emergency (max.) flow allowed in downstream channel											
# col 5	dead storage fraction (of max. capacity) = min. storage below which outflow is 0.0										
#lines 5-7 : storage thresholds (m3) for critical and normal and flood storage; columns 1-12 are for the monthly values											
#lines 8-10 : storage ouflows (m3/s) for critical and normal and flood outflows; columns 1-12 are for the monthly values											
#######											
Example											
1000.58765	1.683211217	1.790405695	1.00178053	-1.04059E-05	0	0					
1											
10111969533	100	1	1090	0.1							
10000000000	20000000000	30000000000	40000000000	50000000000	60000000000	70000000000	80000000000	90000000000	10000000000	11000000000	12000000000
15000000000	25000000000	35000000000	45000000000	55000000000	65000000000	75000000000	85000000000	95000000000	15000000000	16000000000	17000000000
18000000000	28000000000	38000000000	48000000000	58000000000	68000000000	78000000000	88000000000	98000000000	18000000000	19000000000	20000000000
1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
1700	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700	1700
#######											

Appendix D: Template files for diversions

Provided below are the diversion template files for the domains of the Yukon, Mackenzie, Churchill and Nelson rivers, the Great Lakes St. Lawrence River, and the terrain draining to the Gulf of St. Lawrence. The files provide the name of the diversion, the latitude and longitude of the source and end points of the diversion in the model world, and the values of coefficients used by WATROUTE. For the locations of the source and end points of the diversion in the model, the point is placed at the outlet of a reach or on the appropriate river of the shed file and either below or above the entry of a tributary or other geographical feature as appropriate. Consequently, the model's locations may not be identical to the locations of the diversion's end points in the real world. See Sect. 3.7 for an explanation of the coefficients.

Table D1: Diversions represented by the Yukon River (yuk) domain

None						

Table D2: Diversions represented by the Mackenzie River (mck) domain

:ColumnName	From_chu				
:ColumnLocationX	-103.6464				
:ColumnLocationY	58.5564				
:Coeff1	0				
:Coeff2	0				
:Coeff3	0				
:Coeff4	0				
:Value1	0				
Default value 1	-1				
Default value 2	10				

Table D3: Diversions represented by the Churchill River (chu) domain

:ColumnName	To_mck	06EC002			
:ColumnLocationX	-102.7771	-98.1433			
:ColumnLocationY	58.7985	57.3647			
:ColumnLocationX1	-999.9999	-999.9999			
:ColumnLocationY1	-999.9999	-999.9999			
:Value1	0.1	1			
:Value2	2	2			
:Value3	1500	0			
:Value4	709	0			
Default value 1	-1	-1			
Default value 2	10	935			

Table D4: Diversions represented by the Nelson River (nel) domain

:ColumnName	05AD021	05AD027	05AE026	05JG006	05LL019	06EC002	
:ColumnLocationX	-113.551	-113.6751	-113.0419	-106.8666	-98.3258	-999.9999	
:ColumnLocationY	49.337	49.3209	49.3709	51.2796	49.9457	-999.9999	
:ColumnLocationX1	-113.259	-113.56	-999	-106.401	-98.3334	-99.3258	
:ColumnLocationY1	49.254	49.271	-999	50.9793	50.0459	55.8538	
:Value1	1	1	1	1	1	1	
:Value2	1	1	2	1	1	3	
:Value3	0	0	0	0	0	0	
:Value4	0	0	0	0	0	0	
Default value 1	-1	-1	-1	-1	-1	-1	
Default value 2	28	25	40	5	0	935	

Table D5: Diversions represented by the Great Lakes St. Lawrence River (gls) domain

:ColumnName	02AD009	04JD003	ChicagoR	CalumetR	ChicDiv3	Kipawa	Cabonga2W	Cabonga2E	Kenogami	Chambly
:ColumnLocationX	-999.9999	-999.9999	-87.6099	-87.5684	-82.4188	-79.2607	-76.4604	-76.7602	-71.2022	-73.2438
:ColumnLocationY	-999.9999	-999.9999	41.8902	41.6569	43.0072	47.0397	47.3063	47.5152	48.3151	45.3076
:ColumnLocationX1	-88.2023	-87.0688	-999.9999	-999.9999	-999.9999	-79.0271	-76.7605	-76.4522	-71.2767	-73.2604
:ColumnLocationY1	50.6318	49.0571	-999.9999	-999.9999	-999.9999	46.7734	47.5151	47.2985	48.3653	45.4488
:Value1	1	1	1	1	1	1	1	1	0.5	1
:Value2	3	3	2	2	2	1	1	1	1	1
:Value3	0	0	0	0	0	0	0	0	0	0
:Value4	0	0	0	0	0	0	0	0	0	0
Default value 1	-1	-1	-1	-1	68	12	-1	5	-1	-1
Default value 2	113	45	-1	-1	68	12	-1	5	-1	0

Table D6: Diversions represented by the Gulf of St. Lawrence (gsl) domain

None						

Appendix E: Event template file

Table E1 presents the event file. The same event file is used for all domains. This file is used to pass parameter values to WATROUTE. These parameters govern various aspects of the performance of WATROUTE. Capitalized words are replaced with the appropriate value for the domain by DHPS before launching WATROUTE on that domain.

Table E1: The event file used to set parameters for the domain

#	
:fileType	.evt
:FileVersionNo	10
:year	YEAR
:month	MONTH
:day	DAY
:hour	HOUR
#	
:snwflg	n
:sedflg	n
:vapflg	n
:smrflg	n
:resinflg	n

:tbcflg	n
:resumflg	y
:contflg	n
:routeflg	n
:crseflg	n
:ensimflg	n
:picflg	n
:wetflg	n
:modelflg	r
:shdflg	n
:trcflg	n
:frcflg	n
:initflg	n
:fstflg	y
:chnlflg	n
:mndrflg	y
:r1nflg	y
:r2nflg	y
:rlakeflg	y
:nocrashflg	y
:rbmflg	n
:splrpnflg	n
:tresh_back	n
#	
:intSoilMoisture	0.25 0.25 0.25 0.25 0.25 0.25
:rainConvFactor	1
:eventPrecipScaleFactor	1
:precipScaleFactor	0
:eventSnowScaleFactor	0
:snowScaleFactor	0
:eventTempScaleFactor	0
:tempScaleFactor	0
#	
:hoursRainData	168
:hoursFlowData	168
:deltat_report_discharge	1
:deltat_report_flowICs	RUNLEN
:deltat_report_lakelevs	RUNLEN_ASSIM
:da_ratio	0
#	
:basinFileName	PATHINPUT/shed.fst
:parFileName	
:channelparfile	PATHINPUT/shed.fst
:pointDataLocations	
:snowCoverDepletionCurve	
:waterqualitydatafile	
#	
:pointsoilsoisture	

```
:pointsrecip
:pointsemps
:pointsetsadiation
:pointHumidity
:pointWind
:pointLongwave
:pointShortwave
:pointAtmPressure
#
:streamflowDataFile                 PATHINPUT_STR_FILE
:reservoirReleaseFile               PATHINPUT/YEARMONTHDAY_REL.tb0
:reservoirParamFile                 PATHINPUT/DZTR_params.csv
:reservoirInflowFile
:snowCourseFile
#
:radarFile
:rawRadarFile
:clutterFile
:griddedInitSnowWEQ
:griddedInitSoilMoisture
:griddedInitLSZ
:griddedRain
:griddedSnow
:griddedTemperature
:griddedNetRadiation
:griddedHumidity
:griddedWind
:griddedLongwave
:griddedShortwave
:griddedAtmPressure
:griddedRunoff                      PATHINPUT/YEARMONTHDAY_RFF.fst
:griddedRecharge                    PATHINPUT/YEARMONTHDAY_RCH.fst
:griddedLeakage
#
#
#
#
#
#
#
#
:diversionDataFile                  PATHINPUT/YEARMONTHDAY_div.tb0
#
:noEventsToFollow                   0
#
EOF
```