Sensitivity Analyses and Modifications to the IOS River Temperature Model

J. M. Morrison and M. G. G. Foreman

Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, British Columbia
V8L 4B2

1998

Canadian Technical Report of Fisheries and Aquatic Sciences 2224

Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

Technical reports contain scientific and technical information that contributes to existing knowledge but which is not normally appropriate for primary literature. Technical reports are directed primarily toward a worldwide audience and have an international distribution. No restriction is placed on subject matter and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Technical reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1 - 456 in this series were issued as Technical reports of the Fisheries Research Board of Canada. Numbers 457 - 714 were issued as Department of the Environment, Fisheries and Marine Service Technical Reports. The current series name was changed with report number 925.

Technical reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport technique canadien des sciences halieutiques et aquatiques

Les rapports techniques contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui ne sont pas normalement appropriés pour la publication dans un journal scientifique. Les rapports techniques sont destinés essentiellement à un public international et ils sont distribués à cet échelon. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports techniques peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports techniques sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annual des publications scientifiques et techniques du Ministère.

Les numéros 1 à 456 de cette série ont été publiés à titre de rapports techniques de l'Office des recherches sur les pêcheries du Canada. Les numéros 457 à 714 sont parus à titre de rapports techniques de la Direction générale de la recherche et du développement, Service des pêches et de la mer, ministère de l'Environnement. Les numéros 715 à 924 ont été publiés à titre de rapports techniques du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 925.

Les rapports techniques sont produits à l'échelon regional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Technical Report of
Fisheries and Aquatic Sciences 2224

1998

SENSITIVITY ANALYSES AND MODIFICATIONS TO THE IOS RIVER TEMPERATURE MODEL

by

J. M. Morrison and M. G. G. Foreman

Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, British Columbia
V8L 4B2

For further information contact M. Foreman at mike@ios.bc.ca (email),
(250) 363-6306 (tel.), or (250) 363-6746 (fax)

Cat. No. Fs 97-6/2224E ISSN 0706-6457

Correct citation for this publication:

Morrison, J.M. and M.G.G. Foreman. 1998. Sensitivity analyses and modifications to the IOS river temperature model. Can. Tech. Rep. Fish. Aquat. Sci. 2224: 14 p.

ABSTRACT

Morrison, J. M., and M. G. G. Foreman. 1998. Sensitivity analyses and modifications to the IOS river temperature model. Can. Tech. Rep. Fish. Aquat. Sci.: 2224: 14p.

Water temperature forecasts in the Fraser and Thompson rivers are produced by the Institute of Ocean Sciences River Temperature Model (IOSRTM) on a bi-weekly basis throughout the salmon migration season. This model uses an Euler forward difference scheme to calculate water temperatures in segments of a river, taking into account atmospheric heat exchange and the contribution of its tributaries. Sensitivity analysis conducted on the model inputs revealed that the model was stable and, for the most part, responded linearly to its inputs. Changes in tributary temperature was found to be the input variable that caused the largest change in the temperature predictions.

Localizing the weather data and increasing the accuracy of the surface area measurements, together with minor changes to the atmospheric heat exchange formulation, resulted in a near 25% improvement in model predictions when compared to measured temperatures in 1995, 1996 and 1997. Recommendations for further improvement to the model include: i) increasing the accuracy of the tributary water temperature calculations, ii) increased localization of the weather data, and iii) a detailed analysis of the accuracy and reliability the 10 day forecasts produced by the model.

Keywords: temperature model, river, sensitivity analysis

RÉSUMÉ

Morrison, J. M., and M. G. G. Foreman. 1998. Sensitivity analyses and modifications to the IOS river temperature model. Can. Tech. Rep. Fish. Aquat. Sci.: 2224: 14p.

Des prévisions de température de l'eau pour les fleuves Fraser et Thompson sont produites par le modèle IOSRTM de l'Institut des Sciences de la Mer deux fois par semaine pendant la saison de migration des saumons. Ce modèle utilise un procédé Euler de differences vers l'avant pour calculer la tempérture de l'eau dans des sections d'un fleuve, tenant compte de la contribution de ses affluents. Une analyse d'instabilité des entrées du modèle révéla que le modèle est stable et réagit linéainement aux entrées. Nous constatâmes que la température des affluents était la variable d'entrée qui produisait le changement le plus considérable des prévisions de température.

La localisation des données météorologiques et l'amélioration de l'exactitude des mesures de surface, conjointement avec des modifications secondaires de l'expression de l'échange de chaleur atmosphérique ont produit une amélioration des prévisions du modèle de presque 25% par comparaison avec les températures mesurées en 1995, 1996, et 1997. Des recommandations pour une amilioration additionnelle du modèle includent: i) augmenter l'exactitude des calculs de la température de l'eau des affluents, ii) augmenter la quantité des données atmosphériques locales, et iii) une analyse détaillée de l'exactitude et de la fiabilité des prévisions de dix jours produites par le modèle.

Mots-clé: modéle de température, fleuve, analyse d'instabilité

INTRODUCTION

River water temperature plays a key role in the ability of migrating salmon to spawn in their natal streams(Gilhousen 1990). When the water is too cool, the metabolic rate of the salmon declines making it difficult to overcome the river currents. When the water is too warm the metabolic rate increases depleting critical energy reserves. Energy conservation is critical to returning salmon since they do not eat once they enter the river. They must reach their spawning grounds on whatever energy reserve they have when they start their upstream migration. In 1994, a large discrepancy between predicted and counted sockeye salmon prompted the formation of the Fraser River Sockeye Public Review Board. Among their conclusions was the recommendation to develop a predictive water temperature model for the Fraser River and it's major sockeye tributaries (Fraser River Sockeye Public Review Board 1995).

The Institute of Ocean Sciences River Temperature Model (IOSRTM) is such a model. It is run bi-weekly during the salmon migration season providing 10 day forecasts of river water temperatures along the Fraser River from Shelley (north of Prince George) to Hope, and along the Thompson from Chase to the confluence with the Fraser at Lytton. Plans for the 1998 season call for the expansion of IOSRTM to include the Stuart-Nechako, Quesnel, and Horsefly Rivers.

This paper describes sensitivity analyses of the IOSRTM model and changes that were made to the model in response to those sensitivities.

FLOW MODEL

The Fraser River watershed (see Fig. 1) encompasses one quarter of British Columbia, which is to say approximately 230,000 km^2 . It's intricate network of tributaries combine to form the largest Canadian River flowing into the Pacific Ocean. The river originates in the Rocky Mountains near Jasper Alberta and flows 1370 km to empty into the Strait of Georgia just south of the City of Vancouver. Discharges near Hope peak at about 7000 m^3/s (Thompson 1981) in May and June and drop to 1000 m^3/s during the winter.

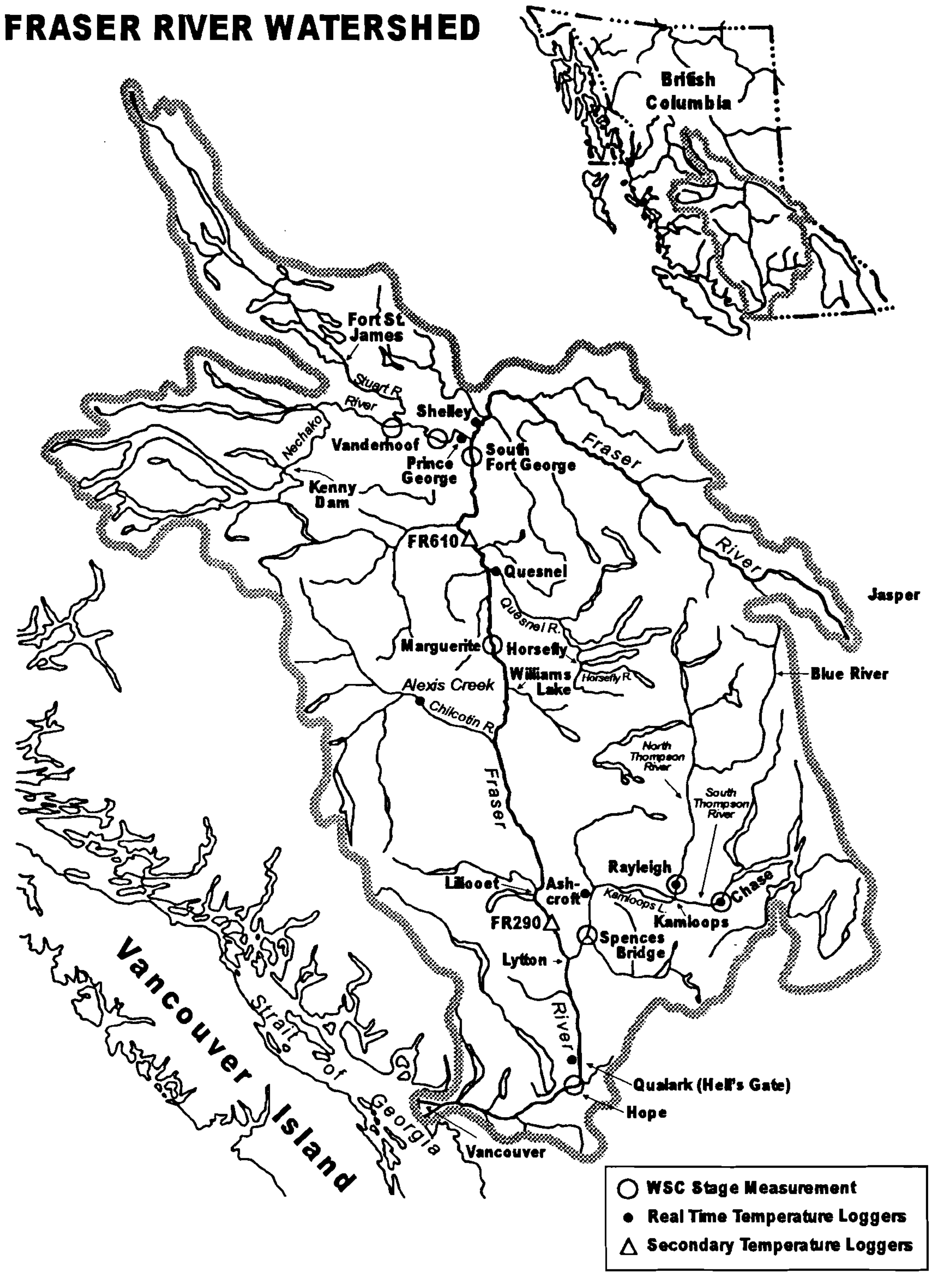

Fig. 1. Map of the Fraser River watershed

The one-dimensional flow model used to prepare volumetric flow and velocity data for the temperature model is described in Quick and Pipes (1975). Water Survey of Canada (WSC) stage discharge and stage velocity measurements are used to calculate routing coefficients and parameters for this model. This model overcomes the difficulties associated with a river system that has large ungauged lateral inflows and very limited flow data. Their technique meant that the flow model was pre-calibrated before the routing commenced regardless of the ungauged lateral input.

The Fraser model, between Shelley and Hope, consists of sixty seven 10 km segments called reaches. The Thompson has 19 10 km segments, 6 of which are above Kamloops Lake and 13 of which are below the lake. (The slow moving and deep lake water requires a different treatment than the fast moving, thoroughly mixed, river.) The 10 km reach length was selected to approximately match the travel time of the water within the reach. When the new tributaries are added for the 1998 season their reach lengths will be adjusted to match their velocities.

TEMPERATURE MODEL

ENERGY BALANCE

The temperature model for the rivers in the Fraser river basin uses the same division into reaches as the flow model. IOSRTM is based on the energy balance in these reaches. For a given reach, the energy balance is

$$\Delta E = E_{in} - E_{out} \tag{1}$$

Many simplifying assumptions are made. Kinetic and potential energy are ignored, as is viscous heating. There is no provision for heat transfer through the river bottom, nor is there allowance for heat transfer due to ground water infusion. The heat effect of the silt transported by the rivers is also ignored. Equation (1) thus becomes

$$\mathbf{E}_{\mathbf{final}} - \mathbf{E}_{\mathbf{initial}} = \mathbf{E}_{\mathbf{flowin}} + \mathbf{E}_{\mathbf{trib}} + \mathbf{E}_{\mathbf{atm}} - \mathbf{E}_{\mathbf{flowout}} \tag{2}$$

where

$$\begin{aligned}
\mathbf{E}_{\mathbf{final}} &= \rho c \mathbf{T}_{(n,t)} \mathbf{A}_{(n,t)} \mathbf{h}_{(n,t)} \\
\mathbf{E}_{\mathbf{initial}} &= \rho c \mathbf{T}_{(n,t-1)} \mathbf{A}_{(n,t-1)} \mathbf{h}_{(n,t-1)} \\
\mathbf{E}_{\mathbf{flowin}} &= \rho c \mathbf{T}_{(n-1,t)} \mathbf{Q}_{(n-1,t)} \Delta \mathbf{t} \\
\mathbf{E}_{\mathbf{trib}} &= \rho c \mathbf{T}_{\mathrm{trib}(n,t)} \mathbf{Q}_{\mathrm{trib}(n,t)} \Delta \mathbf{t} \\
\mathbf{E}_{\mathbf{atm}} &= \mathbf{Hn}_{t} \mathbf{A}_{(n,t)} \Delta \mathbf{t} \\
\mathbf{E}_{\mathbf{flowout}} &= \rho c \mathbf{T}_{(n,t)} \mathbf{Q}_{(n,t)} \Delta \mathbf{t}
\end{aligned}$$

and

$\mathbf{A}_{(n,t)}$ - Surface area for reach n at time t

$\mathbf{c}$ - Specific heat of water

$\mathbf{Hn}_t$ - Net heat flux

$\mathbf{h}_{(n,t)}$ - River depth for reach n at time t

ρ - Density of water

$\Delta \mathbf{t}$ - Time interval

$\mathbf{T}_{(n,t)}$ - Temperature of the water in reach n at time t

$\mathbf{T}_{trib(n,t)}$ - Temperature of the tributary entering reach n at time t

$\mathbf{Q}_{(n,t)}$ - Volumetric flow rate out of reach n at time t

$\mathbf{Q}_{trib(n,t)}$ - Volumetric flow rate of the tributary into reach n at time t

It should be noted that all of the time levels appearing in the terms on the right hand side of equation (2) are at t because we are using a Euler forward difference scheme to solve our model. Thus (2) becomes

$$\begin{aligned}\rho c T_{(n,t)} A_{(n,t)} h_{(n,t)} - \rho c T_{(n,t-1)} A_{(n,t-1)} h_{(n,t-1)} &= \\ \rho c T_{(n-1,t)} Q_{(n-1,t)} \Delta t + \rho c T_{trib(n,t)} Q_{trib(n,t)} \Delta t + Hn_t A_{(n,t)} \Delta t &- \rho c T_{(n,t)} Q_{(n,t)} \Delta t\end{aligned} \tag{3}$$

Re-arranging for T we get

$$T_{(n,t)} = \frac{T_{(n-1,t)} Q_{(n-1,t)} + T_{trib(n,t)} Q_{trib(n,t)} + Hn_t A_{(n,t)} / \rho c + T_{(n,t-1)} A_{(n,t-1)} h_{(n,t-1)} / \Delta t}{A_{(n,t)} h_{(n,t)} / \Delta t + Q_{(n,t)}} \tag{4}$$

ATMOSPHERIC HEAT EXCHANGE

Fig. 2 gives an indication of both the relative magnitude (at noon on a sunny day), and direction of the components, that make up the heat exchange between the atmosphere and the river water.

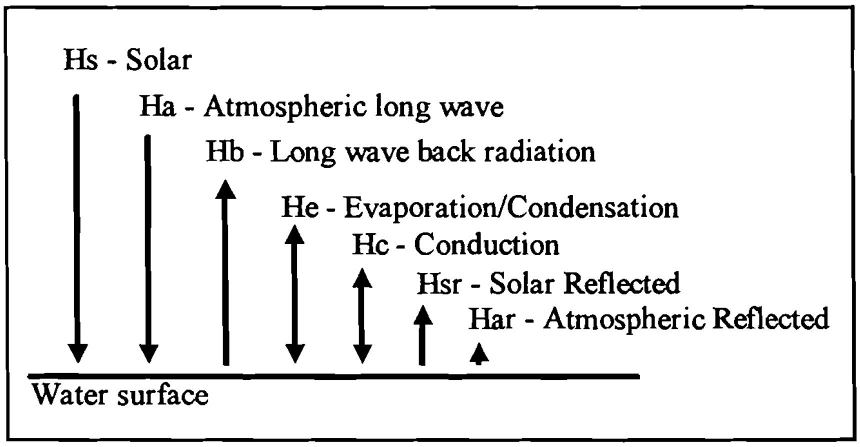

Fig. 2. Atmospheric heat exchange with river surface

The net heat flux is

$$\mathbf{Hn = (Hs - Hsr) + (Ha - Har) - Hb - He - Hc = Hsn + Han - Hb - He - Hc} \tag{5}$$

The formulations of the components of the heat flux were taken from Edinger et al. (1974) and Wunderlich (1972) and are as follows:

$$\mathbf{Hsn = 0.94Hs} \tag{6}$$

$$\mathbf{Han = (0.937 \times 10^{-5})\sigma(Ta + Tz)^6(1 + 0.17C^2)(1 - 0.03)} \tag{7}$$

$$\mathbf{Hb = (0.96)\sigma(Ts + Tz)^4} \tag{8}$$

$$\mathbf{He = f(W)(e_s - e_a)} \tag{9}$$

$$\mathbf{Hc = (0.47)f(W)(Ts - Ta)} \tag{10}$$

where

$$\mathbf{f(W) = 9.2 + 0.46W^2} \tag{11}$$

$$\mathbf{e_a = e^{2.3026[aT_d/(T_d+b)+c]}} \tag{12}$$

$$e_s = e^{2.3026[aTs/(Ts+b)+c]} \qquad (13)$$

and

Ta - Air Temperature (C)
Td - Dew Point Temperature (C)
Ts - Water Surface Temperature (C)
Tz - Temperature Conversion Constant C to K (273.15)
C - Cloud cover (fraction)
σ - Stefan-Boltzmann constant (5.67×10^{-8} $Wm^{-2}K^{-4}$)
W - Wind Speed (m/s)

with the constants for calculating the partial pressure of water in air
a - 7.5
b - 273.3
c - 0.6609.

SENSITIVITY ANALYSIS

Extensive testing of the model's validity and accuracy have been made (Foreman et al., 1997) and close agreement (typically < 1 ° C) between measured temperatures and model temperatures were found when historical flow, temperature and weather data were used to force the model. However, temperature equation (4) in the model and its subsidiary equations (5 through 11) do not readily reveal how the various input variables interact and contribute to the final calculated temperature. As a part of the effort to expand and improve the model, it was decided to analyze the sensitivity of the input variables. This would reveal where errors in input data would have the greatest impact on the models predictive capabilities. Identification of the sensitive variables would also suggest which elements of the model should be examined more closely in order to improve the model accuracy.

METHOD

Sensitivity to each input variable was measured by changing one variable at a time and then comparing the results against a control run. The data for the control run was taken from an arbitrarily chosen 15 day period starting Aug. 27, 1997, which was near the end of the 1997 forecast season. In order to test the linearity of the sensitivity, all variables were changed by multiplying their original values by 1.01, 1.05, 1.10 and 1.20.

Variable	Change Amount			
	1%	5%	10%	20%
Tributary Temperature	-0.094	-0.471	-0.943	-1.883
Tributary Flow	-0.094	-0.471	-0.943	-1.883
Mainstream Flow	0.099	0.478	0.917	1.696
Head Water Volume	-0.018	-0.087	-0.174	-0.345
Head Water Temperature	-0.018	-0.087	-0.174	-0.345
Air Temperature	-0.017	-0.084	-0.169	-0.339
Solar Radiation	-0.013	-0.065	-0.131	-0.262
River Width	-0.010	-0.052	-0.103	-0.213
Dew Point Temperature	-0.005	-0.025	-0.070	-0.104
Cloud Cover	-0.002	-0.012	-0.025	-0.051
Wind Speed	0.002	0.010	0.020	0.042
Initial Temperature*	0.000	0.000	0.000	0.000

Table 1. Sensitivity analysis results - mean of the difference between the original and the modified temperatures (mean of control minus test).

Comparisons between the control run, using the original data, and the test runs, using the modified data, were made at the lower end of the river (near Hell's Gate at reach 59) to ensure that changes in weather and tributary variables had time to influence the mainstream temperature.

INTERPRETATION

The greatest sensitivity was found to be due to the tributary temperatures, the tributary flow levels, and the headwater conditions (which are special cases of the first two variables). These values are observed or derived from other models. The sensitivity of the river temperature model to variations in these input values demonstrates the importance of flow model accuracy, and measured or predicted tributary temperatures, to the prediction of reliable river temperatures.

Of the remaining variables, the river temperature model is most sensitive to air temperature. This is not surprising in that **Ta** influences heat transfer due to atmospheric long wave radiation **Han** (7), and conduction **Hc** (10). Changes in solar radiation levels were found to cause significant changes in the river water temperature. Changes in water temperature due to changes in the river width were also significant. The model is seen to be less sensitive to changes in dew point temperature, cloud cover and wind speed. (It was subsequently found that the wind speeds in the selected test period were low and that the model was more sensitive to changes at higher wind velocities.) Interestingly, the initial temperature had absolutely no effect on the model after the third day, implying that the initial temperature field had been replaced by that time.

When the sensitivity results were examined for linearity it was found that, in spite of the various nonlinear factors[1] in equations 6-11, only the differences due to changes in the dew point temperature varied non-linearly with respect to the linear change in the inputs. The scale of the

---

[*] measured on days 4 through 15

[1] A 20% change from 20C to 24C is only a 1.7% change when temperature is converted from Celsius to Kelvin. This scale shift taken together with the other temperature terms accounts for the apparent linearity of the models response to its inputs.

change, associated with the dew point temperature variation, decreased, as shown by the size of the output change, with respect to the size of the input change. This pattern of change, linear for the majority of variables and decreasing scale for the non-linear case , meant that the model was stable. Furthermore, moderate changes in any of the input variables did not cause any overly large changes in the output temperatures.

DENSITY AND SPECIFIC HEAT

Density and Specific Heat are both elements of the model that do not lend themselves to the sensitivity testing using large (20%) changes in their values. Changes of this magnitude are not physically possible for the temperature range covered by this model, thus the sensitivity to density and specific heat was evaluated separately.

Two possible sources of error in the heat flux term containing density and specific heat were evaluated. The first possible problem could arise from the use of constant values of ρ and c in spite of the fact that changes in water temperature and elevation would cause changes in these variables. The other possible error is due the silt carried by the rivers. Although this material would be undergoing the same heat cycle as the water that carried it, its very different density and specific heat capacity could possibly affect the water temperature. However, applying the assumptions made by Burtsaert (1982) for soil moisture content to river water implied that ρ and c could be averaged for water and silt.

It was found that relatively large changes in ρc would not cause significant changes in the predicted river temperatures. This insensitivity to changes in the ρc term meant that we could continue to use the constant values of ρ and c. Furthermore, it meant that we need not be concerned about the quantity, density, or the specific heat, of the silt carried by the river.

MODEL CHANGES

ATMOSPHERIC LONG WAVE RADIATION

Examination of equation (7) suggests why air temperature is the most sensitive of the atmospheric variables. In this equation air temperature is raised to the power of 6. This exponent arises from a combination of the familiar T^4 component common to all radiation heat transfer formulations and a T^2 term used to calculate the emissivity of the water as determined by Swinbank and reported in Wunderlich (1972). Brutsaert (1982) compared the results of several empirical calculations of emissivity. It can be seen in Bursaert's graph (1982, fig 6.7 page 142) of calculated versus measured radiation that the formulation of Satterlund produced the most accurate results over the widest range of radiation levels. The Satterlund calculation, equation (15), is now incorporated in this model. It was also noted in Brutsaert (1982) that the cloud cover constant of 0.17 that is used in equation (7) applies to altocumulus clouds. It was felt, since we did not get cloud type in our weather data, that we should change to the average cloud constant of 0.22. This constant is included in the new **Han** formulation :

$$\mathbf{Han} = \varepsilon_a \sigma (\mathbf{Ta} + \mathbf{Tz})^4 (1+0.22C^2)(1-0.03) \qquad (14)$$

where

$$\varepsilon_a = 1.08(1 - e^{-pp^{(Td+273.15)/2016.0}}) \qquad (15)$$

and

$$pp = e_a/0.75006 \qquad (16)$$

WIND SPEED

While reviewing the model formulation, it was noted that the wind speed function (11) taken from Edinger et al. (1974) was only one of 2 non-linear formulations, and that both of these formulations had only been tested at low wind speeds of 2.2 and 6.9 m/s. Our wind speeds have been observed to reach the 12 m/s level. With winds so much higher than those tested by the formulators of the equation selected for our model, it was felt that it would be better to switch to a formulation that had been tested over the range of wind speeds that we encountered. The new wind speed function, also from Edinger et al. (1974), is

$$f(W) = 8.1 + 3.9W \qquad (17)$$

FORECAST COVERAGE

El-Kourdahi (1993) emphasizes the importance of good weather forecast data in predicting river temperatures. Indeed Foreman et al. (1997) compared the results of using different weather data on this model but this test was limited to selecting which of two forecast areas to use for the model. In order to improve the results, the model was modified so that weather input became reach dependent. In the northern part of the model, forecasts were taken from the Prince George while the southern areas are still governed by Kamloops forecasts.

RIVER WIDTH

As all of the energy transfer between the atmosphere and the river takes place through the water surface, the accuracy of the water surface area is important to accurate model temperature predictions. Since the model uses fixed length reaches, the width of the river at each reach controls the model's heat transfer between the atmosphere and the water. The model calculated the width of the river based on volumetric flow and WSC empirical formulas (Foreman et al., 1997) derived for their measuring stations. There are few WSC measuring stations, thus the same calculated widths had to be applied to long stretches of the river. Casual examination of topographical maps of the Fraser River revealed that there was considerable variation in the width of the river throughout its length. The width derived from the flows showed little variation with large changes in the flow rate. It was felt that more model accuracy could be gained by obtaining more realistic river widths even if they no longer changed with respect to flow rate.

New river widths were obtained by calculating reach areas from province of British Columbia Terrain Resource Information Maps (TRIM) which have an accuracy of ± 10 m. Comparison of the model widths with the digitized river widths showed that for the Fraser River the model had been under calculating the area by approximately 30%. Further, it could be seen that the model widths in the upper reaches were generally too narrow while the widths at the lower end were too wide. Consequently there should have been more atmosphere/river heat exchange in the upper river and less at the lower end.

INITIAL TEMPERATURE

During the salmon migration season, the standard operating procedure is to run the model for 15 days. The first 5 days use real measured data for the inputs, while the last 10 days use forecast data. The output for the last 10 days of the model run is the river water temperature forecast. Since the initial temperature conditions have no effect after 3 days, the initial temperature file was replaced by an initialization calculation that is a weighted average based on the tributary temperatures and flows.

EVALUATION OF THE MODEL CHANGES

To test the validity of the changes, the model was run with measured data as inputs. Actual water temperatures and river flows as well as the recorded weather data were used as input to the model.

An attempt was made to assess each model change individually in a manner similar to the sensitivity analysis. A single model change was made and the results were then compared to the control run. In most cases, the changes produced less accurate results than the original model in some parts of the river. It was noted, however, that some changes tended to increase the predicted temperatures, while other changes decreased the predictions. Only when all of the changes were tested together was consistent improvement observed.

To avoid the possibility of choosing non-representative data (as was the case for the wind speed during the sensitivity analysis) the new model was validated by over the whole 1995, 1996 and 1997 forecast seasons. The change in the river widths and the change to reach dependent weather forecasts meant that changes would manifest themselves differently along the river. Therefore comparisons were made at different locations along the length of the Fraser River. The results of the validation tests can be seen in Table 2 and the site locations are shown in Fig. 1. Table 2 shows the Root Mean Square (RMS) of the differences of the between the model temperatures and the actual temperatures.

From discussions with Atmosphere Environment Services it could not be determined, from climatic data, where it was most appropriate to switch from the Prince George to the Kamloops weather data. Evaluation of the model using a variety of transition points was undertaken. Table 2 shows the test results of eight different weather data transition points. The numbers in the Prince George Weather utilization column show the range of the reach numbers where the Prince George weather was used.

Unfortunately, from the point of view of multi-year evaluations, the methods and exact locations of data observations changed from year to year due to operational constraints. For example, the Prince George Weather data used in this evaluation is derived from daily measurements in 1995 and 1997, and from hourly measurements in 1996. These changes in the available input data mean that year to year differences in model runs cannot be effectively evaluated. Year to year differences are indicative of the models response to different conditions. However, it is not possible to determine if the differences are due to real changes, that the model is handling poorly, or simply due to the differences in the way that the data is collected and applied to the model.

	Reaches using	RMS (degrees C)					
Test	Prince George Weather	FR610 (reach 18)	FR550 (reach 24)	FR290 (reach 50)	FR200 (reach 59)	by Test	by Weather Utilization
1995 Old	0	0.34	0.47	0.70	0.53	0.53	0.50
1995 New	0	0.60	0.53	0.54	0.31	0.51	0.64
New	1 - 12	0.24	0.31	0.46	0.30	0.34	0.41
New	1 - 14	0.20	0.27	0.45	0.31	0.32	0.38
New	1 - 16	0.21	0.25	0.45	0.31	0.32	0.37
New	1 - 18	0.26	0.25	0.45	0.33	0.33	0.38
New	1 - 20	0.26	0.27	0.45	0.34	0.34	0.38
New	1 - 22	0.26	0.30	0.46	0.35	0.35	0.40
New	1 - 31	0.25	0.39	0.64	0.51	0.47	0.50
1996 Old	0	0.36	0.35	0.46		0.39	
1996 New	0	1.03	0.88	0.86		0.93	
New	1 - 12	0.48	0.49	0.59		0.52	
New	1 - 14	0.37	0.40	0.54		0.44	
New	1 - 16	0.28	0.34	0.50		0.38	
New	1 - 18	0.23	0.29	0.47		0.35	
New	1 - 20	0.23	0.23	0.41		0.30	
New	1 - 22	0.23	0.29	0.47		0.35	
New	1 - 31	0.23	0.24	0.43		0.31	
1997 Old	0	0.41	0.64	0.62		0.57	
1997 New	0	0.41	0.45	0.37		0.41	
New	1 - 12	0.26	0.35	0.42		0.35	
New	1 - 14	0.35	0.36	0.44		0.39	
New	1 - 16	0.44	0.37	0.46		0.43	
New	1 - 18	0.53	0.40	0.48		0.47	
New	1 - 20	0.53	0.43	0.51		0.49	
New	1 - 22	0.53	0.46	0.53		0.51	
New	1 - 31	0.53	0.76	0.71		0.67	

Reach	Location
1	Shelley
3	Prince George
20	Quesnel
24	Marguerite
31	Williams Lake
50	Lillooet
59	Hell's Gate

Table 2. Improved model test results.

It can be seen the from the RMS "by Test" column of Table 2, which is the RMS of values calculated at each location, that the new model constantly produced better results in 1995 even when the Prince George weather was used as far south as William's Lake. The best results, a 40% reduction in the RMS, for 1995 occurred when the Prince George data was used down to reaches 14 and 16.

In 1996 the improvements were not as dramatic. With Prince George weather data used down to the Quesnel area reductions in the RMS were seen to be about 25%.

Widespread improvement was also observed in 1997. The smallest RMS was found to occur when the use of Prince George data was limited to the area north of reach 13. When used at reach 12 the improvement in the RMS was about 40%

The combined results of the three years tested is shown in the RMS "by Weather Utilization" column of Table 2. It can be seen the that improvement in the RMS values is very constant when the Prince George data is anywhere between reach 12 and 22, with an expected improvement of 18-26%.

CONCLUSIONS

SENSITIVITY

The input variables for the river temperature model can be classed into 3 types;

- flow (volume and temperature)
- atmosphere
- physical properties

The model is most sensitive to the flow properties that are tributary temperature, tributary volumetric flow rate, and mainstream volumetric flow rate. Relatively small errors, say 10%, in any of these values can result in significant changes of almost 1C in the modeled temperatures. It is important to note however that, in the real world, mainstream flow is not independent of tributary flow. A discrepancy in the size of a tributary flow will result in an error of the same size in the mainstream flow down river from the confluence with the tributary. The temperature change observed when these variables were changed independently has the opposite sign indicating that the affect of a real tributary flow error would be mitigated by the corresponding change in the mainstream flow. This linkage between mainstream and tributary flow means that tributary temperature stands alone as the most sensitive input variable in the river temperature model.

It is not reasonable to expect that all tributaries would have the same error at the same time, as was the assumption with the sensitivity test. However, in as much as the headwater data enter the model in the same way that a tributary does, it can be seen, from the model sensitivity to the headwaters, that errors in calculating the any of the input water temperatures could result in significant model temperature prediction errors.

To a lesser degree, the model was affected by changes in the weather components. The old model had a built in systematic weather error in that it only used Kamloops weather data for the whole river system. Reaches that are distant from Kamloops experience different weather than that observed in the immediate vicinity of Kamloops. Obtaining data for additional locations (as was done with Prince George) and applying it to the nearby reaches will improve the performance of the model by minimizing the systematic weather bias built into the model.

The sensitivity to physical properties was mixed, with density and specific heat having a minimal effect on model performance. River width and it's affect on water surface area, on the other hand, played a significant role. It was important to discover a 30% discrepancy between the calculated water surface area and the measured area.

MODEL CHANGES

The changes that were made to the model; the heat flux equations, the river width, and the reach specific weather input, resulted in improved model performance in 20 of 24 tests. The RMS, which is a measure of the variability of the model from the observed river temperature, was, on average, reduced from 0.49 to 0.37 °C representing a 25% improvement in the models accuracy.

RECOMMENDATIONS

The accuracy and reliability of the method used to determine the temperature of the water, both headwater and tributary, that enters the model should be evaluated and improved if possible. Input water temperature was identified as the most sensitive variable in affecting the model's predictions. Thus to ensure the accuracy of the model, it is essential that the temperature of the water entering the model is as accurate as possible. All of the other sensitive inputs were evaluated and improvements have been made, where feasible.

The model changes that were described here should be implemented, en mass, for the 1998 forecast season. For the 1998 season, the Prince George weather data should be used for reaches 1- 18. When the actual data for 1998 becomes available, selection of the dividing line between Prince George and Kamloops data can be re-evaluated. The use of this new model should result in a modest improvement in the accuracy of the temperature predictions for 1998.

Additional weather data should be obtained if feasible. Weather data for William's Lake, Lillooet, and Hope would likely improve the performance of the model.

An analysis of the reliability of the 10 day forecasts should be undertaken. This would lead to more sophisticated reporting of the model results. It would be desirable to develop a methodology for establishing a confidence intervals that could be reported to the fishery biologists. This would provide a measure of accuracy and reliability of the IOSRTM predictions.

REFERENCES

Brutsaert W. 1982. *Evaporation into the Atmosphere*, D. Reidel Publishing Company, Dordrecht, Holland. 299 pp.

Edinger J. E., D. K. Brady, and J. C. Geyer. 1974. Heat Exchange and Transport in the Environment, Electric Power Research Institute, Palo Alto, CA, 124 pp.

El-Kourdahi G. 1993 *Modèlisations Dèterministe et Stochastique de la Tempèrature de l'Eau en Riviere*, Université de Moncton, Moncton, NB. 142pp.

Foreman M. G. G., C. B. James, M. C. Quick, P. Hollemans, and E. Wiebe, !997. Flow and Temperature Models for the Fraser and Thompson Rivers, ATMOSPHERE-OCEAN 35 (1), 109-134

Fraser River Sockeye Public Review Board, 1995. *Fraser River Sockeye 1994: Problems & Discrepancies.* Public Works and Government Services Canada, Canada Communications Group - Publishing, Ottawa. 131 pp.

Gilhousen P. 1990. Prespawning Mortalities of Sockeye Salmon in the Fraser River System and possible Causal Factors. Bulletin XXVI, International Pacific Salmon Fisheries Commission. Vancouver, BC. 53 pp.

Thompson R. 1981. Oceanography of the British Columbia Coast, Canadian Special Publication of Fisheries and Aquatic Sciences 56, Department of Fisheries and Oceans, Ottawa. 291 pp.

Quick M. C. and A. Pipes. 1975. Nonlinear Channel Routing by Computer, J. Hydraul. Div. ASCE, Vol. 101 HY6:651-664

Wunderlich W. 1972. Heat and Mass Transfer Between a Water Surface and the Atmosphere, Water Resources Research Laboratory Report No. 14 (report No. 0-6803), Tennessee Valley Authority, Norris TN. 164 pp