Fraser River Temperature and Discharge Forecasting: 2004 Review

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2005

FRASER RIVER TEMPERATURE AND DISCHARGE FORCASTING: 2004 REVIEW

by

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Table of Contents

Abstract

Morrison, J. 2005. Fraser River temperature and discharge forecasting: 2004 review. Can. Tech. Rep. Fish. Aquat. Sci. 2594: iv + 16 p.

The tributaries of the Fraser River provide spawning habitat to large numbers of sockeye salmon that are known to be susceptible to both high flow and high temperature conditions. Twenty semi-weekly 10 day forecasts for flow and water temperature were made for the 2004 migration season (July 1-Sept. 15). The RMS error for daily average temperature was 0.86°C. The RMS error for daily average flow was 10.4%. The accuracy of the flow forecasts, the temperature forecasts and the weather forecasts (used to force the temperature forecast model) is shown to decrease with the length of the forecast. The instrumentation used to establish initial conditions for the models and for forecast validation is described. The report concludes with set of recommendations for improving the river forecast models and their operation.

Résumé

Morrison, J. 2005. Fraser River temperature and discharge forecasting: 2004 review. Can. Tech. Rep. Fish. Aquat. Sci. 2594: iv + 16 p.

Les tributaires du fleuve Fraser constituent un habitat de frai pour un grand nombre de saumons rouges qui sont sensibles au fort débit et aux températures élevées. Vingt prévisions bihebdomadaires de 10 jours ont été effectuées au cours de la saison de migration de 2004 (1 juillet – 15 septembre). L'erreur type de la température quotidienne moyenne était de 0.86°C. L'erreur type du débit quotidien moyen était de 10.4%. Il est démontré que la précision des prévisions de débit et de température ainsi que les prévisions météorologiques (qui servent de forçage pour le modèle de température) diminue avec la durée de la prévision. L'instrumentation utilisée pour déterminer les conditions initiales des modèles et pour valider les prévisions est décrite. La conclusion de ce rapport formule des recommandations pour améliorer les modèles de prévision du fleuve et leur exploitation.

1. Introduction

The tributaries of the Fraser River provide spawning habitat to large numbers of sockeye salmon (*Oncorhynchus nerka*) (DFO 1999). These salmon are known to be susceptible to both high flow and high temperature conditions (http://www-sci.pac.dfo-mpo.gc.ca/fwh/index_e.htm) and when they encounter either of these harsh conditions during their upstream migration, their en route mortality increases (Macdonald et al. 2000a; Macdonald et al. 2000b).

Sockeye fishery management is based on achieving spawning escapement targets. The targets are of the number of sockeye salmon that are required to meet conservation objectives for each stock. Test fisheries in the marine approach areas, Juan de Fuca and Johnstone Straits, estimate the abundance and the timing of the returning stocks. Any returning sockeye that are surplus to the spawning requirements are eligible for allocation to the sockeye salmon fishery. However, it is known that some fish die en route to their spawning grounds or reach the spawning beds in poor condition. Thus additional fish are added to the spawning escapement target to account for this en route mortality. These additional fish are referred to as a Management Adjustment (MA).

In recent years it has become more recognized that en route mortality is affected by river temperature and flow. Therefore, a management adjustment model was developed, called Environmental Management Adjustment (EMA) model (http://www.psc.org/info_runsizeworkshop.htm) to take into account the river flow and temperature conditions. The calculation for the number of sockeye available to the fishery is:

Fishery allocation = Returns (run size) – Spawning Requirement – EMA.

The commercial fishery largely targets sockeye before they enter the Fraser River. Thus to set the commercial limit using the EMA model it is necessary to forecast the river conditions that the salmon are expected to encounter. The Institute of Ocean Sciences River Temperature Model (IOSRTM) (Foreman et al. 1997, Morrison and Foreman, 2005) is run twice weekly to produce river temperature forecasts throughout the salmon migration season (generally mid June through mid September). Flow forecasts are based on historical trends derived from Phase Matched Hydrographs PMH (Morrison and Foreman, 2005) using a UBC routing model (Quick and Pipes 1976).

Normally forecasts are produced for the period running from mid-June until mid-September. In 2004 funding uncertainties delayed the start of forecasts until early July. In total 20 ten-day forecasts were produced between July 5 and September 16 with a river temperature root mean square (RMS) error at Qualark of 0.86°C and river flow RMS errors at Hope of 10.5%.

Overall, the season was characterized by record high temperatures and very low flows. (A slide that temporally blocked the Chilcotin River also made for a memorable year.) Day-of-the-year temperature records were set on 15 days and a new all time daily mean high of 21.5°C was set on Aug 18 at Qualark. This was 0.3°C higher than the previous record set on Aug 3 1998.

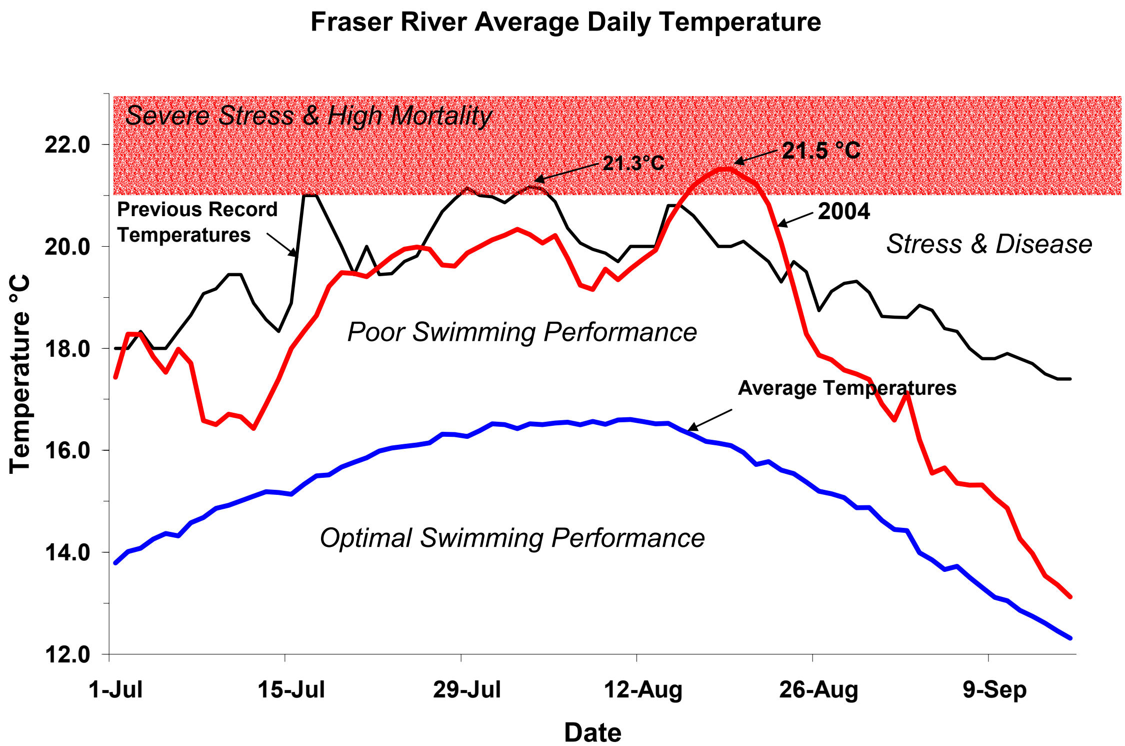


Figure 1. 2004 temperature observations at Qualark

2. Forecast Process

The forecast production has become increasingly more automated. It now takes about 3 hours of effort to produce a ten-day forecast of flows and temperatures throughout the Fraser watershed.

Temperature data is recorded on an hourly basis at 10 locations See Figure 2. A scheduled program attempts to download the most recent data from these loggers at 07:00 each morning. The forecaster reviews the communication log to verify that the downloads were successful. If a communication failure occurred for any logger, a new download for that logger

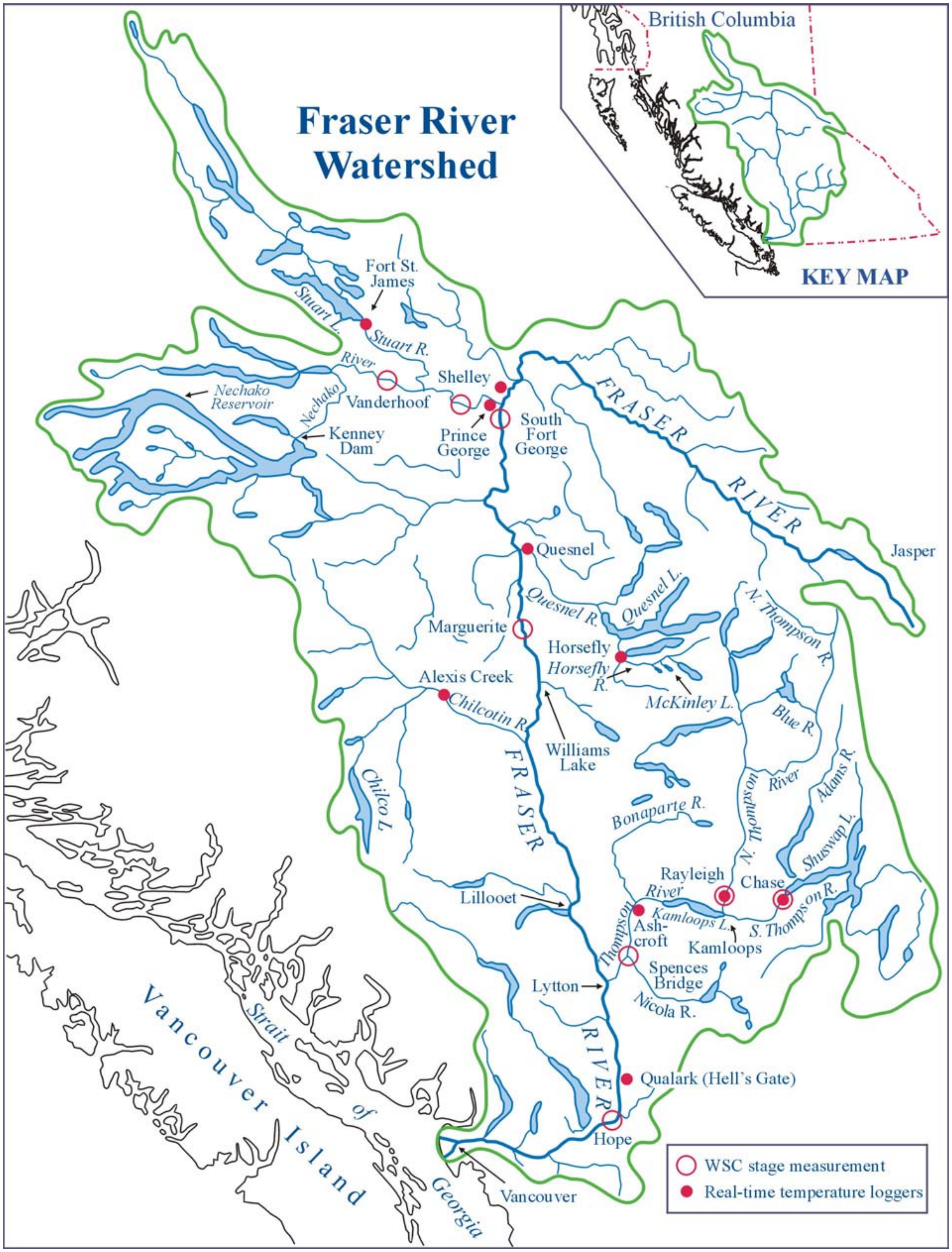


Figure 2 Fraser River Watershed

is initiated manually. This year logger failures at Qualark and at Shelley, both critical sites in the watershed, were overcome by the use of manual spot temperature readings that were phoned in to the forecaster by local personnel on a daily basis. Once all of the available temperature data has been collected, a computer job is run to update the temperature master files.

Flow data is collected from the Environment Canada web site at http://scitech.pyr.ec.gc.ca/waterweb/formnav.asp?lang=0 . Daily data is collected for 13 sites by estimating average daily flow from graphs of hourly data. This process is both labour intensive and prone to transcription and interpretation error. There is often data missing from the web site. Data gaps have to be filled by interpolation, extrapolation, or estimation based on changes at adjacent sites. The derived flow data is then entered into a spreadsheet. A program initiated from the spreadsheet transfers the data to the flow master files.

Tributary flow forecasts are produced from the latest flow data and historic trends are derived from Phase Matched Hydrographs.

Weather history and forecasts are received as e-mail attachments. A program is run that converts the daily attachment data into the hourly files used by IOSRTM.

The tributary flows and the weather forecasts are used to drive neural network programs that forecast water temperatures for each of the tributaries.

The UBC Flow program is used to forecast the river flows. An assimilation process adjusts the input flows so that the flow at the start of the forecast matches the latest observed flow.

Finally, the IOSRTM model is run to produce the temperature forecasts. Assimilation is also used here to adjust the tributary temperatures so that the first forecast temperature matches the last observed temperature.

On Mondays, the UBC Watershed program is run at UBC using the weather forecasts as inputs. The UBC Watershed program produces tributary flow forecasts that are received as an e-mail attachment 1 to 2 hrs after the weather forecast is received. These tributary flow forecasts are input into the UBC Flow program to produce the UBC river flow forecasts. On Thursdays, the UBC Flow program is run by extending the Monday forecast by 3 days.

3. Temperature Forecasts

Table 1 shows the accuracy for the individual forecasts produced this year, as well as the forecast error in other years for which detailed analysis is available. The 2004 forecasts had the lowest annual RMSE in spite of the 2.0° C RMSE for the August 9 forecast[1].

[1] Note. The Aug. 9 river temperature forecast error can be attributed to an exceptionally large error (11°c below the subsequently observed value) in the air temperature forecast.

Table 1. Temperature forecast error.

Date	RMSE	Mean
05-Jul	0.88	0.77
12-Jul	1.40	-0.97
15-Jul	1.25	-1.05
22-Jul	1.19	0.00
26-Jul	1.11	-1.09
29-Jul	1.04	-0.88
03-Aug	0.31	0.05
05-Aug	0.45	-0.10
09-Aug	**2.00**	**-1.32**
12-Aug	0.73	-0.48
16-Aug	0.64	-0.37
19-Aug	0.41	-0.34
23-Aug	0.55	-0.44
26-Aug	0.32	0.01
30-Aug	1.25	0.91
02-Sep	0.45	-0.15
06-Sep	0.48	0.12
09-Sep	1.32	1.02
13-Sep	0.47	-0.41
16-Sep	0.89	0.70
2004	0.86	-0.20
1999	1.26	
2000	0.92	
2001	0.88	
2002	1.12	

Figure 3. shows individual forecasts as well as the observed temperatures at Qualark in 2004. It can be seen that, for the most part, that the forecasts generally follow the shape of the observations.

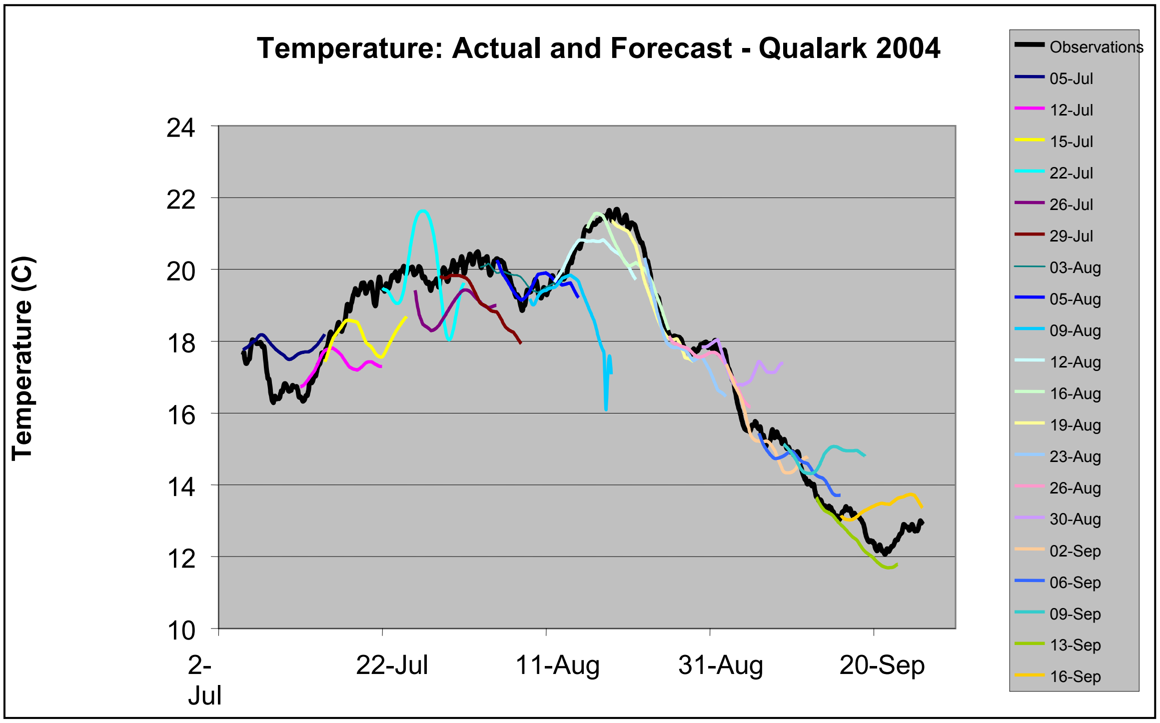


Figure 3. Fraser River temperature forecasts at Qualark

The extent of the divergence is illustrated in figure 4 where the annual RMSE is plotted as a function of the forecast day.

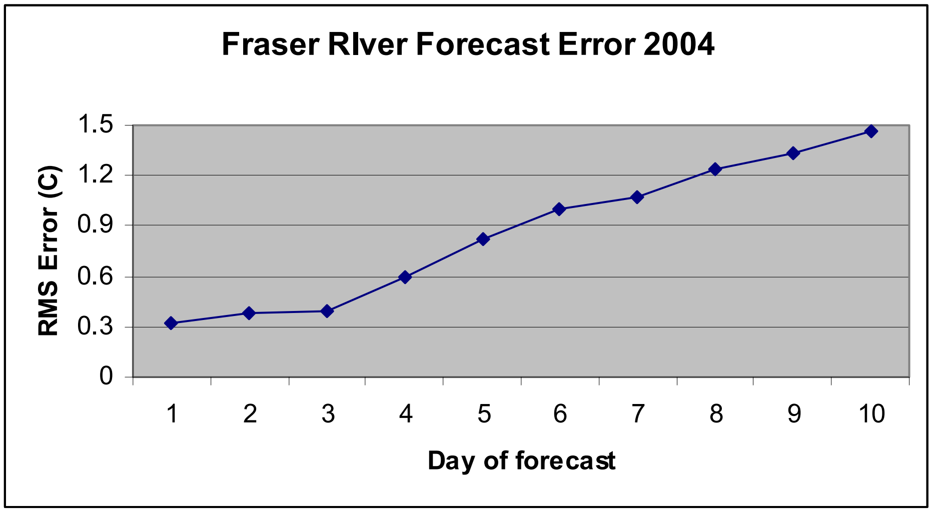


Figure 4 Average RMS Error versus forecast day for Qualark.

4. Flow Forecasts

A comparison of the two flow forecast methods (see table 2) using a paired Student's t-test indicates, as it has in other years, that the phase matched hydrograph method is superior to the UBC method in both overall accuracy as measured by RMSE, and bias as indicated by the smaller Mean error.

Table 2 Flow forecast error at Hope

	PMH		UBC	
Date	RMSE %	Mean %	RMSE %	Mean %
05-Jul	4.6	3.0	7.2	-6.1
12-Jul	6.2	3.7	10.3	-9.9
15-Jul	7.8	-5.0	8.0	-2.1
22-Jul	5.8	4.0	13.7	-13.6
26-Jul	8.3	6.8	4.5	3.2
29-Jul	6.4	5.5	2.8	0.4
09-Aug	2.9	-0.1	5.4	-3.6
12-Aug	7.0	-3.9	9.5	-8.0
16-Aug	10.2	-8.9	14.1	-12.1
19-Aug	6.8	-6.6	16.5	-16.3
23-Aug	3.6	0.0	3.8	-1.6
26-Aug	14.0	-4.2	17.4	-11.0
30-Aug	32.1	-26.9	25.3	-0.6
02-Sep	24.6	-23.7	24.7	-19.9
06-Sep	13.1	-10.5	20.3	-16.5
09-Sep	19.8	-17.8	26.3	-25.0
13-Sep	7.3	3.6	13.8	-8.8
16-Sep	8.9	7.5	16.4	-15.6
	10.5	-4.1	13.3	-9.3

The large flow errors on Aug. 30 and Sep. 2 were the result heavy rainfall that caused a large (1500 cms) increase in the Fraser River flow at Hope. This rainfall was not in the weather forecasts. Although the PMH method does not use weather in its forecasts, it is sensitive to large rainfall induced increases in flow because the Phase Matched Hydrograph continually decreases throughout the forecast season. The UBC method is also sensitive to rainfall so that unpredicted large rainfall events, as were observed this year and in previous years, cause it to underestimate flows.

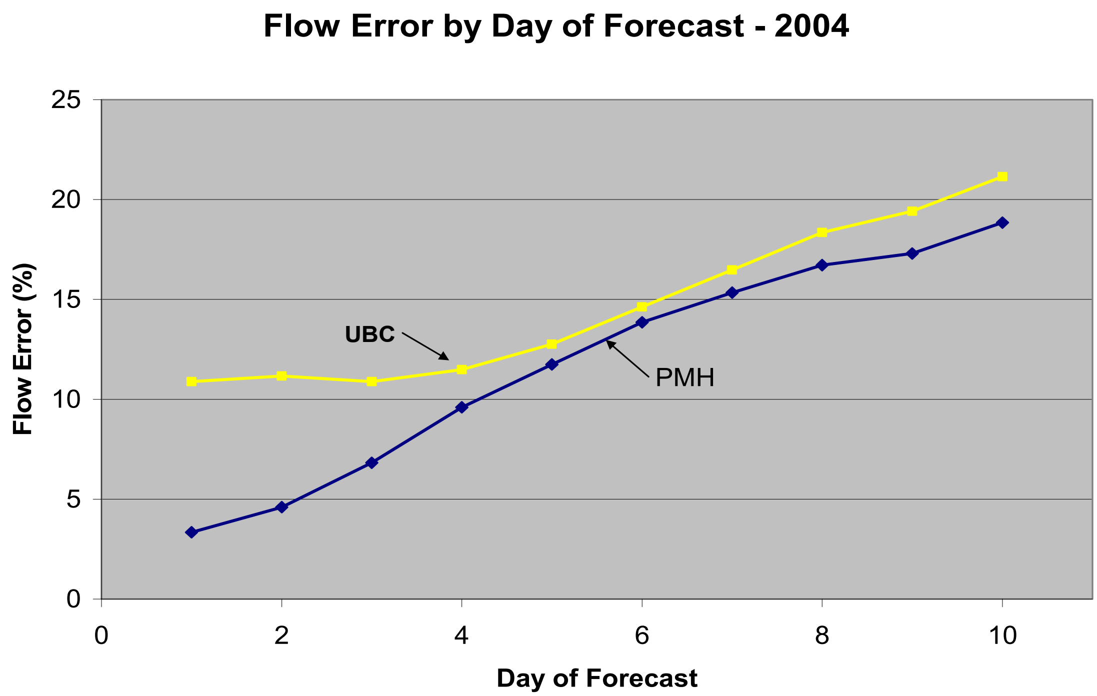


Figure 4. Flow average RMSE error as a function of day of forecast.

The application of data assimilation in the PMH method ensures that the forecasted flow matches the observed flow at the start of the forecast period. Figure 4 shows that the PMH method is clearly superior to the UBC method at the beginning of the forecast.

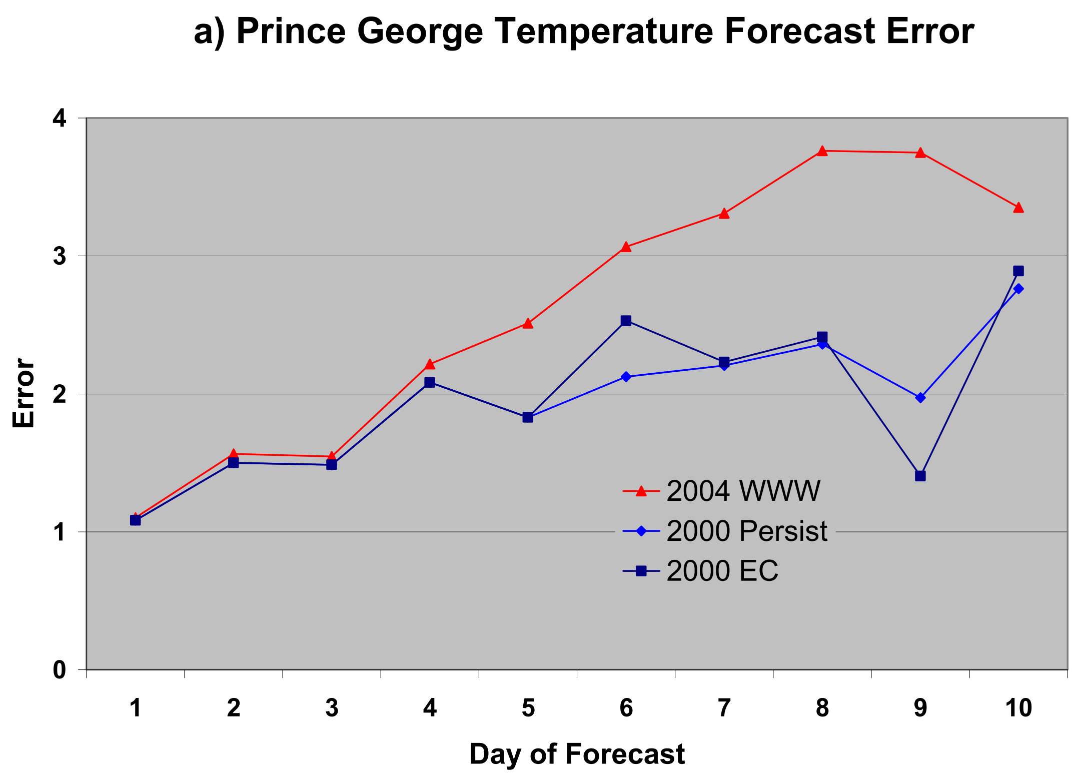
5. Weather Forecasts

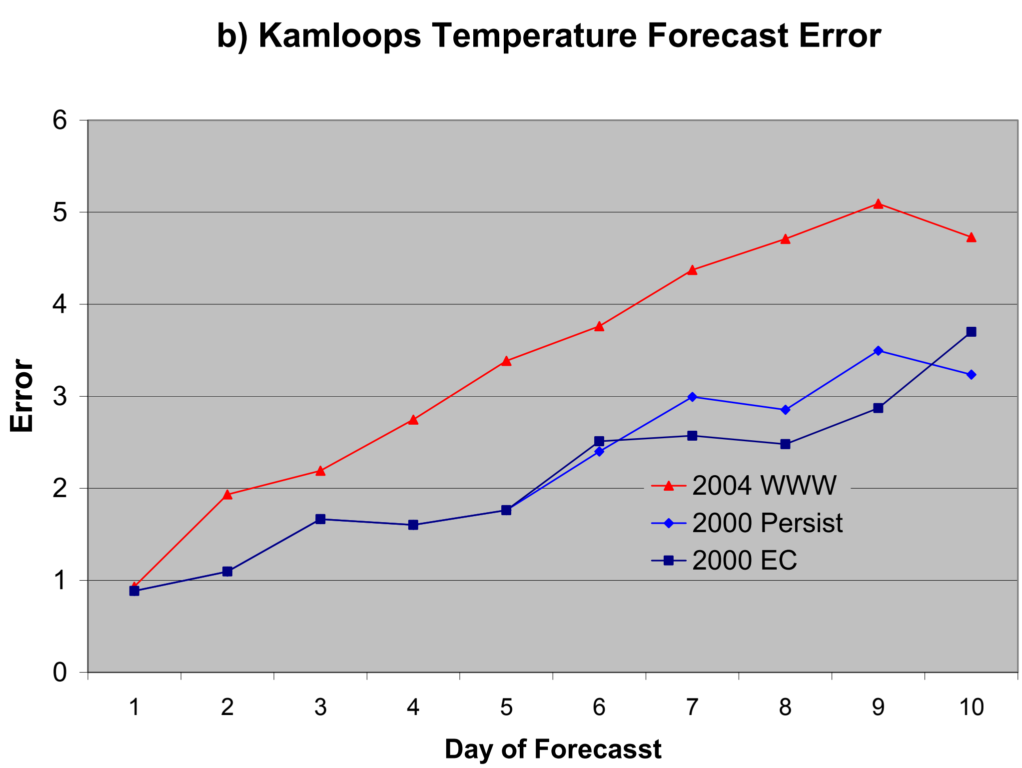
In previous years we used weather forecasts provided by the Environment Canada weather office at Kelowna. However this year due to staff cutbacks and the closure of that office, Environment Canada was unable to provide the same 10 day weather forecasts for Kamloops, Prince George and Blue River as it had in the past. Though a reduced product could have been purchased from EC, it was decided to contract World Weatherwatch (WWW) to provide our weather predictions for this year. Table 3 shows the margin of error for the forecasts for this year and two previous years. With the exception of air temperature at Kamloops and Prince George and solar radiation at Kamloops, the level of error and the range of error is the same for all years. For air temperature, the World Weatherwatch forecasts were not as accurate as the Environment Canada forecasts. On the other hand WWW did provide more accurate solar radiation forecasts.

Table 3 Forecast error comparisons, 2000 and 2001 Environment Canada, 2004 WWW.

		Kamloops				Prince George			
	Year	RMS Error	Mean Error	Minimum Error	Maximum Error	RMS Error	Mean Error	Minimum Error	Maximum Error
Temperature	2000	2.11	0.27	-6.90	7.25	1.98	-0.34	-5.30	4.40
°C	2001	2.57	0.07	-7.55	6.25	1.90	0.31	-4.50	9.40
	2004	3.56	-1.94	-11.35	4.10	2.61	-0.80	-11.00	6.40
Dew Point	2000	2.41	0.15	-6.00	6.00	2.57	-0.03	-8.00	6.00
Temperature	2001	2.75	0.51	-10.00	9.00	2.72	0.03	-7.00	9.00
°C	2004	2.41	-0.69	-7.10	6.00	2.65	-0.27	-7.10	9.20
Solar	2000	71.34	-2.44	-196.71	219.95	51.52	-0.69	-141.67	126.25
Radiation	2001	75.42	-0.88	-177.29	231.38	59.07	6.48	-151.77	163.73
W/m^2	2004	51.47	-5.86	-174.33	145.28	54.94	-7.76	-153.03	145.28
Cloud Cover	2000	27.05	-0.97	-70.00	73.76	28.14	-6.71	-80.00	60.00
Percent	2001	26.56	-4.61	-70.00	60.00	25.76	-5.52	-70.00	80.00
	2004	22.80	7.59	-40.00	80.00	25.56	8.47	-50.00	70.00
Wind Speed	2000	1.28	0.37	-3.33	2.78	1.21	0.41	-2.50	3.06
Km/hr	2001	1.56	0.50	-3.89	4.72	1.30	0.69	-2.22	4.44
	2004	1.21	-0.30	-4.86	2.64	1.06	0.07	-3.89	3.03

Forecasts were more accurate at the beginning of the forecast period with accuracy falling off as the day of forecast increased. Figures 5 a), b) and c) show the day of forecast error for temperature and radiation. The persistence line in these graphs shows the level of accuracy that can be achieved by simply extending the 5^{th} day of the forecast through the next 5 days. The fact that forecasts start with an error (approx 1°C for the temperature on day one) that then increases throughout the forecast imposes a limit on the accuracy that can be achieved by the river temperature model.


a) Prince George Temperature Forecast Error
Error
0
1
2
3
4
1
2
3
4
5
6
7
8
9
10
Day of Forecast
2004 WWW
2000 Persist
2000 EC


b) Kamloops Temperature Forecast Error
Error
0
1
2
3
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Day of Forecasst
2004 WWW
2000 Persist
2000 EC

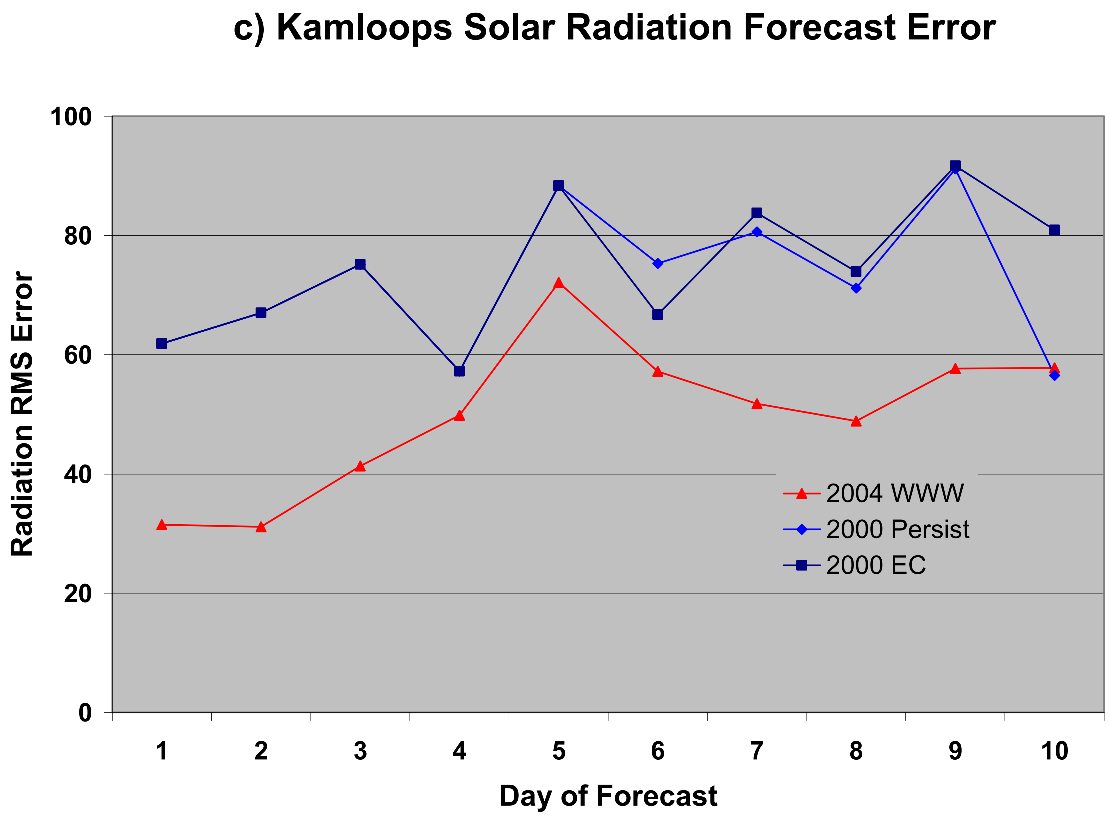

Figure 5. Average RMS Error comparisons

6. Instrumentation

Real time temperature data loggers are located at ten strategic locations throughout the watershed. For the most part they have proven to be highly reliable, however, we did experience some periods where data was unavailable from some loggers:

Chilcotin	18 days
Qualark	6 days
Shelley	34 days
Nechako	8 days

The impact of the loss at Chilcotin and Nechako was minor in that any resulting tributary forecast errors were applied to relatively small volumes of water and thus had a small contribution to the forecast error at Qualark. The outage at Shelley was more of a problem because of the larger volume of water involved and because of the duration of the outage. It was mitigated to some extent by use of manual temperature readings. The problem at Qualark was the most critical even though it was the shortest outage. Qualark temperatures are critical to the assimilation process that ensures that the forecast temperatures start at the latest observation. Fortunately it was possible to get manual observations at Qualark during the period when the logger was not functioning.

Flow data is required for twelve locations in the model. Though recorded data from fourteen locations are available on the web, these do not include all of the flows required by the model. Thus some of the required flows are derived from analysis and interpretation of available flows. Missing data is a further problem.

Outages this season were:

Shelley	22 days
Chase	27 days
Mclure	7 days
Spence's Bridge	11 days

Shelley was the most problematic station since it defines the Fraser headwater directly and the Stuart headwater indirectly through a water balance calculation. The loss of one of the Thompson stations is not critical as the relationship among the 3 Thompson stations is well understood. However for 6 days this season, all three Thompson River stations were unavailable and manual estimates had to be made for the whole Thompson system.

7. Recommendations

7.1 Forecast Process

As outlined in section 2 the process of producing a forecast is labour intensive. It is complex and susceptible operational errors that can take the form of graphic interpolation errors, transcription errors, parameter data entry errors, and run sequence errors.

The processing that consumes the most time and is most susceptible to operator error is associated with the flow model.

- The Phase Matched Hydrograph model has been run in parallel with the UBC watershed model for 3 years and has run with a smaller RMS error in each of those three years. *The UBC watershed model should be discontinued.*

- Manual interpolation and transcription of flow data is both time consuming and error prone. *A concerted effort should be made well before the forecast season to obtain access to machine readable real-time flow data.*

- The flow assimilation procedure was developed as an iterative process using the existing foreground flow system. The UBC flow program can only be invoked from the keyboard and requires several inputs at each iteration for each river. *A router program that can be run in the background should be obtained (a US Army Corps of Engineers router is available free on the web) or developed. A control process should then be designed to automatically assimilate the observed data for all of the rivers being modeled.*

The temperature assimilation procedure was also developed outside of the IOSRTM temperature model and it also requires manual intervention at each iteration. *IOSRTM should be updated to include assimilation within its code. Consideration should be given to converting from 'C' to Fortran in order to simplify future development and maintenance*

7.2 Weather

If the UBC watershed model is discontinued, the forecast for Blue River will no longer be required. Similarly winter precipitation and temperature data will not be required to run the UBC Watershed model over the previous winter. *Funds for these two items should be re-directed to a mid river weather station, such as Williams Lake or Lillooet.*

Weather forecasts are provided on a daily basis and the model runs with an hourly time step. Air temperature has a highly non linear affect on water temperature (2^{nd} and 4^{th} order) and this time step mismatch contributes to the overall model error by smoothing out the observed diurnal temperature cycle. Literature has been located that describes methods for interpolating hourly temperature data from daily data. *Code should be developed to implement these methods.*

7.3 Instrumentation

The Stuart River flow is derived from the difference between Shelley flow and South Fort George flow. *A pressure gauge should be added to the Stuart River temperature logger so that we can improve Stuart River flow estimates both in terms of value and reliability***.**

The Cariboo River flow is derived from the difference between Quesnel flow and Likely flow. *A pressure and temperature logger should be installed on the Cariboo River so that we can improve our Cariboo flow and temperature estimates both in terms of value and reliability.*

Security of the temperature loggers is always a problem. *Co-location with Environment Canada flow stations should be investigated. If this is feasible then pressure loggers should be placed at these locations to provide real-time machine readable flow data.*

7.4 Schedule

In 2004, the final decision to run the temperature model was not made until late June and this, in combination with the retirement of the employee who had previously run the predictions, made it difficult to spin the program up in timely manner. As can be seen in Figure 1 by the time the first forecast had been run the river temperature had already exceeded the critical 18°C threshold. *In order to ensure the timely delivery of accurate forecasts the following schedule should be adopted.*

- *May 2 Final decisions on all system operating parameters for 2005*
  - *Selection of which of the above recommendations to implement*
  - *Start implementation of IOSRTM system changes*

- *May 15 Selection of data providers*
    - *Weather*
    - *Flow*
- *June1 Instrumentation field work complete*
    - *IOSRTM system changes completed*
    - *Sample weather and flow data files received*
- *June7Full scale test run complete*
- *June 14 First Production Forecast*

8. Acknowledgments

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