Water temperature dynamics downstream of reservoirs

Research Report #1347

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TABLE OF CONTENT

TABLE OF CONTENT ..... **I**

LISTE OF TABLES ..... **III**

LIST OF FIGURES ..... **IV**

1.0 INTRODUCTION **1**

2.0 METHODS **2**

2.1 STUDY SITES AND TEMPERATURE MONITORING 2
2.2 THERMAL INDICES 4

3.0 RESULTS **5**

3.1 THERMAL INDICES ON HYDRONET RIVERS 5
3.2 MONITORING OF WINTER TEMPERATURE ON THE FOURCHUE RIVER. 11

4.0 CONCLUSION AND FUTURE WORK **12**

5.0 REFERENCES **13**

6.0 APPENDIX: THERMAL INDICES **14**

LISTE OF TABLES

TABLE 1. LIST OF RIVERS AND THEIR LOCATIONS. 2
TABLE 2. DEFINITION OF THERMAL INDICES. 4

LIST OF FIGURES

FIGURE 1. LOCATION OF THE RECOVERED THERMOGRAPHS DEPLOYED DURING THE 2011-2012 WINTER IN THE FOURCHUE RIVER. 4
FIGURE 2. BOX PLOTS OF A SUBSAMPLE OF THERMAL INDICES OF THE BATCHAWNA AND MAGPIE RIVERS..... 7
FIGURE 3. BOX PLOTS OF A SUBSAMPLE OF THERMAL INDICES OF THE AUBINADONG AND MISSASIGI RIVERS. 8
FIGURE 4. BOX PLOTS OF A SUBSAMPLE OF THERMAL INDICES OF TWILICK BROOK AND WEST SALMON RIVER. 9
FIGURE 5. BOX PLOTS OF A SUBSAMPLE OF THERMAL INDICES OF PETIT-SAGUENAY AND ST-JEAN RIVERS.. 10
FIGURE 6. TIME SERIES OF WATER TEMPERATURE IN THE FOURCHUE RIVER DURING THE WINTER PERIOD. .. 11

1.0 INTRODUCTION

Fisheries and Oceans' Center of Expertise on the Effects of Hydropower on Fish and Fish Habitat (CHIF) is conducting research in partnership with the HYDRONET NSERC (Natural Science and Engineering Research Council) network. As part of this partnership, researchers from the Gulf Region (D. Caissie) and INRS-ETE (A. St-Hilaire, A. Daigle, A. Maheu and L. Beaupré) are involved in investigating the potential impact of dams on the thermal regime of rivers. A large part of this research deals with water temperature modelling and is being conducted as a sub component of HYDRONET project dealing with the thermal regime of rivers. In addition, the present project, which is funded by CHIF, deals with the characterization of the thermal regime on impounded and natural rivers.

The specific objectives of this project are complementary to those of HYDRONET subcomponent 6.3.2 (Effects of dams on the thermal regime of rivers). These objectives include: 1) to monitor both regulated and unregulated (control) HYDRONET sites for comparison purposes and assess the degree of thermal modifications, with an emphasis on winter thermal conditions and summer extremes, 2) to study the spatial variability of thermal conditions immediately downstream of reservoirs and to define thermal indices that characterize this variability. Additional specific objectives identified in the proposal have not been addressed in the present study, but will be components of the theses of the two graduate students involved in the project (L. Beaupré and A. Maheu).

2.0 METHODS

2.1 Study sites and temperature monitoring

Within the research framework of HYDRONET, study sites include paired rivers (one impounded, one natural) located in the provinces of Newfoundland and Labrador, Québec, Ontario, Manitoba, Alberta and British Columbia. Water temperature monitoring was initiated in 2011 in a subset of those rivers in Ontario, Québec and Newfoundland (Table 1). In some cases, the initial selection of HYDRONET pairs was respected. However, other rivers were also added due to close proximity and field logistics. The Fourchue River was monitored both upstream and downstream of its dam. The upstream reach of the Fourchue was selected in addition to its original paired river (Du Loup), because the Du Loup River is located mostly in the agricultural portion of the watershed, whereas the reach of the Fourchue river located downstream of the dam is mostly draining a forested region. The Etchemin River, a regulated river, was monitored, but no nearby natural river was monitored. To compensate, the Ste-Marguerite River was added to the list. Water temperature was recorded in a total of 13 rivers. A Microsoft Access database was constructed and is made available to all CHIF and HYDRONET researchers.

Table 1. List of Rivers and their locations.

	River	Dam	Province	Latitude	Longitude
1a	Etchemin	Yes	Qc	46,649	-71,069
1b	Ste-Marguerite	No	Qc	48,268	-69,899
2a	Du Loup	No	Qc	47,604	-69,654
2b	Fourchue Upstream	No	Qc	47,599	-69,529
2c	Fourchue Downstream	Yes	Qc	47,677	-69,520
4a	StJean	Yes	Qc	48,208	-70,230
4b	Petite Saguenay	No	Qc	48,201	-70,059
5a	Aubinadong	No	Ont	46,954	-83,421
5b	Mississagi	Yes	Ont	46,896	-83,283
6a	Batchawana	No	Ont	46,998	-84,523

	River	Dam	Province	Latitude	Longitude
6b	Magpie	Yes	Ont	48,035	-84,827
7a	West Salmon	Yes	NFL	48,171	-56,228
7b	Twilick Brook	No	NFL	48,117	-55,577

Thermographs were deployed during the ice-free period on all rivers listed in Table 1. Given the large spatial dispersion of the selected sites, the deployment was conducted in collaboration with local HYDRONET research partners. This explains in part the variability of the onset of the monitoring period across the country. On all rivers except the Fourchue and Du Loup, water temperature was recorded using Onset Hobo Pendant temperature logger (precision of 0.5 °C). On the three aforementioned river reaches, Hobo Pro V2 (precision of 0.2 °C) were used. Ten thermographs were deployed on each river, except for the Fourchue River, where 20 loggers were deployed per reach.

In addition to water temperature monitoring during the ice-free season, an attempt was made to monitor the thermal regime of the Fourchue River during the winter of 2011-2012. Six thermographs were deployed (three upstream and three downstream of the dam) on 21 November 2011. Of the six deployed, four (two upstream and two downstream of the dam) were recovered on 16 March 2012 (Figure 1).

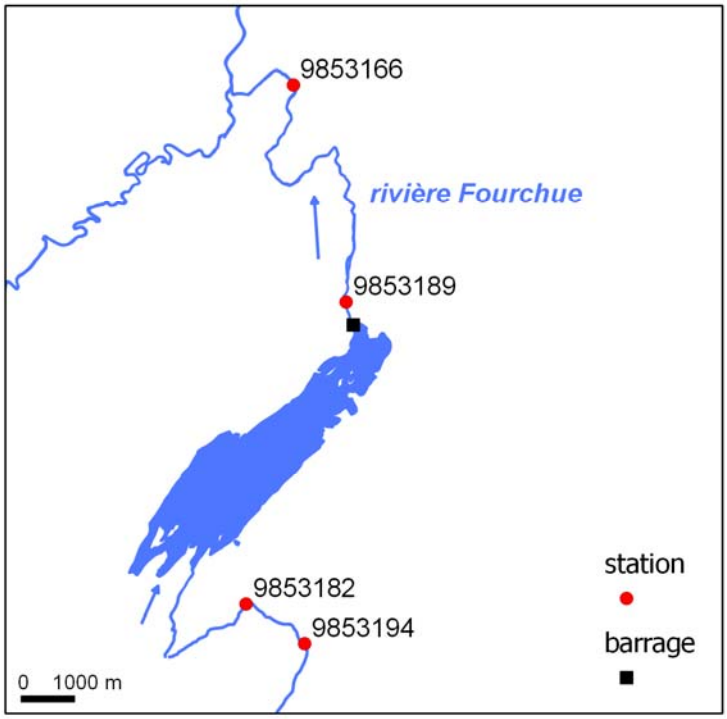

Figure 1. Location of the recovered thermographs deployed during the 2011-2012 winter in the Fourchue River.

2.2 Thermal Indices

The comparison of the thermal regimes of different rivers can be partly achieved by calculating thermal indices from the recorded time series. Thermal indices are descriptive statistics of the magnitude (e.g. monthly minimum, mean or maximum), timing (e.g. date of occurrence of the monthly maximum) or variability (e.g. standard deviation) of the water temperature time series. The indices that were calculated on the recorded time series are listed in Table 2.

Table 2. Definition of thermal indices.

Mean	Monthly mean (°C) for the stated month (7=July, 8=August, 9=September). Means are only calculated on complete monthly time series
Max	Maximum water temperature for the stated period (e.g. max 07-09 means the maximum value recorded between July and September).

Julian day of max	Date of occurrence of the maximum temperature
SD	Standard deviation of monthly temperature (°C).
Max_Dailyrange	Maximum observed daily temperature range for the stated period (°C).
Julian day of max range	Date of occurrence of the Maximum observed daily temperature range.
Degreedays	Sum of daily mean temperature of the stated period (°C-days).

3.0 RESULTS

3.1 Thermal indices on HYDRONET Rivers

Figures 2-5 show boxplots of some of the thermal indices for four pairs of HYDRONET rivers. Tables of indices are in Appendix. Each boxplot represents the empirical distribution of the thermal index, calculated individually for all thermographs deployed in the river. The red line is the median, the limits of the rectangle represent the 25th and 75th percentiles, while the whiskers represent the 10th and 90th percentiles. Outliers are shown as asterisks. On each plot, the natural river is represented by the left-hand side box, and the impounded river by the right-hand side box.

All river pairs show contrasts in the median values of most magnitude indices. Three of the four pairs show higher median mean monthly temperatures for natural rivers than regulated rivers. Monthly means (July, August and September) show median differences varying 0.6 °C and 3.14 °C (difference in medians of monthly means of July between the Magpie and Batchwana rivers). The Abinadong River, which is unregulated, had lower monthly means than its regulated counterpart, the Mississagi River, for the months of August and September.

Thermal variability was quantified at each station by calculating monthly standard deviations. Unsurprisingly, unregulated (natural) rivers had median standard deviations larger than regulated rivers. The difference in median standard deviation between natural rivers and their impounded counterpart varied between 0.14°C (St-Jean vs. Petit Saguenay in August) to 1.5 °C (Abinadong vs. Mississagi in August).

The date of occurrence of the maximum temperature did not show a systematic difference between regulated and unregulated rivers. Both the Magpie and Mississagi rivers, which are regulated, reached their maximum temperature at a later date than their unregulated counterpart. However, the occurrence of maximum temperature was only separated by one day in the case of Twilick Brook and West Salmon Rivers and maximum occurred on the same day for the St-Jean and Petit Saguenay rivers.

The date of occurrence of maximum daily range showed high variability and no consistent differences between regulated and natural rivers.

Degree-days were summed up for the monitoring period on each river to approximate heat accumulation over the summer. Again, results showed a marked difference between pairs of rivers, with three pairs showing higher degree-days in the impounded river than in the unregulated river and two pairs showing lower degree-days for the regulated system than for the unregulated river.

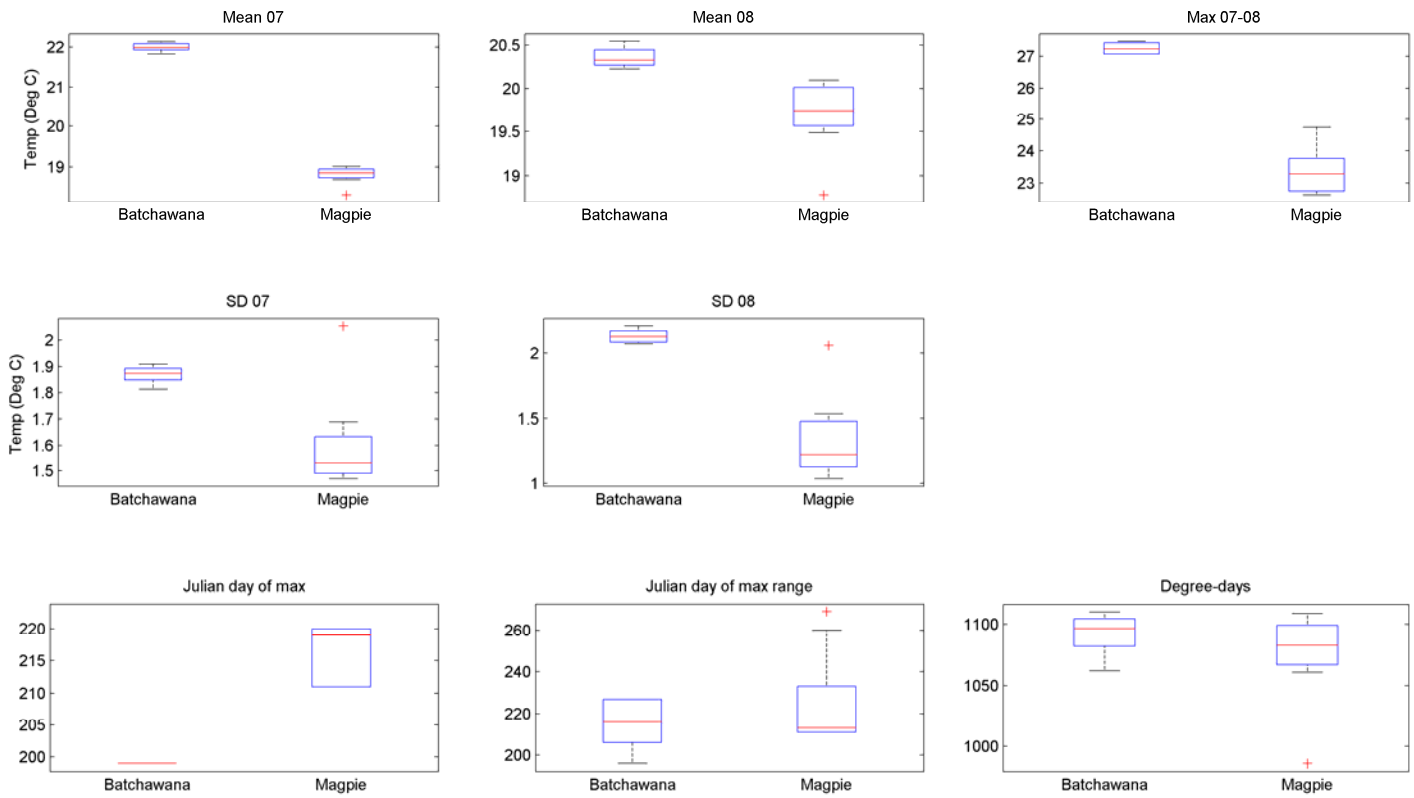

Figure 2. Box plots of a subsample of thermal indices of the Batchawna (natural) and Magpie (regulated) rivers.

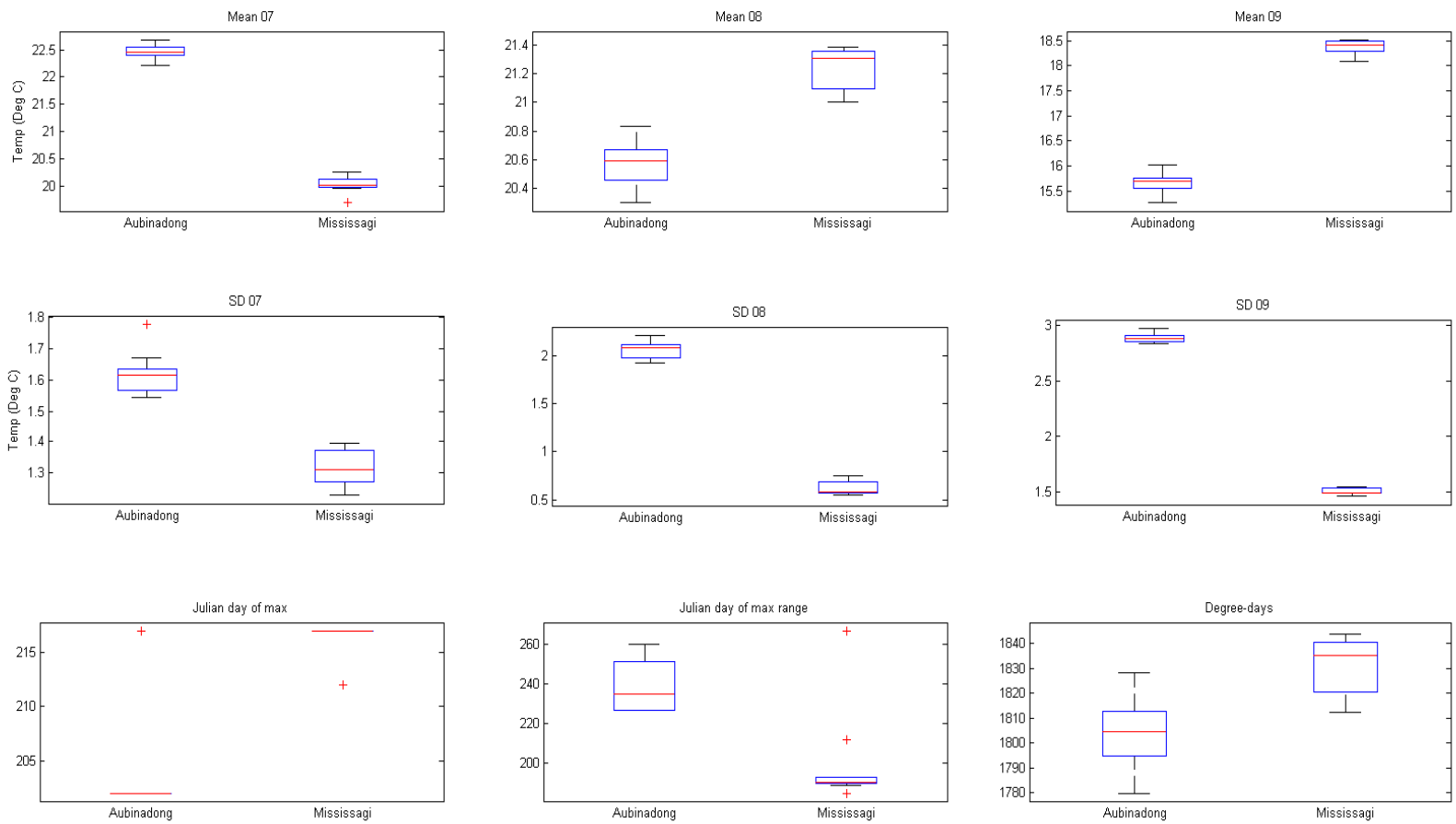

Figure 3. Box plots of a subsample of thermal indices of the Aubinadong (natural) and Missasigi (regulated) rivers.

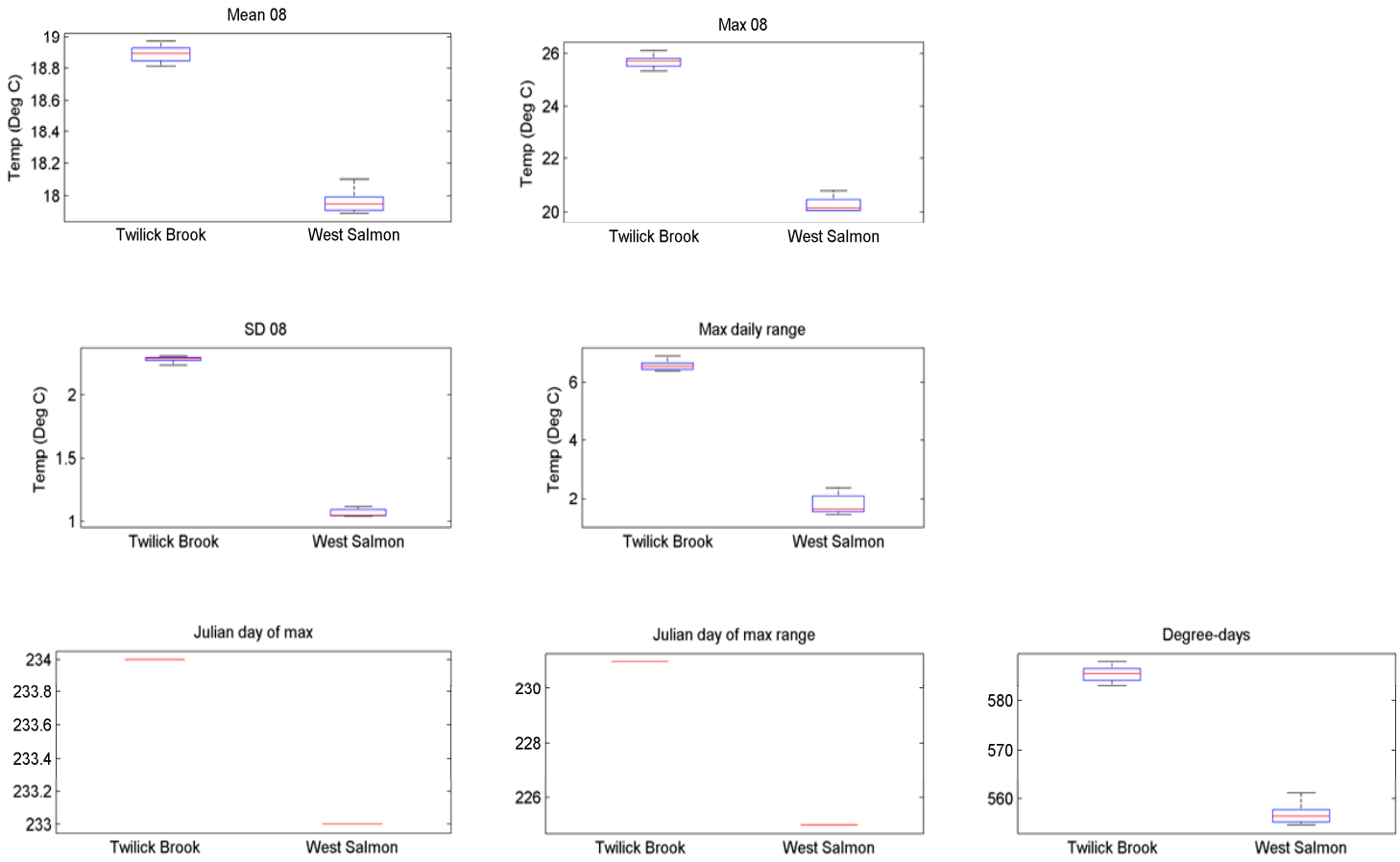

Figure 4. Box plots of a subsample of thermal indices of Twilick Brook (natural) and West Salmon River (regulated).

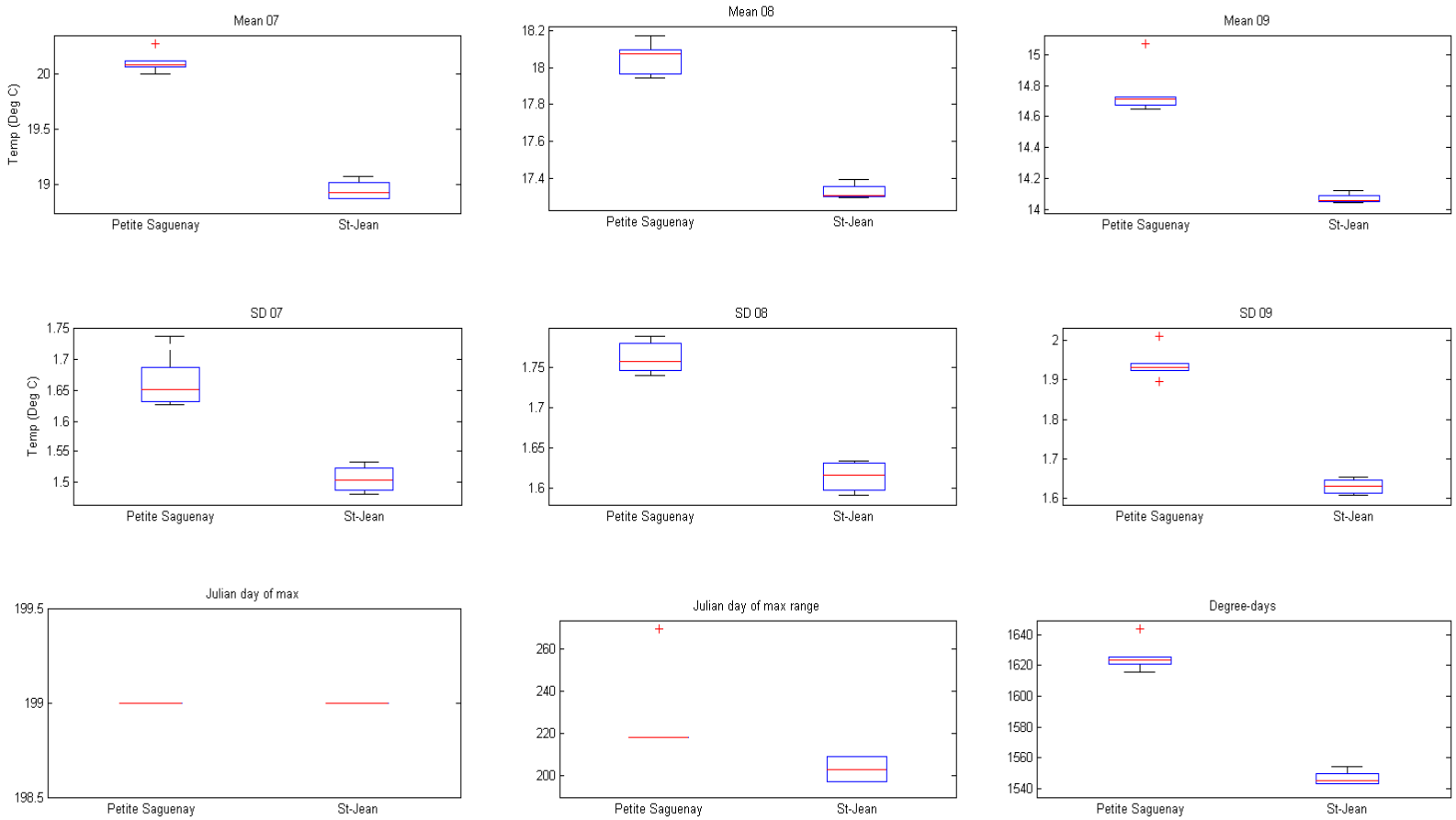

Figure 5. Box plots of a subsample of thermal indices of Petit-Saguenay (natural) and St-Jean (regulated) rivers.

3.2 Monitoring of winter temperature on the Fourchue River.

Figure 6 shows the time series of water temperature measured at four sites on the Fourchue River (two below the dam and two upstream of the reservoir, see Figure 1). As expected, the two thermographs that were deployed downstream of the dam show more variability than the thermographs located in the unregulated reach of the river, upstream of the reservoir during winter. Thermograph 9853189, located 100 m downstream of the dam, recorded positive temperatures throughout the winter, with an average of 1.7 °C and a maximum of 3.8 °C in 2011 and 2.4 °C in 2012. Thermograph 9853166, located approximately five km downstream of the dam and 10 m below a breached weir showed high variability, with temperatures ranging from 0°C to 4.1 °C. In the unregulated reach, temperatures varied for the first few weeks, but stabilize to near-zero values in mid-January and showed little variability for the rest of the sampling period.

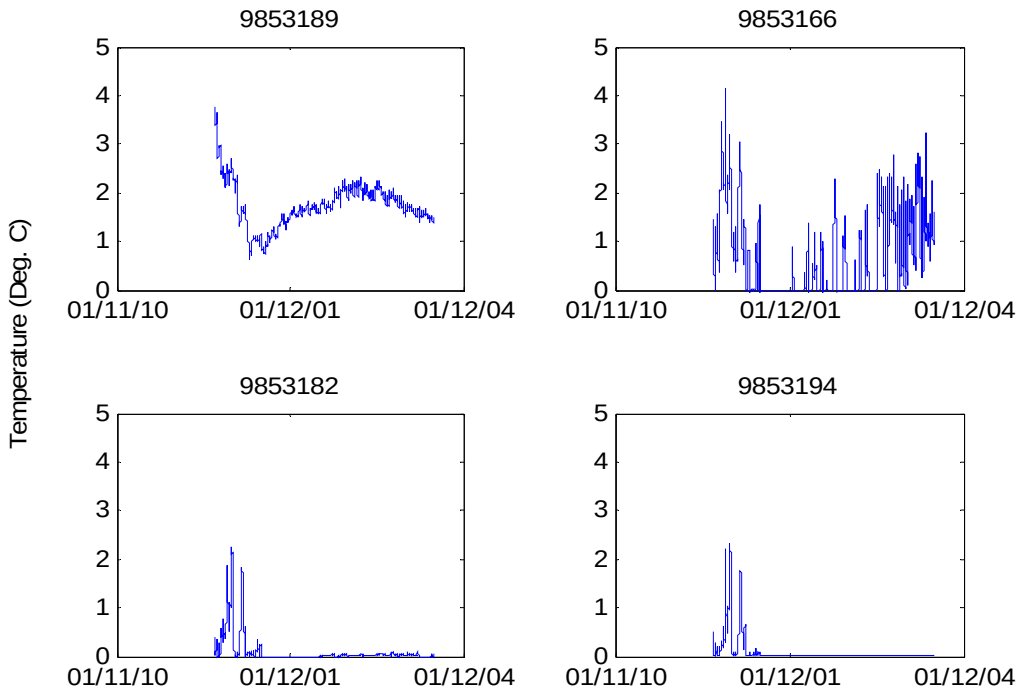

Figure 6. Time series of water temperature in the Fourchue River during the winter period. Downstream = 9853189 and 9853166. Upstream = 9853182 and 9853194.

4.0 CONCLUSION AND FUTURE WORK

This report highlights the recent and ongoing activities of our CHIF project.

In summary:

- Water temperature monitoring was initiated in 2011 and will continue in the forthcoming years. The number of rivers to be monitored will be increased during the summer of 2012.
- A water temperature database was created and is available in a Microsoft Access format. This database will be expanded in 2012-2013.
- Thermal indices were calculated for a limited number of pairs of rivers to characterize the thermal regime. These indices clearly show that the approach will allow contrasting the water temperature magnitude, variability and timing of events on regulated and natural rivers.
- Our first attempt at monitoring water temperature during the winter was successful. The winter time series clearly show striking differences in the thermal regime of the regulated vs. unregulated reaches of the Fourchue River.

It is anticipated that an additional four rivers will be monitored during the ice-free season of 2012. Thermal indices during the spring will be calculated on the Fourchue River to complete summertime indices. In addition to the Fourchue River, water temperature on a second pair of rivers will be monitored during the winter of 2012-2011. Thermal indices will be calculated on all time series. Prior to making a final selection on a limited number of indices to be used to compare impounded and natural rivers, the initial list of indices will be expanded to include a characterization of event frequency and duration (e.g. number of consecutive days above biologically relevant thresholds). The choice of indices will be completed using a combination of multivariate approaches (e.g. Daigle et al., 2011) and enthropy measures (Yoo et al., 2011)

5.0 REFERENCES

DAIGLE, A., A. ST-HILAIRE, D. BEVERIDGE, D. CAISSIE, L. BENYAHYA. 2011. Multivariate analysis of low flow regimes in eastern Canadian rivers. *Hydrological Sciences Journal* 56(1):51-67.

YOO, CHULSANG; KU HYEJIN, K. KEEWOOK. 2011. Use of a Distance Measure for the Comparison of Unit Hydrographs: Application to the Stream Gauge Network Optimization. *Journal of Hydrologic Engineering*, 198.73.162.9: 880-890.

6.0 APPENDIX: THERMAL INDICES

Batchawana-Magpie

River	FlowRegime	SerialNum	Mean 07	Mean 08	Mean 09	Max07-08	Date_max07-08	SD07	SD08	SD09	Max_range07-08	Date_max_rangen07-08	Degr-days07-08
Batchawana	NR	2368437	21.82	20.22	--	27.08	2011-07-18 17:30	1.89	2.18	--	5.72	2011-08-15	1061.40
Batchawana	NR	2368441	22.11	20.48	15.71	27.47	2011-07-18 19:00	1.88	2.09	2.65	5.48	2011-08-04	1105.65
Batchawana	NR	2368444	21.98	20.33	15.60	27.08	2011-07-18 18:30	1.87	2.07	2.67	5.54	2011-07-15	1097.77
Batchawana	NR	2368447	22.10	20.50	15.73	27.47	2011-07-18 18:15	1.90	2.13	2.73	5.67	2011-08-04	1106.82
Batchawana	NR	2368450	21.95	20.30	15.55	27.27	2011-07-18 18:30	1.87	2.10	2.64	5.47	2911-08-04	1095.24
Batchawana	NR	2368464	21.92	20.24	nan	27.17	2011-07-18 18:00	1.83	2.17	nan	5.91	2011-08-15	1079.71
Batchawana	NR	2368466	22.06	20.42	15.68	27.17	2011-07-18 18:30	1.87	2.08	2.66	5.55	2011-07-15	1102.68
Batchawana	NR	9742670	21.97	20.31	15.57	27.08	2011-07-18 18:30	1.87	2.08	2.66	5.45	2011-07-15	1100.42
Batchawana	NR	9742675	22.13	20.54	15.79	27.47	2011-07-18 18:00	1.91	2.12	2.71	5.58	2011-08-04	1109.83
Batchawana	NR	9742682	21.98	20.30	nan	27.27	2011-07-18 18:00	1.83	2.16	nan	5.91	2011-08-15	1083.66
Batchawana	NR	9742683	22.07	20.42	nan	27.37	2011-07-18 17:00	1.89	2.20	nan	6.10	2011-08-15	1091.12
Batchawana	NR	9742708	21.91	20.23	nan	27.08	2011-07-18 17:30	1.81	2.15	nan	5.82	2011-08-15	1080.15
Magpie	R	2368430	18.95	20.09	nan	22.81	2011-08-08 17:30	1.47	1.05	nan	3.81	2011-08-01	1105.50
Magpie	R	2368433	18.76	19.74	nan	22.72	2011-08-08 17:30	1.47	1.13	nan	4.09	2011-08-01	1082.35
Magpie	R	2368434	18.85	19.49	nan	23.68	2011-07-30 17:15	1.63	1.48	nan	5.92	2011-07-30	1060.34
Magpie	R	2368436	18.30	18.78	nan	23.77	2011-08-07 20:00	2.05	2.06	nan	8.40	2011-08-28	986.08
Magpie	R	2368440	19.01	19.64	nan	24.74	2011-07-30 15:30	1.69	1.54	nan	6.88	2011-07-30	1068.42
Magpie	R	2368442	18.92	20.07	nan	24.26	2011-08-08 18:00	1.54	1.22	nan	5.81	2011-09-26	1108.70
Magpie	R	2368449	18.73	19.86	nan	22.91	2011-08-07 17:45	1.48	1.12	nan	4.47	2011-08-01	1092.11
Magpie	R	9742677	18.68	19.65	nan	22.72	2011-08-08 17:30	1.52	1.15	nan	6.50	2911-09-17	1072.26
Magpie	R	9742678	18.72	19.75	nan	22.62	2011-08-08 17:30	1.49	1.11	nan	4.00	2011-08-01	1084.51
Magpie	R	9742680	18.83	20.10	nan	22.62	2011-08-07 18:15	1.49	1.04	nan	3.71	2011-08-01	1108.34

Magpie	R	9742688	18.89	19.55	nan	23.68	2011-07-30 17:30	1.64	1.49	nan	5.92	2011-07-30	1066.02
Magpie	R	9742696	19.00	19.99	nan	23.29	2011-08-08 18:00	1.53	1.28	nan	4.68	2011-09-17	1090.85
Magpie	R	9742701	18.85	19.49	nan	23.68	2011-07-30 17:30	1.62	1.48	nan	5.92	2011-07-30	1060.71
Magpie	R	9742706	18.94	20.02	nan	22.91	2011-08-08 17:15	1.52	1.18	nan	4.00	2011-08-01	1101.24
Magpie	R	9742711	18.71	19.63	nan	24.45	2011-07-30 16:00	1.64	1.29	nan	6.31	2011-07-30	1078.62

Note : R = Regulated, NR = Unregulated.

Aubinadong-Nississagi

River	FlowRegime	SerialNum	Mean07	Mean08	Mean09	Max07-09	Date_max07-09	SD07	SD08	SD09	Max_range07-09	Date_max_range07-09	Degays07-09
Aubinadong	NR	2368453	22.35	20.41	15.51	26.88	2011-07-21	1.64	2.11	2.85	5.713	2011-08-23	1790.63
Aubinadong	NR	2368427	22.41	20.49	15.54	27.37	2011-08-05	1.67	2.21	2.86	6.496	2011-08-15	1795.84
Aubinadong	NR	2368448	22.39	20.56	15.66	26.39	2011-07-21	1.56	1.97	2.92	5.714	2011-09-09	1801.02
Aubinadong	NR	2368462	22.42	20.46	15.26	26.68	2011-07-21	1.61	2.13	2.88	8.584	2011-09-17	1786.84
Aubinadong	NR	2368465	22.40	20.42	15.55	27.08	2011-07-21	1.66	2.11	2.90	6.108	2011-08-15	1793.52
Aubinadong	NR	2368473	22.21	20.30	15.42	26.68	2011-07-21	1.63	2.07	2.86	5.723	2011-08-15	1779.79
Aubinadong	NR	2405508	22.50	20.62	15.72	26.59	2011-08-05	1.58	2.09	2.88	5.81	2011-08-23	1808.03
Aubinadong	NR	2405513	22.46	20.64	15.73	26.59	2011-07-21	1.56	1.94	2.89	5.522	2011-09-09	1807.71
Aubinadong	NR	9742671	22.44	20.45	15.56	26.98	2011-07-21	1.62	2.11	2.84	5.713	2011-08-23	1796.10
Aubinadong	NR	9742672	22.48	20.68	15.78	26.39	2011-07-21	1.55	1.94	2.89	5.525	2011-09-08	1810.85
Aubinadong	NR	9742674	22.55	20.67	15.76	26.49	2011-07-21	1.57	2.06	2.88	5.618	2011-08-23	1812.17
Aubinadong	NR	9742676	22.64	20.83	16.03	26.98	2011-07-21	1.61	1.99	2.98	6.192	2011-09-08	1828.17
Aubinadong	NR	9742681	22.41	20.49	15.59	26.78	2011-07-21	1.61	2.05	2.86	5.629	2011-08-15	1797.47
Aubinadong	NR	9742685	--	20.69	15.79	--	--	--	1.94	2.88	--	--	--
Aubinadong	NR	9742686	22.60	20.81	15.89	26.59	2011-07-21	1.55	1.92	2.88	5.522	2011-09-09	1822.31
Aubinadong	NR	9742692	22.55	20.69	15.76	26.88	2011-08-05	1.62	2.12	2.92	6.192	2011-08-23	1813.00
Aubinadong	NR	9742699	22.69	20.67	15.84	28.06	2011-07-21	1.78	2.16	2.97	6.398	2011-08-15	1818.93
Mississagi	R	2368432	--	--	--	--	--	--	--	--	--	--	--
Mississagi	R	2368445	19.96	21.00	18.08	23.00	2011-08-05	1.27	0.75	1.55	3.521	2011-07-04	1812.34
Mississagi	R	2368446	19.69	21.07	18.33	22.53	2011-08-0	1.39	0.54	1.46	2.951	2011-07-10	1813.36
Mississagi	R	2368451	20.02	21.34	18.49	22.81	2011-08-05	1.37	0.57	1.49	2.854	2011-07-09	1836.76
Mississagi	R	2368460	--	20.69	15.79	--	--	--	1.94	2.88	--	--	--
Mississagi	R	2368474	--	--	--	--	--	--	--	--	--	--	--

Mississagi	R	2358476	--	--	--	--	--	--	--	--	--		--	--
Mississagi	R	9742668	19.97	21.25	18.39	22.91	2011-08-05	1.36	0.59	1.49	2.854		2011-07-09	1829.20
Mississagi	R	9742673	20.26	21.33	18.30	24.93	2011-07-31	1.27	0.69	1.55	3.84		2011-07-31	1838.00
Mississagi	R	9742679	20.09	21.36	18.52	23.39	2011-08-05	1.30	0.56	1.49	3.72		2011-07-10	1840.77
Mississagi	R	9742687	20.25	21.39	18.45	23.68	2011-08-05	1.23	0.60	1.52	3.998		2011-09-24	1844.05
Mississagi	R	9742693	19.97	21.29	18.49	23.10	2011-08-05	1.37	0.57	1.47	2.854		2011-07-09	1833.70
Mississagi	R	9742703	--	--	--	--	--	--	--	--	--		--	--
Mississagi	R	9742704	20.12	21.36	18.52	23.58	2011-08-05	1.32	0.57	1.49	4.576		2011-07-08	1841.39
Mississagi	R	9742705	--	--	--	--	--	--	--	--	--		--	--
Mississagi	R	9742707	--	--	--	--	--	--	--	--	--		--	--
Mississagi	R	9742710	20.02	21.10	18.20	23.29	2011-08-05	1.26	0.71	1.53	3.336		2011-07-12	1820.46

Twilick-West Salmon

River	FlowRegime	SerialNum	Mean08	Max08	Date_max08	SD08	Max_range08	Date_max_range08	Degdays08
Twilick Brook	NR	9916681	18,97	26,097	2011-08-22	2,296	6,868	2011-08-19	588,1318
Twilick Brook	NR	9916682	18,86	25,513	2011-08-22	2,258	6,387	2011-08-19	584,7828
Twilick Brook	NR	9916694	18,83	25,513	2011-08-22	2,265	6,482	2011-08-19	583,7251
Twilick Brook	NR	9916695	18,94	25,805	2011-08-22	2,282	6,675	2011-08-19	587,2512
Twilick Brook	NR	9916708	18,88	25,708	2011-08-22	2,276	6,483	2011-08-19	585,3491
Twilick Brook	NR	9916709	18,81	25,319	2011-08-22	2,230	6,386	2011-08-19	583,2269
Twilick Brook	NR	9916710	18,91	25,708	2011-08-22	2,278	6,579	2011-08-19	586,2434
Twilick Brook	NR	9916720	18,91	25,805	2011-08-22	2,288	6,579	2011-08-19	586,0638
West Salmon	R	9916668	17,89	20,043	2011-08-21	1,039	1,523	2011-08-13	554,6787
West Salmon	R	9916669	17,95	20,043	2011-08-21	1,039	1,427	2011-08-13	556,3941
West Salmon	R	9916683	17,90	20,043	2011-08-21	1,041	1,523	2011-08-13	555,0099
West Salmon	R	9916684	18,00	20,329	2011-08-21	1,060	1,809	2011-08-13	557,8826
West Salmon	R	9916697	18,10	20,805	2011-08-21	1,111	2,379	2011-08-13	561,1935
West Salmon	R	9916707	17,93	20,138	2011-08-21	1,045	1,618	2011-08-13	555,8992
West Salmon	R	9916719	17,98	20,519	2011-08-21	1,098	2,189	2011-08-13	557,4866

Petit-Saguenay-St-Jean

River	FlowRegime	SerialNum	Mean07	Mean08	Mean09	Max07-09	Date_max	SD07	SD08	SD09	Max_range07-09	Date_max_range07-09	Deg-days07-09
Petite Saguenay	NR	2368456	20.11	17.97	14.67	24.35	2011-07-18	1.74	1.79	1.94	4.292	2011-08-06	1620.58
Petite Saguenay	NR	2368637	20.06	18.07	14.70	24.16	2011-07-18	1.64	1.76	1.93	3.913	2011-08-06	1623.01
Petite Saguenay	NR	9742691	19.99	17.95	14.65	24.06	2011-07-18	1.66	1.75	1.93	4.101	2011-08-06	1615.48
Petite Saguenay	NR	9916677	20.07	18.08	14.72	24.06	2011-07-18	1.63	1.74	1.90	3.912	2011-08-06	1624.38
Petite Saguenay	NR	9916689	20.27	18.17	15.07	24.55	2011-07-18	1.69	1.78	2.01	4.576	2011-09-27	1643.97
Petite Saguenay	NR	9916690	15.61	15.80	--	--	--	1.33	0.94	--	--	--	--
Petite Saguenay	NR	9916705	20.09	18.09	14.73	24.16	2011-07-18	1.63	1.75	1.92	4.008	2011-08-06	1625.5206
St-Jean	R	9742694	18.98	17.72	--	--	--	1.52	1.26	--	--	--	--
St-Jean	R	9916675	18.87	17.30	14.06	22.91	2011-07-18	1.48	1.59	1.64	4.006	2011-07-16	1543.04
St-Jean	R	9916678	18.89	17.30	14.06	23.10	2011-07-18	1.50	1.60	1.65	4.197	2011-07-16	1543.57
St-Jean	R	9916702	18.96	17.31	14.04	22.53	2011-07-18	1.53	1.63	1.62	3.713	2011-07-28	1545.96
St-Jean	R	9916704	19.07	17.39	14.12	22.62	2011-07-18	1.51	1.63	1.61	3.617	2011-07-28	1553.98