A STUDY OF VARYING LOGGING PRACTICES ON STREAM TEMPERATURE IN THE BLUE RIVER DRAINAGE, WESTERN OREGON CASCADES

by

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TABLE OF CONTENTS

ABSTRACT

Three (3) streams with desired similar characteristics, located in the Blue River Watershed in the Central Oregon Cascades, were studied to better understand the impacts of forest harvest on stream temperature and aquatic habitat. Of the 3 designated streams, North Fork Quartz Creek, Blue River Face, and Wolf Mann, only the North Fork Quartz Creek Timber Sale has gone through. North Fork Quartz Creek was studied for 2 consecutive summers, pre and post-harvest, while the Blue River Face and Wolf Mann streams were studied for 2 consecutive pre-harvest summers. The North Fork Quartz Creek received 3 different logging prescriptions designated as *control*, *buffered*, and *unbuffered*. Pre and post-harvest data was analyzed to capture any impact to stream temperature resulting from the varying logging practices. The data did not produce any extremely obvious results, but it does appear that the post-harvest *buffered* stream temperature rose by approximately 0.5 to 1°C. The Blue River Face and Wolf Mann stream data analysis will serve as a good baseline for future studies.

I. INTRODUCTION

The intent of this research project is to enhance the understanding of the effect of air temperature, solar radiation (insolation), and human induced influences, as well as other important contributing factors on stream temperature. Dave Kretzing of the Blue River Ranger District in the Willamette National Forest, Oregon, has provided stream temperature data. Data sets were provided for the summer of 1999 and 2000 for 3 timber sale areas within the Blue River watershed. The Blue River watershed, encompassing approximately 57,000 acres, resides in the Central Oregon Cascades adjacent to the HJ Andrews Experimental Forest and is part of the Central Cascades Adaptive Management Area, an allocation of the Northwest Forest Plan. The area was designated to promote forest research in an attempt to heighten understanding of forest management practices, ecosystem management, and natural forest systems.

The logging practices proposed in the 3 timber sale areas was specifically designed for study of subsequent impacts on stream temperature and aquatic habitat. In each of the 3 timber sale areas, certain sections of the 3 streams with desired similar characteristics were designated as "*control*", "*buffered*", and "*unbuffered*". These logging prescription designations and the unnatural or human induced impact of each will be explained further in the design concept section, methods section, and subsequent data analysis. Knowledge gained from such studies is of great interest to many in the business of protecting and utilizing forest resources to elevate the understanding of impacts due to past, present, and future logging practices on stream temperature and aquatic habitat.

II. FACTORS INFLUENCING STREAM TEMPERATURE

Several factors influence the variations in stream temperature with air temperature and direct solar radiation (or insolation) producing the greatest influence. This study is mainly concerned with the affect of climate on stream temperature, but the data analysis may aid in understanding other key characteristics that affect the temperature of these streams. Previous studies have documented the effects of natural and human induced factors on stream temperature dynamics (Johnson and Jones 2000; Beschta et al. 1987), but there is still much to be learned. This is why studies continue, like current projects under way in the Central Cascades Adaptive Management Area, to disprove myths, test hypotheses, evaluate and understand natural ecosystems, confirm new practices, and better understand how to minimize the impact on our surroundings while enabling critical resource extraction. A heightened understanding of the impacts that significant shifts in stream temperature place on the natural function of aquatic ecosystems has lead to efforts in promoting environmental preservation and restoration. Important measures have already been implemented to improve water quality under the Northwest Forest Plan.

A. General Stream Temperature Influences

Stream temperature is considered one of the key indicators of stream health and is primarily influenced by variation in season, air temperature, insolation, adjacent land use practices, hill-slope aspect, vegetation shading, snow pack, substrate composition (groundwater characteristics), channel geomorphology, and basin morphometry. Field studies of Geomorphology and Landscape Ecology in the HJ Andrews Experimental Forest and thorough review of relevant papers such as: Johnson and Jones 2000; Sinokrot and Stephan 1993; Beschta et al. 1987; Brown 1969; Zwieniecki and Newton 1999; and Smith and Lavis 1975, have provided the foundation for understanding important influences that affect the data used in this study.

1. *Energy Flux*

Heat exchange between the stream and surrounding environment occurs as a result of short and long-wave radiation, convection, conduction, advection, and evaporation (Beschta et al. 1987; Brown 1994). The energy balance equation requires that the net heat exchange per unit stream surface area (N_h) equals the net radiation (N_r ~ primarily direct incoming solar short-wave radiation) plus the convection of sensible heat (H ~ energy that heats the air) plus the conduction to the ground surface (G ~ energy from the terrestrial system) or $\{N_h = N_r + H + G\}$.

Direct solar radiation is the dominant source of energy that contributes to stream temperature dynamics (Johnson and Jones 2000). Stream shading from riparian vegetation, the angle of solar incidence, and weather factors like cloud cover all contribute to the availability of solar radiation for stream heating (Sinokrot and Stephan 1993). As the energy flux equation indicates, the response of stream temperature variation to solar radiation is correlated with the total exposed stream surface area and stream discharge. In other words, stream flow rate, surface area exposed, and amount of vegetation shading can have a huge impact on the temperature dynamics of a stream.

Stream temperatures in heavily forested riparian areas generally reach maximum temperatures later in the summer when daily maximum air temperatures have started to cool (Johnson and Jones 2000). Many studies have demonstrated that forest harvesting in riparian areas produce increased stream temperatures earlier in the summer season and overall (Johnson and Jones 2000; Beschta et al. 1987; Brown 1969).

2. *Stream Channel Geomorphology*

Channel geomorphology affects how streams respond to heating and cooling through contact between stream water and substrate materials. The depth and width of channels, as well as channel braiding can significantly affect stream temperatures. Greater stream surface area exposed to solar radiation, due to an increase in channel width to depth ratio, can lead to increased water temperature.

3. *Slope Azimuth and Elevation*

Slope azimuth directly affects how much solar radiation, direct sunlight, and the general warmth the stream area will absorb. Equatorial facing slopes receive more solar radiation for longer periods, which tends to directly increase the energy absorbed. Elevation generally dictates the sensible heat flux or air temperature that contributes to stream cooling or warming. An increase in elevation will normally reduce the sensible heat flux.

B. Forest Harvest

Land use practices have been shown to affect stream temperature. As mentioned previously, adjacent land use practices, climate, and stream flow rate can directly affect stream temperature. Removing forest vegetation and riparian cover has been shown to increase stream temperatures by as much as seven times that of pre-harvest temperatures. This is primarily due to the increase in direct solar radiation on the stream channel (Beschta and Taylor 1988). As riparian vegetation recovers from harvest, stream temperatures will generally decrease (Johnson and Jones 2000). In an unshaded stream, the annual maximum temperature typically peaks in late June when insolation is the greatest. In comparison, shaded streams tend to reach maximum stream temperature in late summer (Johnson and Jones 2000).

C. Other Key Factors Influencing Stream Temperatures

- Hydrological sensitive areas
- Geology and glacial history
- Cumulative spatial and temporal effects
- Warm inputs from industry, human induced
- Debris slides, soil compaction, and soil exposure
- Snow pack and snow melt

III. DESIGN CONCEPT

A. Logging Prescriptions Defined

The primary focus of this study is to understand the impact of specific logging prescriptions on three (3) similar streams. Data was gathered from early July to mid October for the summer of 1999 and 2000. The two (2) consecutive summers of stream temperature data have been analyzed, graphed, and summarized. Information gathered from this study will certainly heighten the understanding of influences affecting these particular streams and streams in the nearby vicinity, with hopes of adding to the overall understanding of unnatural impacts on stream temperature in general.

Of the 3 timber sale areas—North Fork Quartz Creek (NFQC), Blue River Face (BRF), and Wolf Mann (WM), only the NFQC Timber Sale has currently been logged, receiving the planned treatment. Therefore, the NFQC stream temperature data will be analyzed before and after the planned logging implementation. The BRF and WM stream temperature data will be studied for the same period to provide a valuable baseline or pretreatment understanding of the natural characteristics of this area. Then, if and when the sale does go through and the areas are logged, a post treatment study will have an excellent baseline study with which to compare results. Please note that the Wolf Mann stream has recently been renamed Trapper. The stream designation Wolf Mann will continue to be used since all graphs have been generated with the Wolf Mann designation.

1. *North Fork Quartz Creek (NFQC) Timber Sale Logging Prescription*

As discussed previously, NFQC was the only stream of the 3 streams selected that was subjected to the planned logging prescription. Therefore, the NFQC Timber Sale is the main focus of this study and more attention has been given to the specifics of this location and data gathered. Three (3) differing logging prescriptions were implemented from January 2000 to March 2000 in 3 small watersheds within the NFQC watershed. Stream temperatures were gathered for summer 1999 and summer 2000 (i.e. the summer before and after logging implementation). The logging prescriptions were designated as *control*, *buffered*, and no-buffer or *unbuffered.*

- *Control* — stream of similar size and characteristics as other sites where no harvest has occurred
- *Buffered* — 15 to 20 meter no-harvest zone or buffer around the entire length of stream within the harvest unit
- *Unbuffered* — the no-harvest zone or buffer does not apply, however no streambank trees were cut and an increased canopy retention near the stream exists

The *control* and *unbuffered* streams are small, first order, spring dominated streams. The *buffered* stream is a small, second order, spring-dominated stream. All 3 streams are on very steep slopes and drain directly into North Fork Quartz Creek.

2. *Blue River Face (BRF) Timber Sale Logging Prescription*

As mentioned above, the BRF Timber Sale has not gone through, but the planned implementation is the same as that for NFQC.

3. *Wolf Mann (WM) Timber Sale Logging Prescription*

The WM logging has not been implemented either, however the logging prescription is considerably more complicated than that of NFQC or BRF. The logging prescriptions for WM were designated as "A", "B", "C", and control "X". Prescription is explained as:

- "A" — About 2.3 acres will be at 30% canopy retention to provide extra protection and shading for a half site tree (86 feet slope distance to the stream) on each side. This will require 25.9 trees per acre (14.6 for 30% canopy, 8.3 for wildlife trees, and 3.0 for downed woody material). The trees for canopy closure and downed woody material (17.6 trees per acre) will be marked separately with an average spacing of 50 feet and diameters generally greater than 24 inches. This will leave about 106 sq ft of basal area per acre for canopy closure and downed woody material. An additional 34 sq ft will be necessary for wildlife trees, for a total retention of 140 square feet per acre. Approximately 41% of the basal area is being removed.

- "B" — About 4.8 acres will be at 15% canopy retention for a half site tree slope distance along both sides. This will require 27.9 trees per acre (8.0 for 15% canopy, 16.9 for wildlife trees, and 3.0 for downed woody material). The trees for canopy closure and downed woody material (11.0 trees per acre) will be marked separately with an average spacing of 63 feet and diameters greater than 33 inches. This will leave about 77 sq ft of basal area per acre for canopy closure and downed woody material. An additional 71 sq ft will be necessary for wildlife trees, for a total retention of 148 sq ft per acre. Approximately 38% of the basal area will be removed.

- "C" — This stream will be *buffered* on both sides and not part of the harvest unit.

- "X" — This is the *control* stream and not associated with the harvest unit.

B. Stream Temperature Data Acquisition

Temperature gages were placed at the upper 1st, 3rd, and 5th dot, depicted in figure III.1, and referred to as upper, middle, and lower stream gage, respectively. Data was gathered from early July to mid October for 3 gages at the *control*, *buffered*, and *unbuffered* NFQC and BRF streams, and for the "A", "B", "C", and control "X" WM streams. So, 27 stream temperature data sets for the summer 2000 and 30 data sets for the summer 1999 were analyzed in all. Please note that the NFQC middle gage 2000 data is absent because *control* 2000 data was insufficient. See figure III.2 for general location of study.

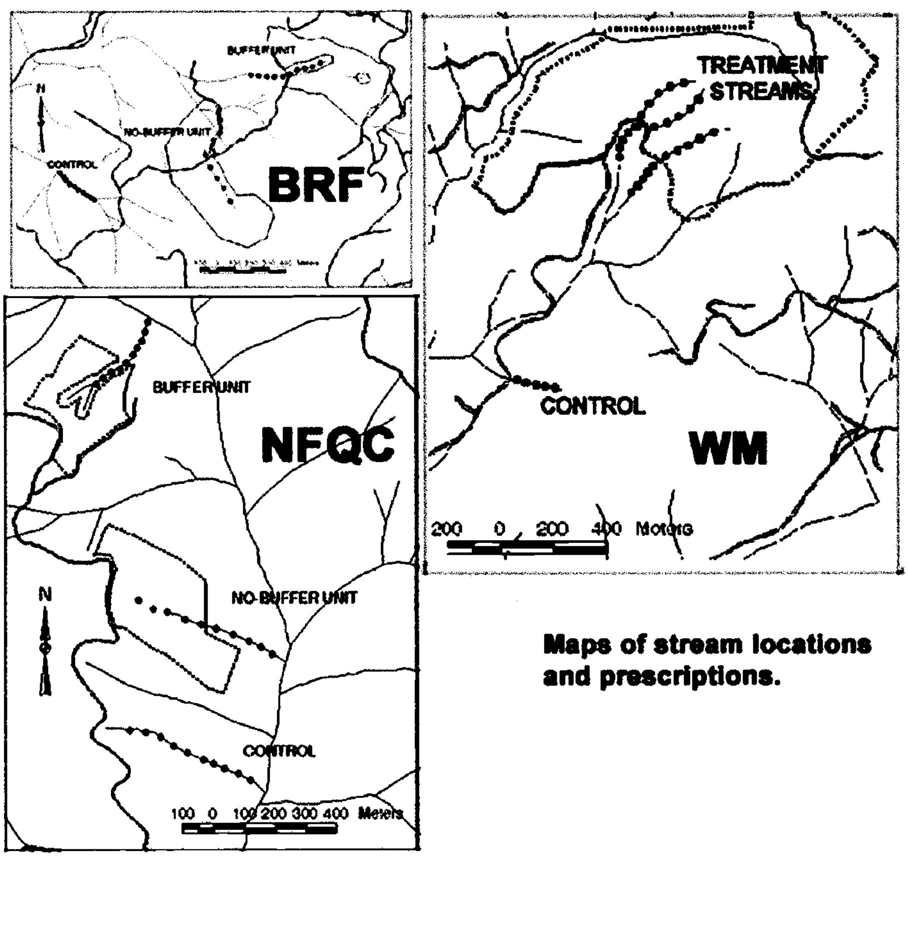


Figure III.1 Gage Locations *(from http://www.fsl.orst.edu/ccem/brls/pubs/matt.html)*

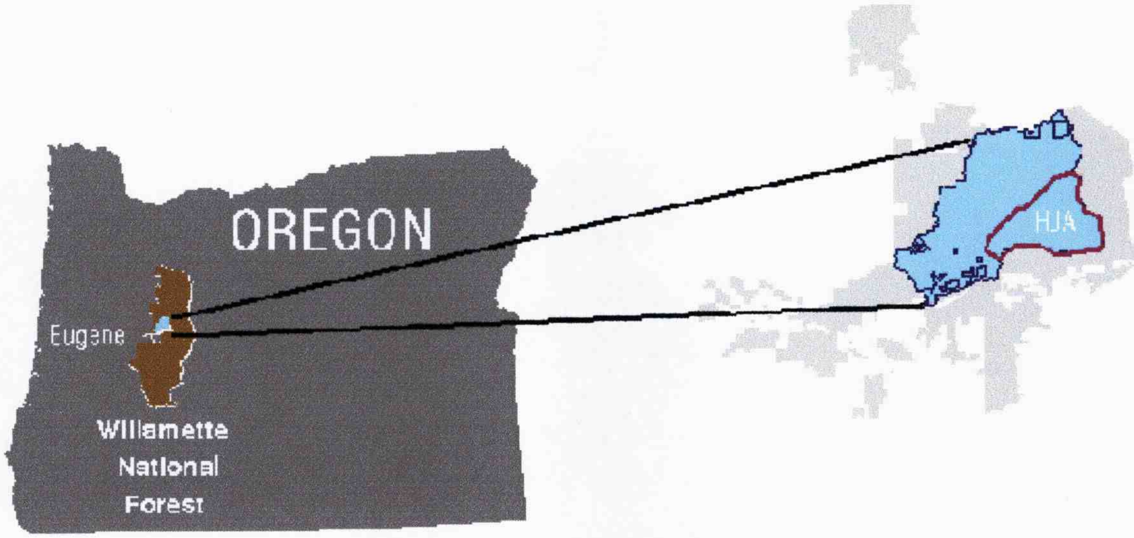


Figure III.2 Blue River Watershed *(from http://www.fsl.orst.edu/ccem/brls/pubs/matt.html)*

IV. METHODS

The 57 stream temperature data sets, referenced above, have been analyzed and plotted in an attempt to better understand the natural and unnatural influences affecting stream temperature for these 3 streams. Considerably more attention was given to the NFQC data since this was the only stream subjected to the logging implementation. Before and after harvest comparisons have been made for NFQC, as well as max, avg, and min plots for all gages, streams, and prescriptions for the summer of 1999 and 2000. Every effort was made to minimize inconsistencies due to faulty data or outliers. In addition, every effort was made to use similar date and temperature ranges to promote quick reference, understanding, and ease of use.

A. Stream Temperature Graphing Technique

1. *North Fork Quartz Creek (NFQC)*

Capture date range was from July 5th through October 4th. This date range best represented useful data available for all gages and for the consecutive summers. There are 6 stream temperature comparison graphs presented with 4 data lines each (figure IV.1, pg. 11). The comparison data is intended to show the temperature difference between the *control* and *buffered* stream and the *control* and *unbuffered* stream for the pre and post-harvest summers. Ideally, the pre-harvest temperature differences will be very near 0°C indicating that the attempt to match similar streams was successful. The intent is to capture any stream temperature changes resulting from logging implementation.

1999 and 2000 Comparison	Upper Gage			Lower Gage		
Control – Buffered 1999	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**
Control – Unbuffered 1999	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**
Control – Buffered 2000	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**
Control – Unbuffered 2000	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**
Section V. Results (6 graphs)	Fig V.3	Fig V.4	Fig V.5	Fig V.6	Fig V.7	Fig V.8

Figure IV.1

In addition, there are 12 graphs presented with 3 lines each, showing the max, avg, and min for 1999 and 2000 upper and lower gage data. Middle gage data for 2000 is absent and for 1999 is only provided in the Appendix for reasons explained above.

2. *Blue River Face (BRF)*

There are 9 graphs presented with 3 lines each, showing the max, avg, and min for summer 2000 upper, middle, and lower gage data. Nine (9) additional graphs of 1999 data are provided in the Appendix. Capture date range was from July 12th to October 11th. The 2000 data will serve as an excellent pre-harvest baseline that will aid future studies if and when the logging prescription is implemented. The 1999 data provides a backup source for pre-harvest data, as well as clues about air temperature and other natural influences affecting stream temperature when compared with 2000. If the sample streams were selected properly, the *control*, *buffered*, and *unbuffered* streams will display similar characteristics for the 2 consecutive summers with slight variation due to normal influences.

3. *Wolf Mann (WM)*

There are 12 graphs presented with 3 lines each, showing the max, avg, and min for summer 2000 upper, middle, and lower gage data. Twelve (12) additional graphs of 1999 data are provided in the Appendix. The 2000 data will serve as an excellent pre-harvest baseline that will aid future studies if and when the logging prescription is implemented. The 1999 data provides a backup source for pre-harvest data, as well as clues about air temperature and other natural influences affecting stream temperature from one summer to the next. If the sample streams were selected properly, the “A”, “B”, “C”, and control “X” streams will display similar characteristics for the 2 consecutive summers with slight variation due to normal influences.

B. Air Temperature Gage (PRIMET)

Air temperature data available on the HJ Andrews Experimental Forest website was used because of its availability, accuracy, and proximity to the streams of interest. The Primary Meteorological Station (PRIMET) is located within the experimental forest at Latitude 44° 12’ 43”, Longitude 122° 15’ 21” at an elevation (MSL) of 430 meters, with Aspect = 0 degrees and Slope = 0 degrees, and the site is described as a maintained clearing. The temperature probe height used was 10 cm above the ground and readings were taken every 15 minutes. The system monitors and records the maximum, average, and minimum air temperature, as well as, the daily time of maximum and minimum. Data was analyzed and graphed for the summer of 1999 and 2000.

V. RESULTS

A. Graph Analysis

1. *PRIMET Air Temperature Data*

Local PRIMET Air Temperature data, provided in figures V.1 and V.2, serve as a useful measure of insolation and the ambient temperature effects on stream temperature in the analysis that follows. Air temperature data is provided from July 12th through Oct 11th. Study of the 2 figures shows rather similar summer highs and lows with the exception of September. September 2000 was approximately 2˚C warmer than September 1999 with significant temperature fluctuations when compared to the consistent September 1999 temperatures.

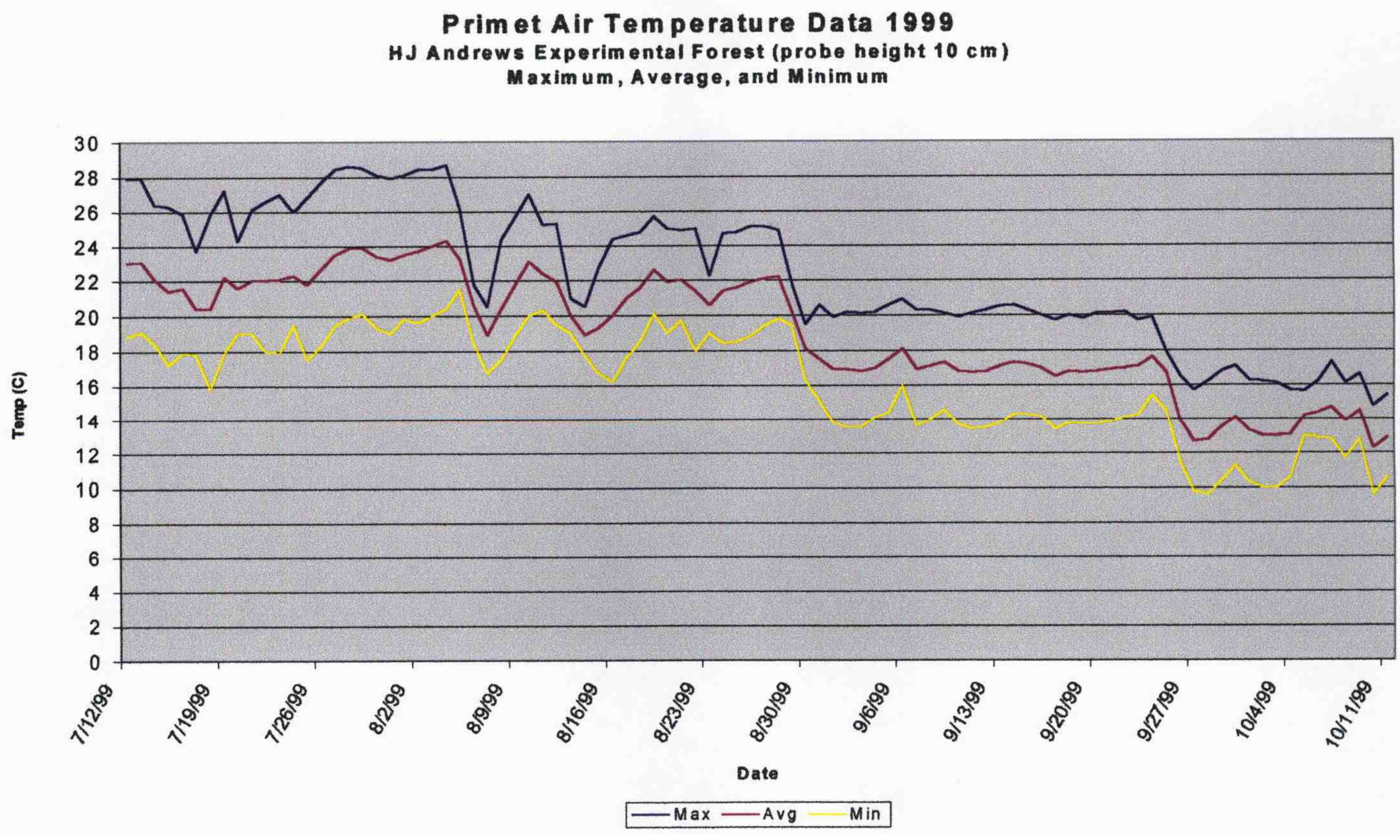


Figure V.1

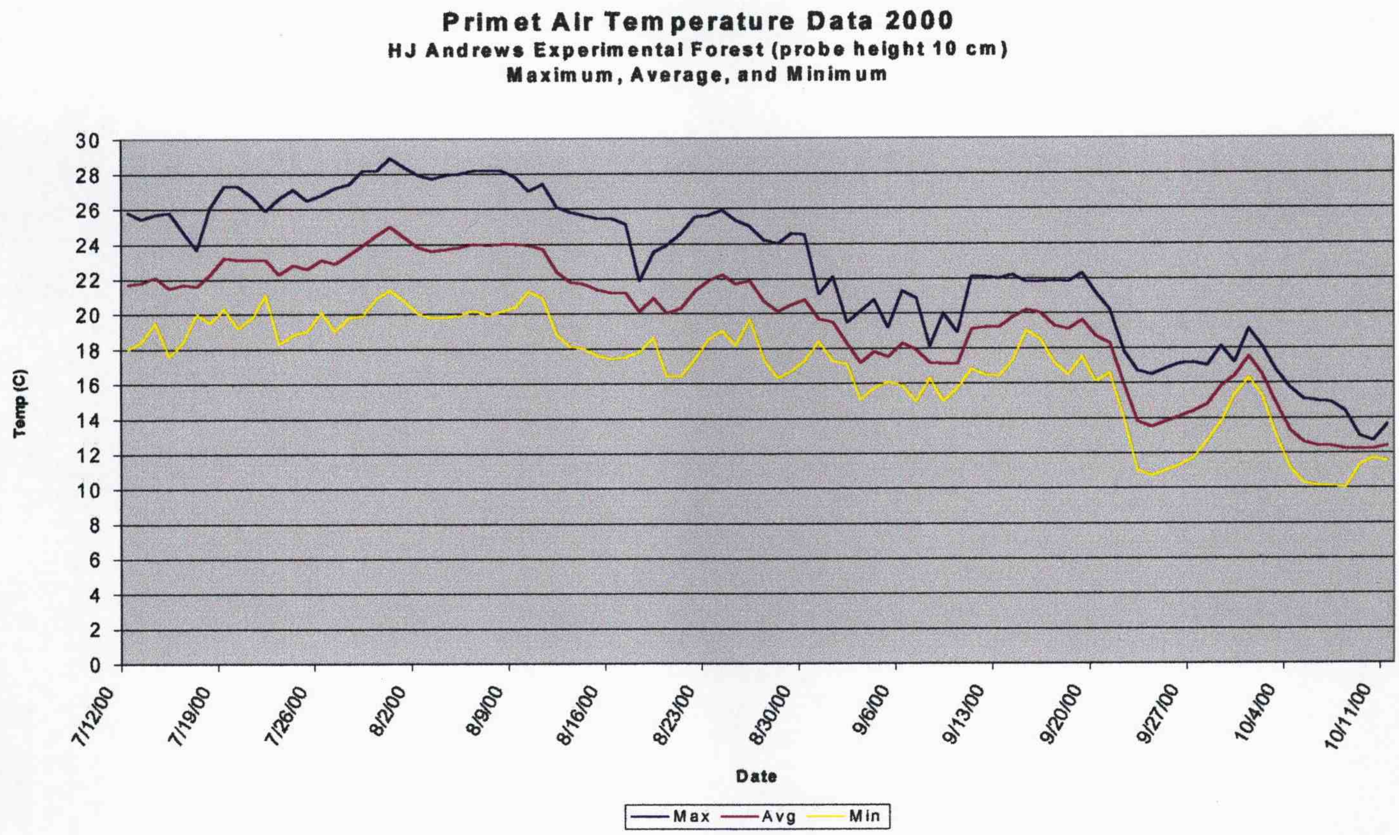


Figure V.2

2. *North Fork Quartz Creek (NFQC) Logging Prescription Comparison [(Control – Buffered) and (Control – Unbuffered)]*

The following 6 graphs (figures V.3 – V.8) are provided to show the maximum, average, and minimum temperature differences at the upper and lower stream gages for (*control – buffered*) and (*control – unbuffered*) and compare data gathered for summer 1999 and summer 2000. This data has potential to be highly significant given that the logging prescription was implemented for this area in January 2000 and completed in March 2000. Summer 1999 and 2000 data provides a before and after harvest look at natural and human induced impacts. Please note that the middle gage data was not sufficient for use in this study. In addition, take careful note of graph definition with regard to gage location (i.e. upper or lower), temperature designation (i.e. maximum, average, and minimum), and prescription stream designation (i.e. *control*, *buffered*, and *unbuffered*) for significance in data represented.

a. *Upper Gage Maximum Daily Stream Temperature Difference For 1999 & 2000*

Figure V.3 on page 16 clearly shows that the max *control* stream temperature is roughly 2 to 3°C warmer than the max *buffered* stream temperature and roughly 1 to 1.5°C cooler than the max *unbuffered* stream through late August for both 1999 and 2000. The 1999 data shows that the *control* and *unbuffered* streams, before harvest, were considerably warmer than the *buffered* stream. This holds true following harvest, but there is some evidence of *buffered* stream warming from early August to late September and *unbuffered* stream warming in mid September. The (*control* – *buffered* 1999) data peaks at 3.7°C in late August and again at nearly 4°C in late September while the (*control* – *buffered* 2000) stays relatively cooler during this period. The (*control* – *unbuffered* 2000) reached –1.5°C in mid September while (*control* – *unbuffered* 1999) was at nearly 0.5°C. Review of figures V.9 and V.11 show that the *unbuffered* 2000 stream was considerably more affected by September air temperatures than the *control* stream and when comparing 1999 data. Overall, the summer 2000 max *buffered* and *unbuffered* streams appear slightly warmer from early August and on when compared to summer 1999. However, PRIMET air temperature data shows a slightly warmer summer for 2000 when compared to 1999. In contrast, the (*control* – *unbuffered* 1999) data appears more affected by insolation spikes than (*control* – *unbuffered* 2000). Review of figure V.9 and V.10 shows that most of the temperature fluctuation for the *(control – buffered 2000)* data results from fluctuations in the *control* stream with the *buffered* stream rather steady throughout the summer at 10°C.

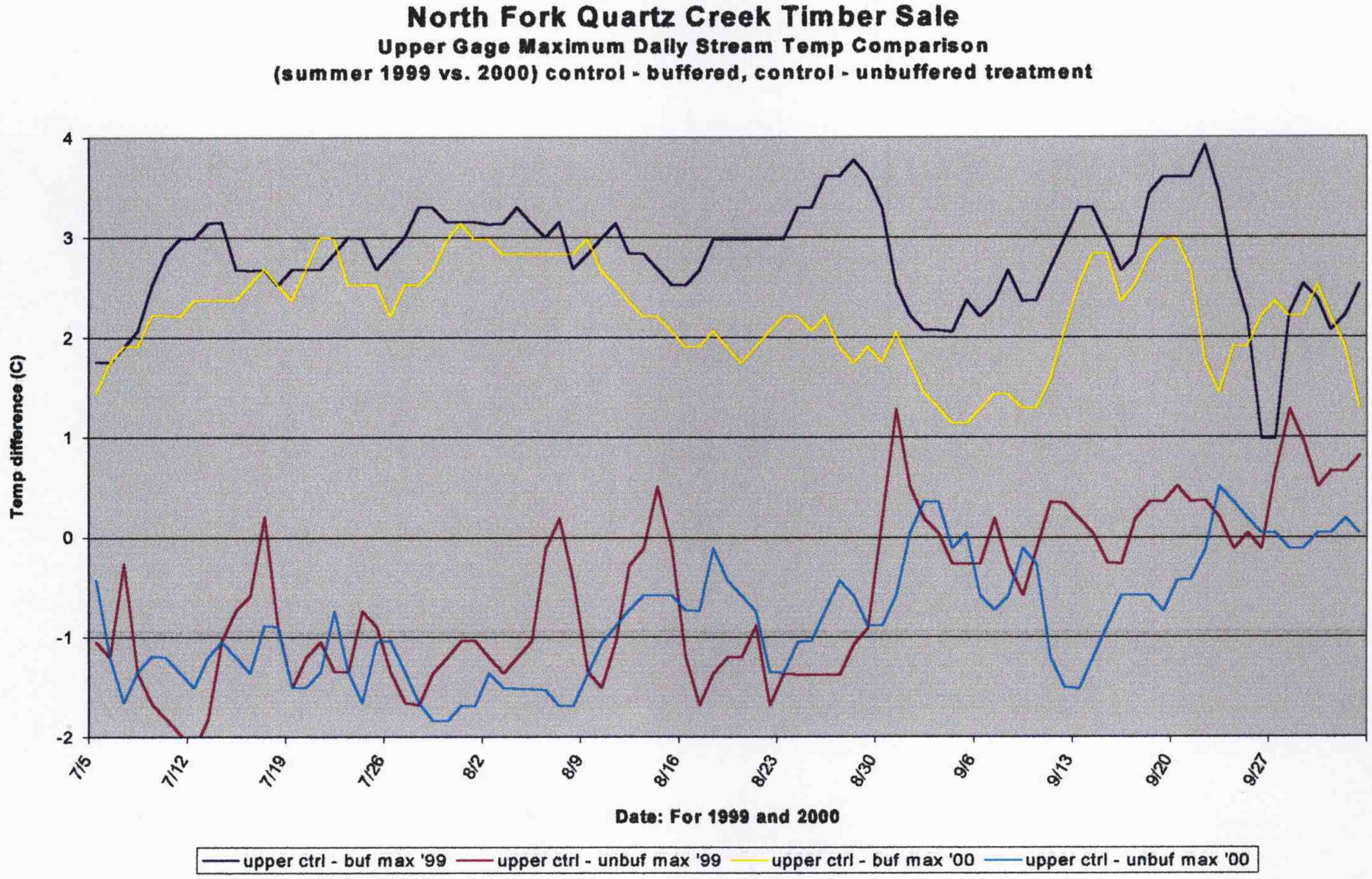


Figure V.3

b. *Upper Gage Average Daily Stream Temperature Difference For 1999 & 2000*

The average data represented in figure V.4 provides similar conclusions to the minimal effects of harvest. The temperature differences trend toward 0˚C in late summer, particularly for the (*control – unbuffered*) comparison. Again, the (*control – buffered*) data shows that *buffered* stream runs 2 to 3˚C cooler through late August and 1 to 2˚C cooler through the fall for both summers. In addition, the (*control – buffered*) data for both 1999 and 2000 seems to indicate that the *control* stream is highly influenced by the air temperature drop and decreased insolation in mid to late September. Review of figure V.9 shows this stream temperature decline.

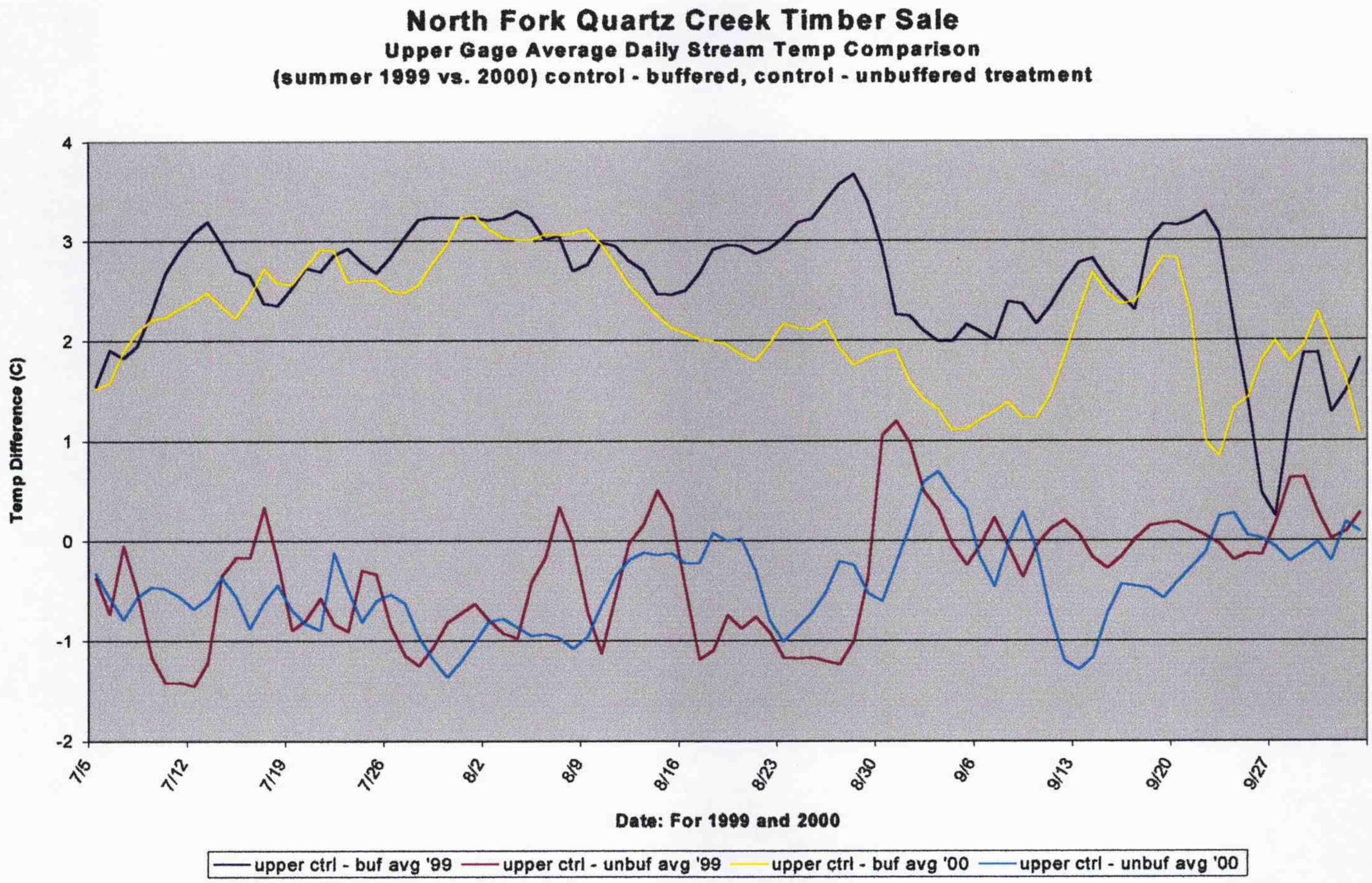


Figure V.4

c. *Upper Gage Minimum Daily Stream Temperature Difference For 1999 & 2000*

Figure V.5 reveals little overall difference in minimum temperatures for the *control* and *unbuffered* streams with the pre-harvest data showing slightly more susceptibility to air temperature changes. The most significant drops are in the minimum *control* temperature, depicted in figure V.9 and V.15, which show up as large spikes when comparing *control* and *buffered* streams for 1999 and 2000. For a short time in late summer 1999, the *buffered* stream remained warmer than *control*. The minimum daily temperature fluctuations for the *unbuffered* stream seem to coincide with fluctuations in the *control* stream. A large temperature drop for the *unbuffered* 1999 stream causes the largest upward spike for the (*control – unbuffered* 1999) data causing the *unbuffered* stream to run 1.5˚C cooler than the *control* for a short period in late August (see figure V.17). This coincides with a large air temperature drop in August 1999 (see figure V.1). Again, comparing (*control – buffered* 1999) with (*control – buffered* 2000) does seem to indicate that the *buffered* stream is slightly warmer following harvest

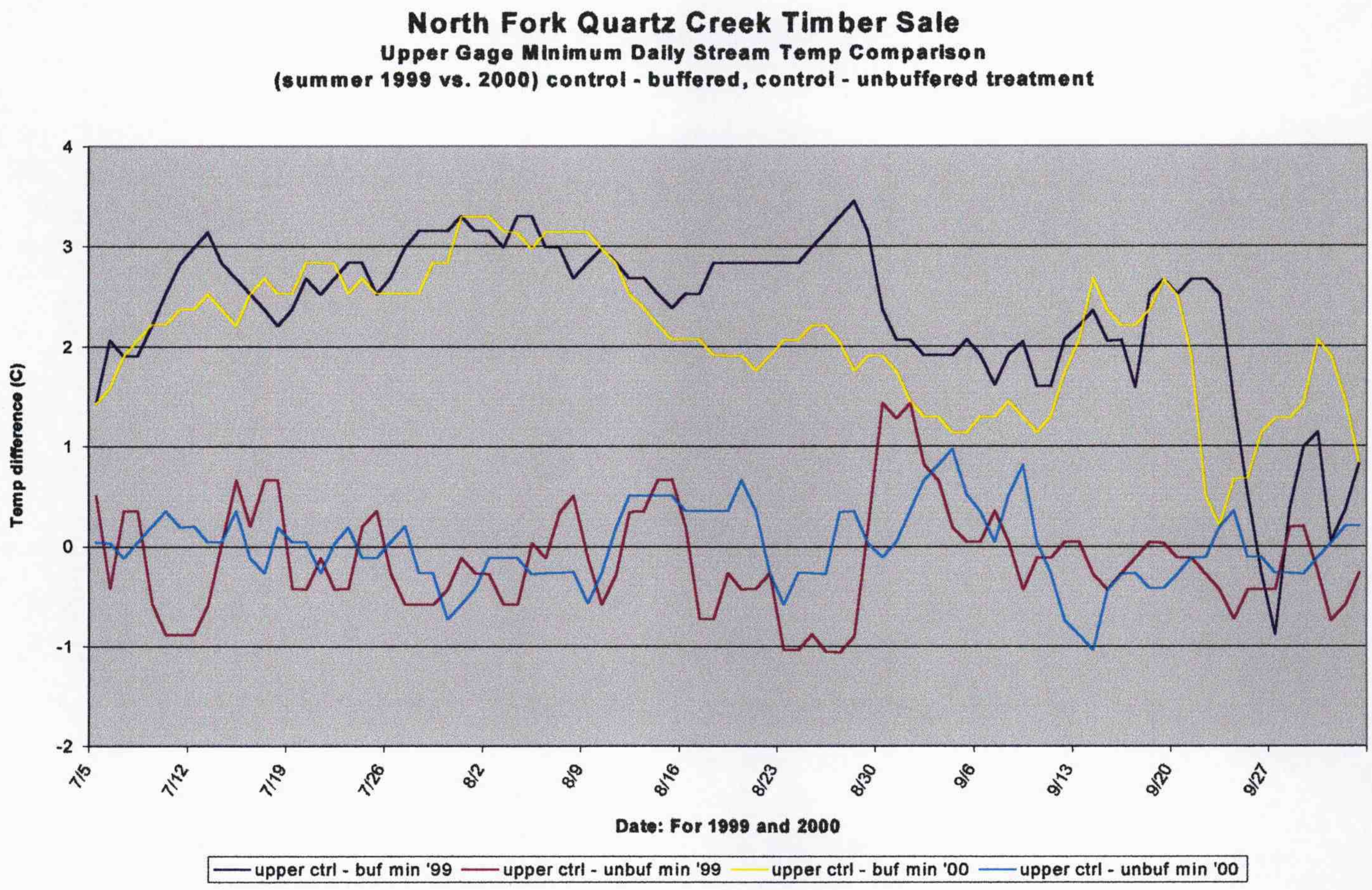


Figure V.5

d. *Lower Gage Maximum Daily Stream Temperature Difference For 1999 & 2000*

Figure V.6 does not reveal much new evidence of the effect of harvest. The max (*control – buffered*) temperature difference holds fairly steady throughout the summer with the *control* stream at about 2°C warmer than *buffered.* The max (*control – unbuffered*) temperature difference remains rather steady with the *unbuffered* stream running at about 0.25 to 1°C warmer. In contrast to the upper gage data that indicates a warmer post-harvest *buffered* stream, lower gage (*control – buffered* 2000) ran about 0.5°C higher than (*control –buffered* 1999) from July through mid August. This would indicate that the lower gage *buffered* 2000 stream is cooler than 1999 casting doubt on temperature increases due to harvest.

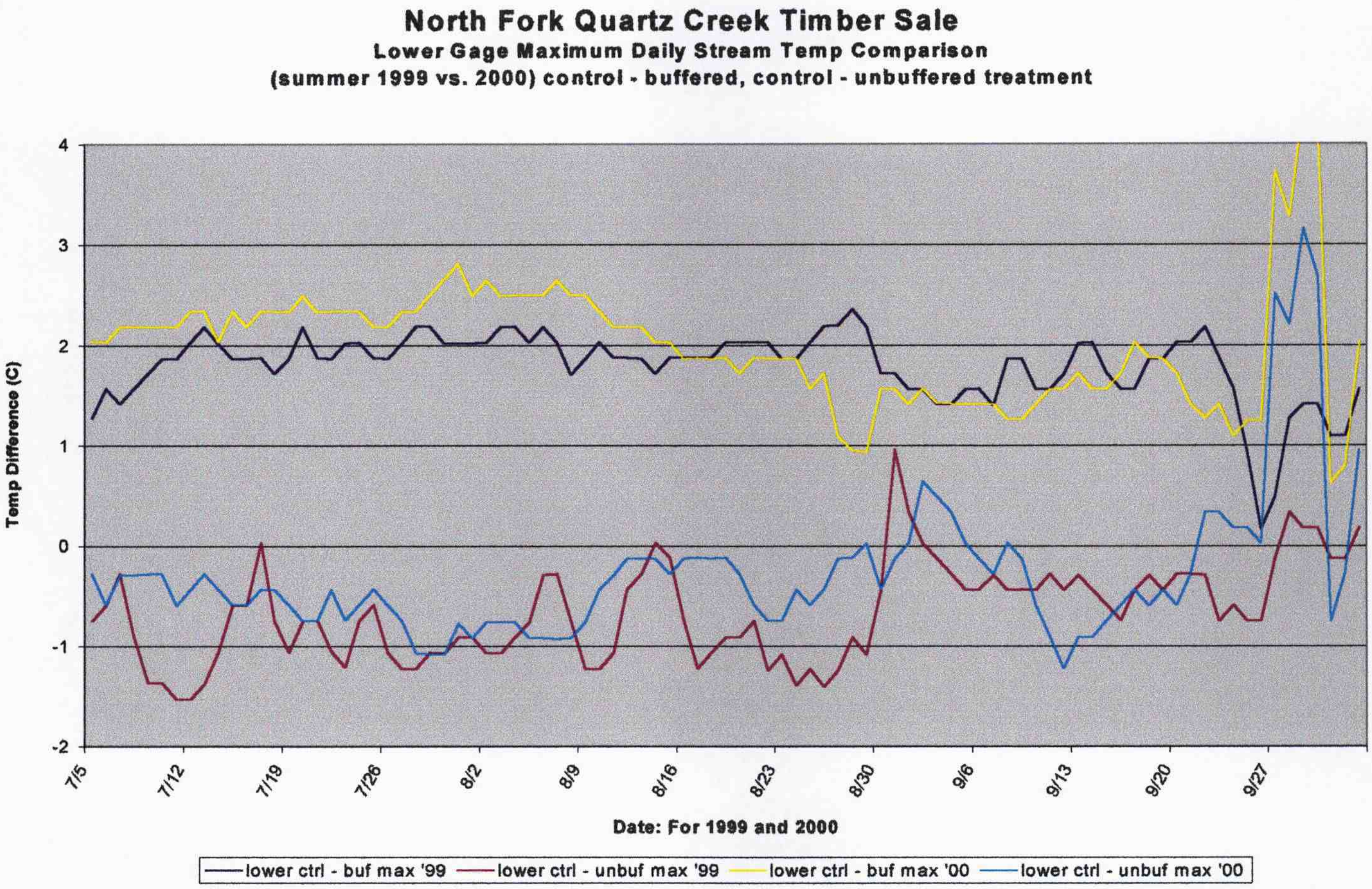


Figure V.6

e. *Lower Gage Average Daily Stream Temperature Difference For 1999 & 2000*

Figure V.7 is very similar to max data with average (*control – buffered*) trending toward 1.5°C and (*control – unbuffered*) trending toward 0°C toward the end of summer. The lower gage *control* data in figure V.12, for late September 2000, reveals some suspect, faulty spikes that cause the (*control – buffered*) and (*control – unbuffered*) lines for 2000 to display large daily temperature variation. The average *buffered* 2000 data still appears cooler than *buffered* 1999 for July through mid August.

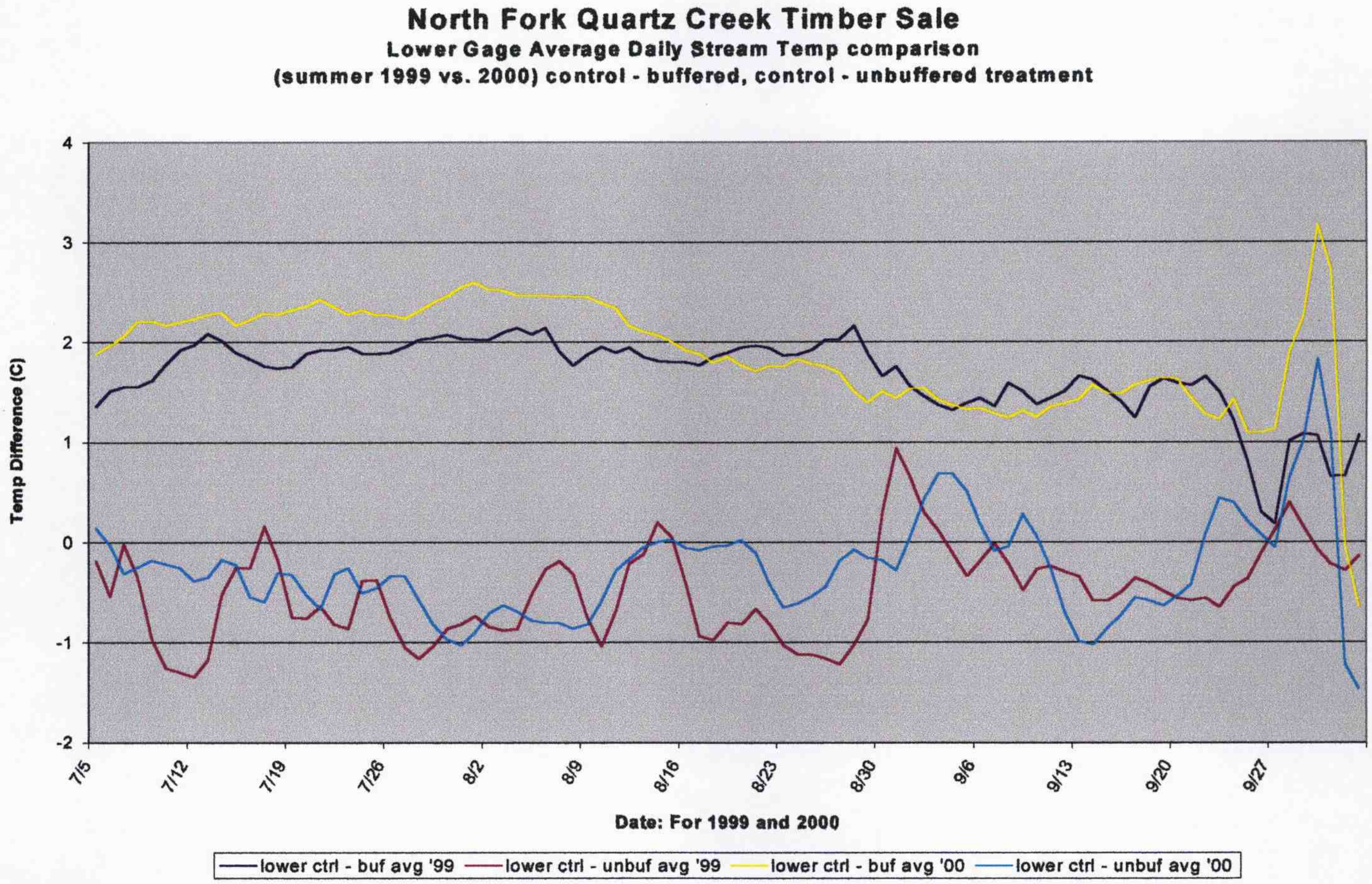


Figure V.7

f. *Lower Gage Minimum Daily Stream Temperature Difference For 1999 & 2000*

Figure V.8 is very similar to max data with (*control – buffered*) trending toward 1.25°C and (*control – unbuffered*) trending toward 0°C toward the end of summer. The (*control – buffered*) temperature differences range from about 1.75 to 2.3°C through August for both summers with the 2000 data about 0.5°C higher. Both summer differences settle in around 1.25°C during the fall. The (*control – unbuffered*) data is fairly consistent around 0 to -1°C throughout the season for both summers. Temperatures spikes are evident in early September where the *control* stream becomes warmer than the *unbuffered* stream.

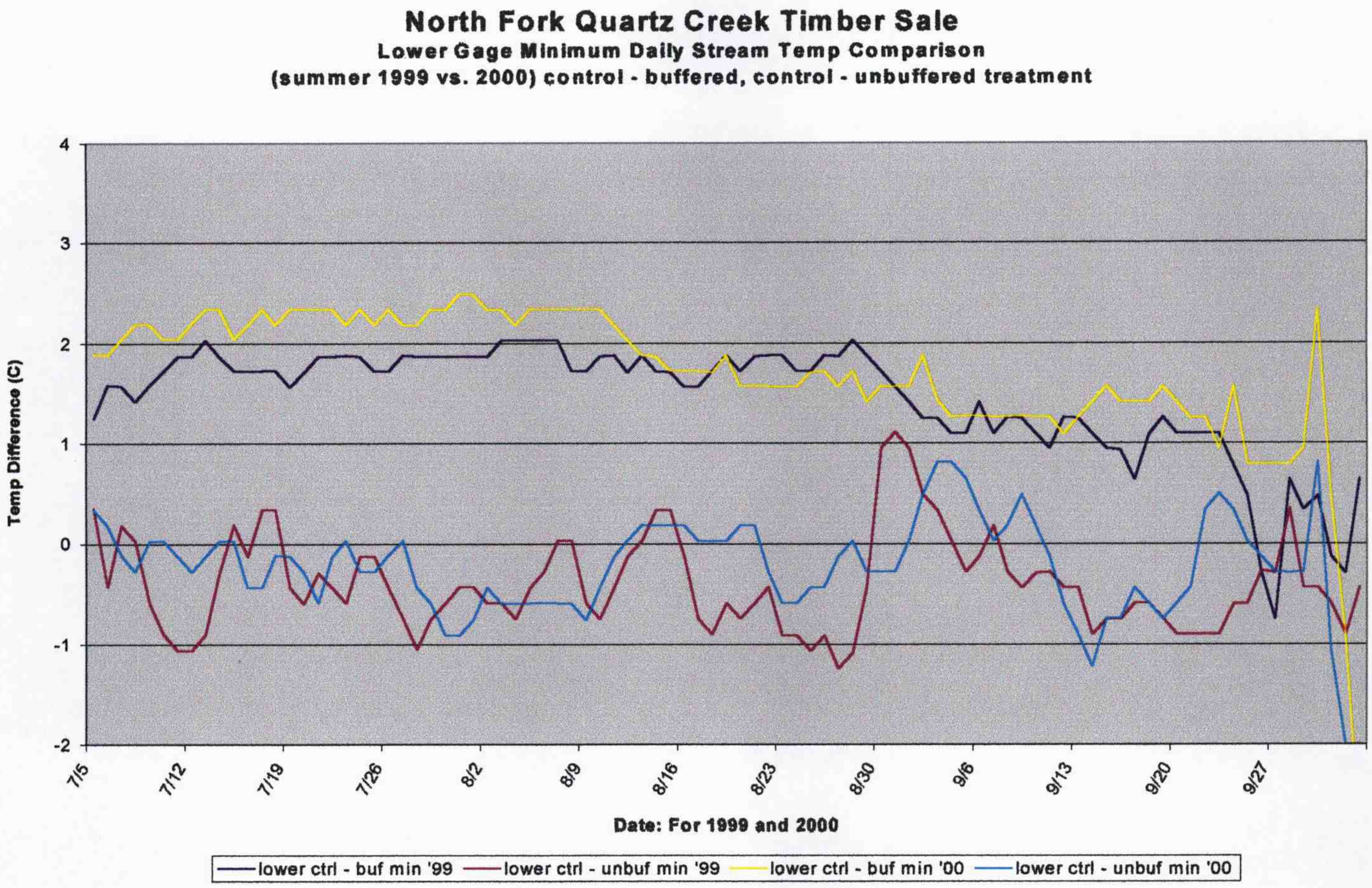


Figure V.8

3. *NFQC 1999 and 2000 Stream Temperature Comparison (Max, Avg, and Min)*

Graphs of the maximum, average, and minimum data are provided for 1999 and 2000 (refer to figures V.9 – V.20). The important observations for these graphs have been discussed above during the analysis of stream temperature differences. The max, avg, and min graphs, along with air temperature data in figures V.1 and V.2, serve as a very useful tool when analyzing temperature difference plots in figures V.3 – V.8.

a. *NFQC Upper Gage*

Upper *control* 2000 data, shown in figure V.9, peaks at 14°C with a small diurnal spread and an increase in daily fluctuation in the fall similar to *control* 1999 data, shown in figure V.15, with the exception of minor ambient air influences. The upper *buffered* 2000 data, shown in figure V.10, is very steady at 10 to 11°C with a small diurnal spread. However, higher *buffered* 2000 temperatures are evident from late July to mid August when compared to 1999, shown in figure V.16, and the 1999 data exhibits an even smaller diurnal spread. Upper *unbuffered* 2000 data, shown in figure V.11, peaks at 16°C and clearly exhibits 1 to 2°C temperatures higher than *control* and 3 to 4°C temperatures higher than *buffered*. *Unbuffered* 2000 data is very similar to 1999 and both exhibit considerably more diurnal fluctuation than the *control* and *buffered* streams.

b. *NFQC Lower Gage*

The lower gage max *control* data, shown if figure V.12, runs slightly warmer than upstream and reaches max temperatures in late July of nearly 15°C. Fall temperatures appear heavily influenced by ambient air conditions. Perhaps there is some false gage data with the peaks shown. The lower gage *buffered* 2000 data, shown in figure V.13, runs about 1°C warmer than upstream. When comparing lower gage *buffered* 2000 with lower gage *buffered* 1999 data, provided in figure V.19, it is difficult to claim strong evidence of logging impacts. The lower gage *unbuffered* 2000 data, shown in V.14, is very similar to upstream, but runs slightly warmer. Again it is difficult to clearly identify logging impacts when comparing the two summers in figure V.14 and V.20.

c. *NFQC Summary*

The upper *control* 2000 data runs about 0.5 to 1°C warmer than 1999 while the lower gage temps are very similar for the 2 summers. The upper gage *buffered* 2000 data is warmer than *buffered* 1999 data from Aug. 1st – 20th by 0.5 to 1°C. It is difficult to see any strong evidence of the impact of logging implementation, but it does appear that the post-harvest *buffered* stream is slightly warmer earlier in the summer.

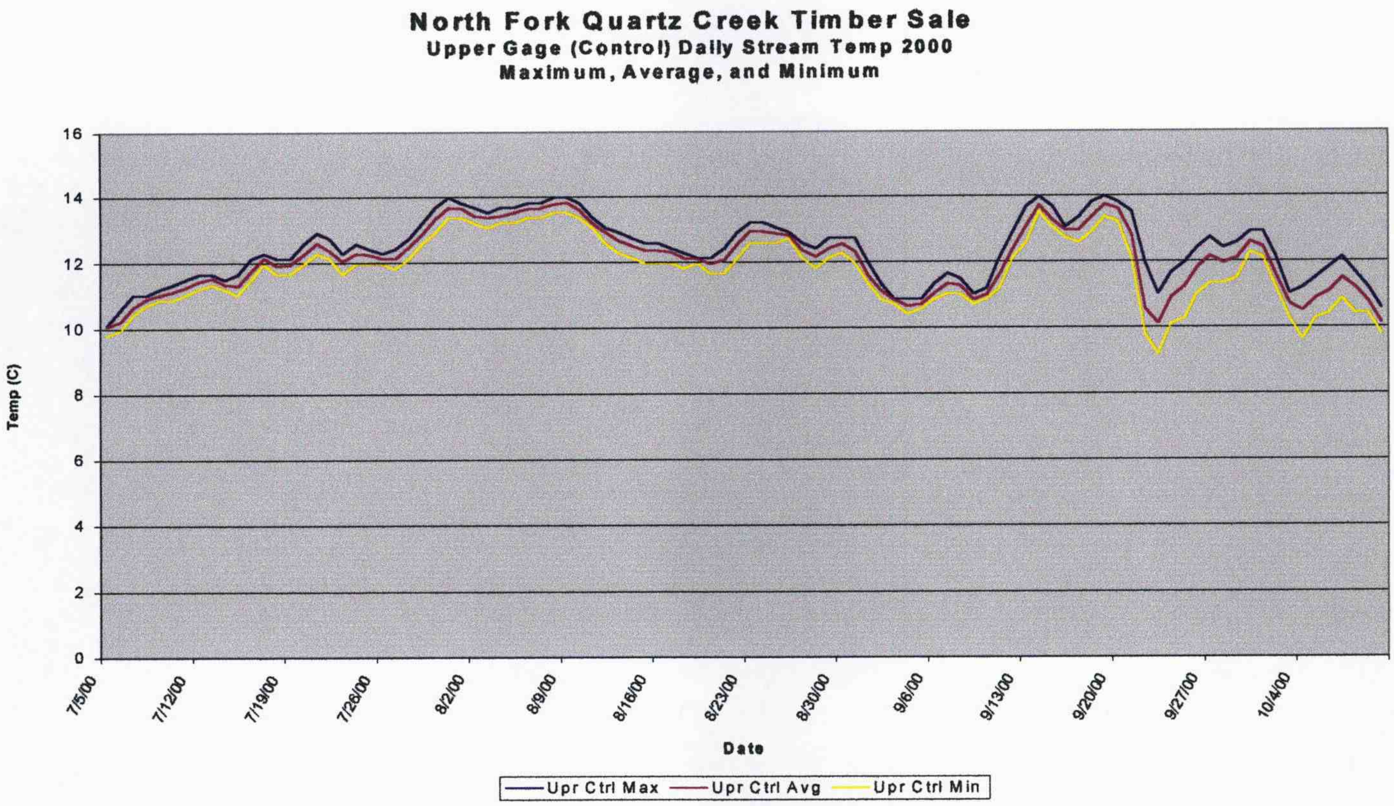


Figure V.9

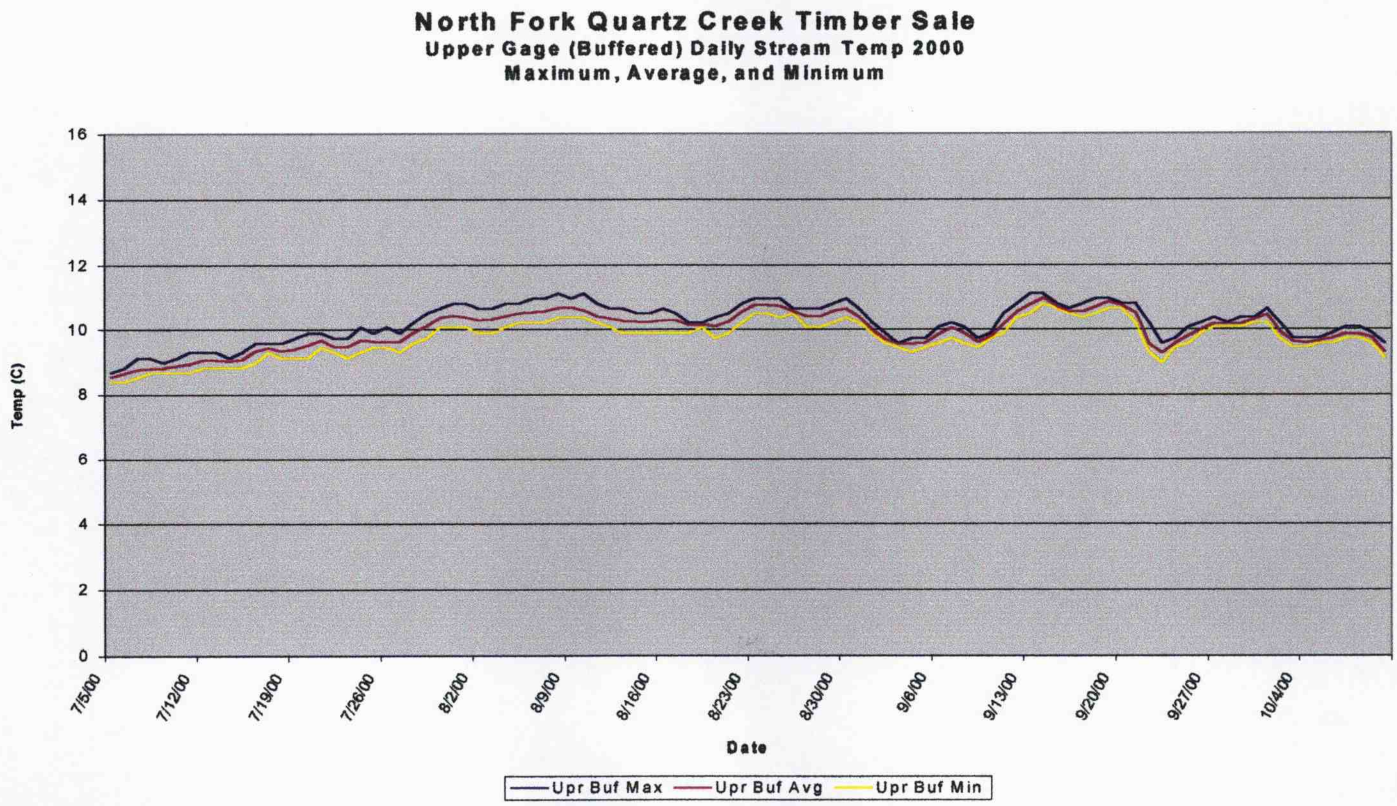


Figure V.10

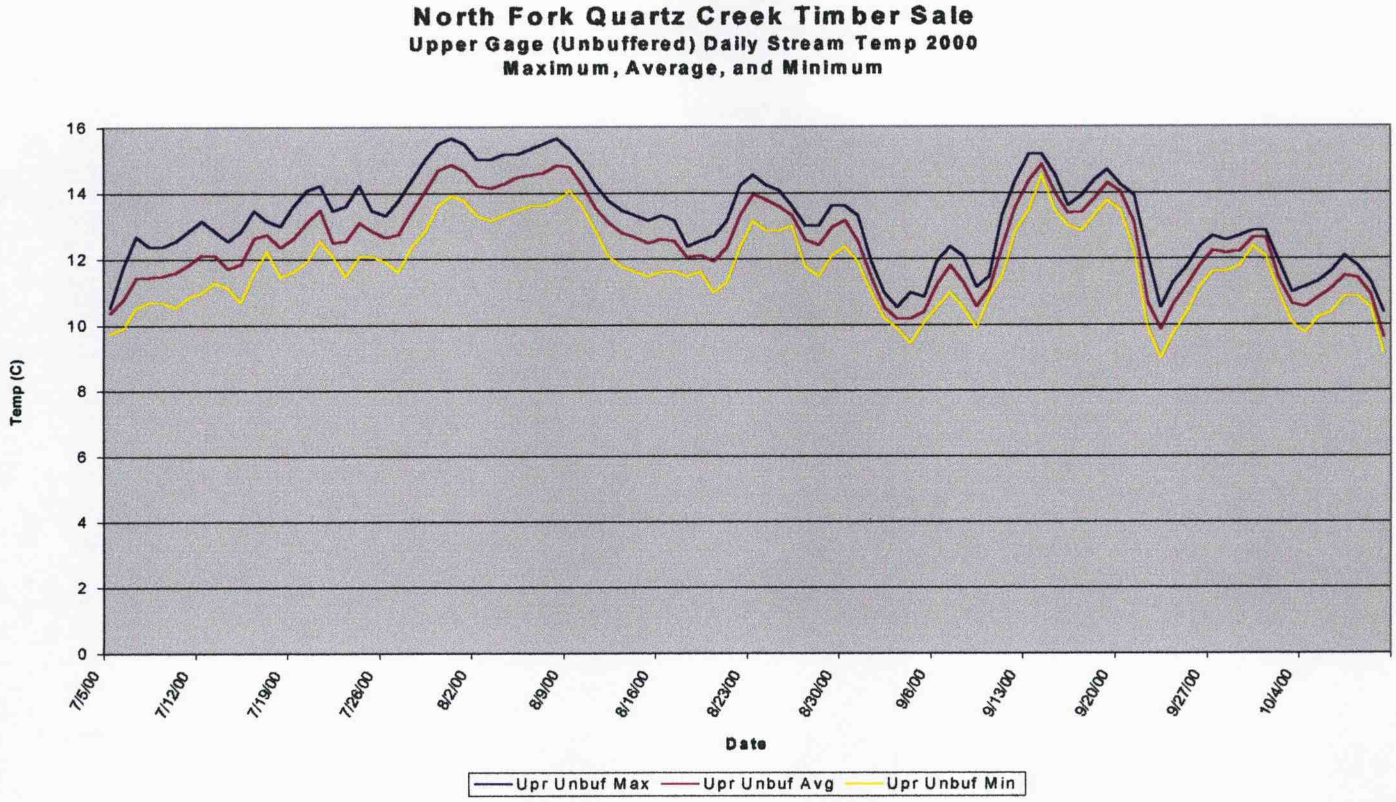


Figure V.11

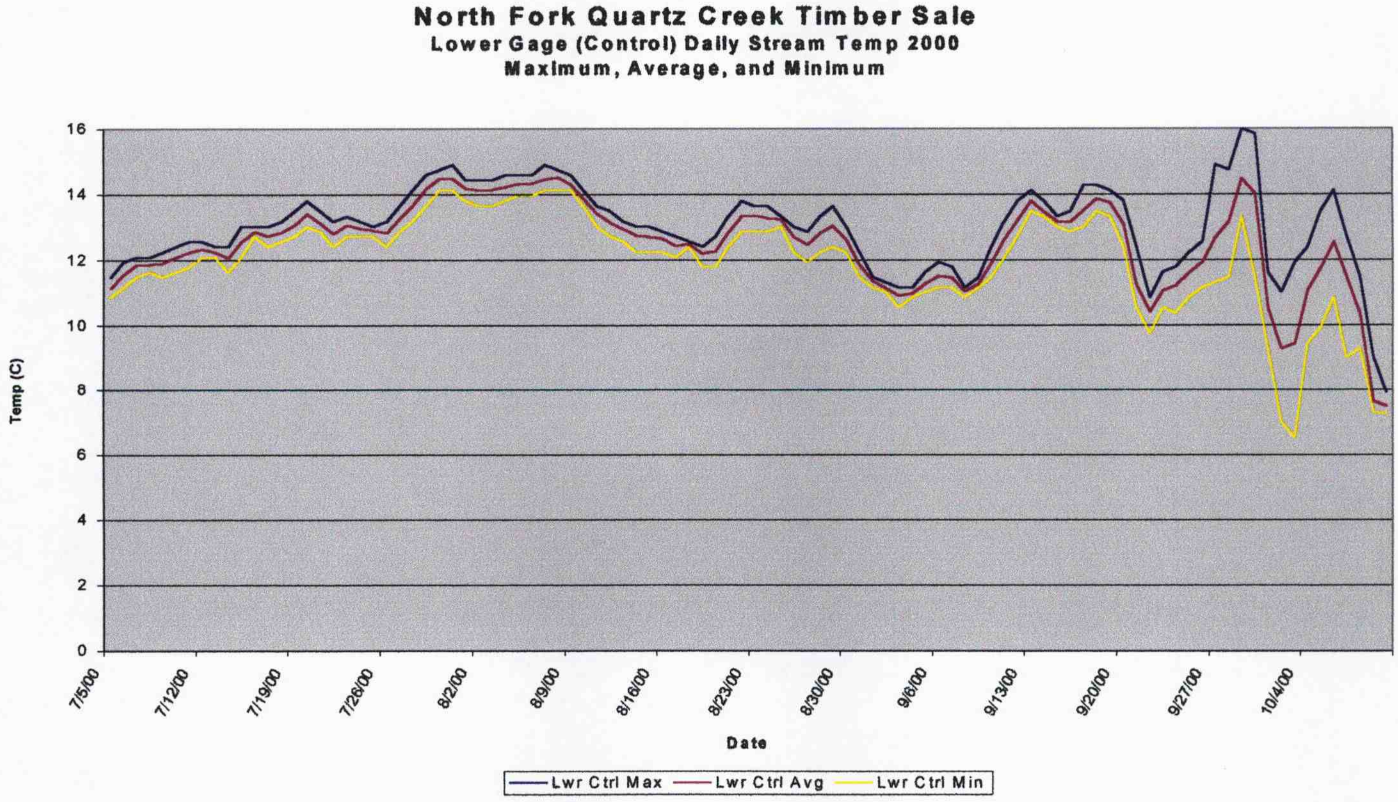


Figure V.12

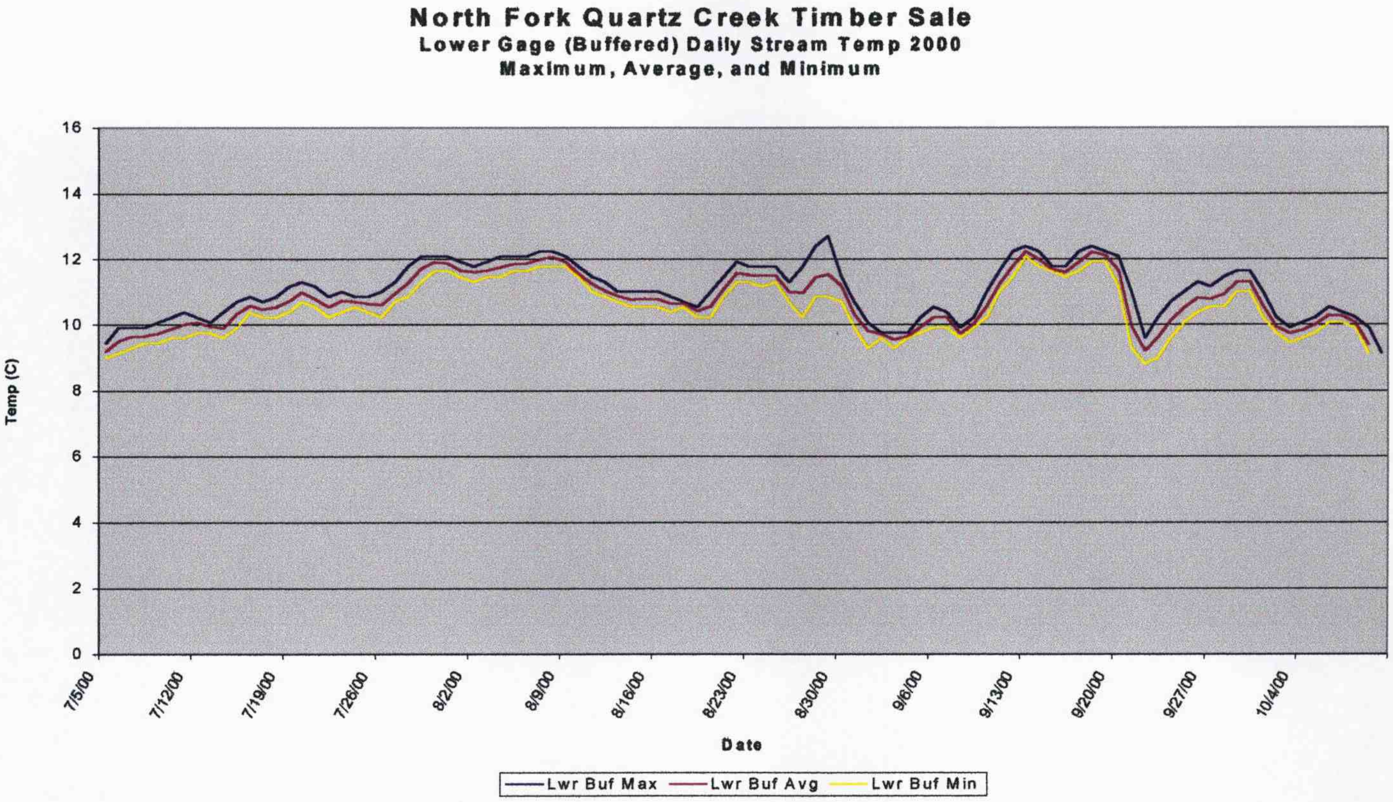
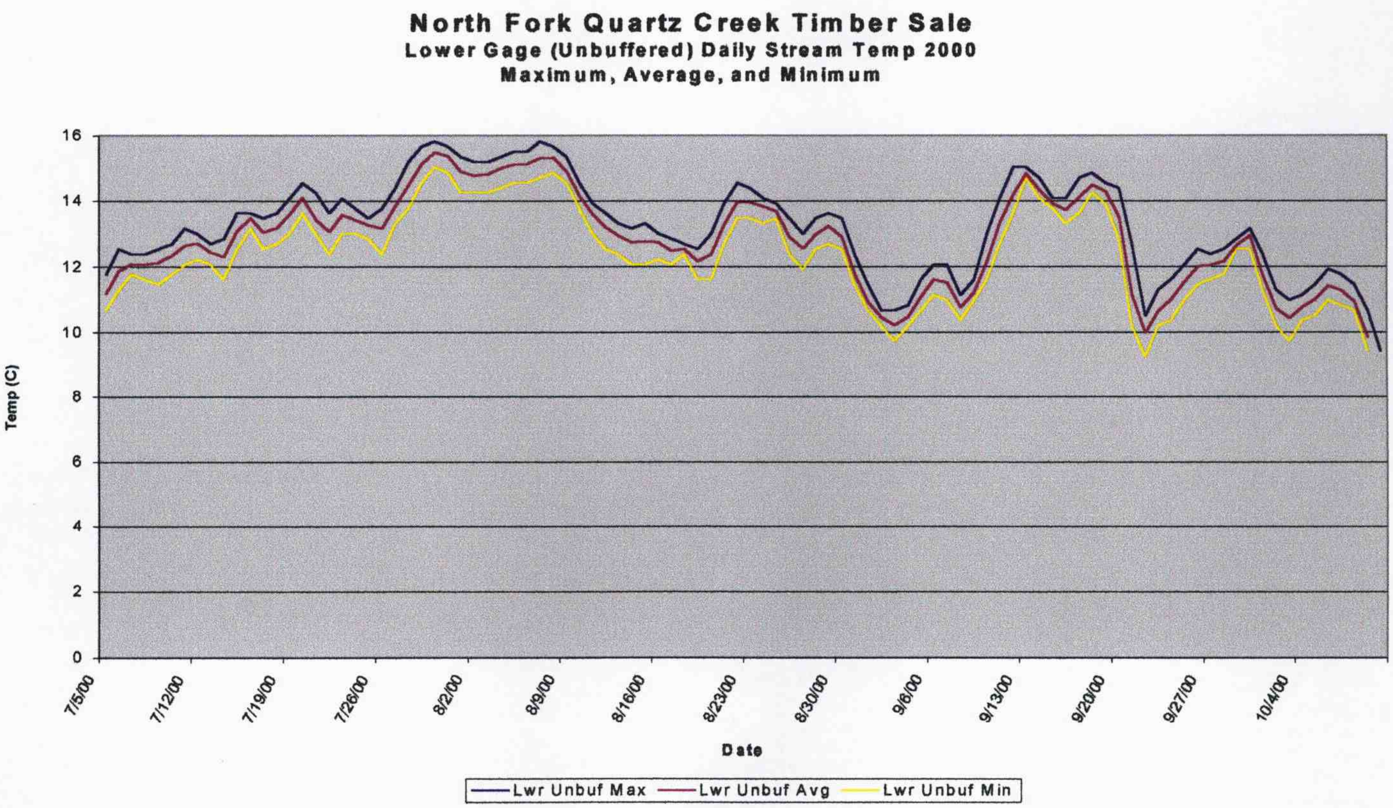


Figure V.13



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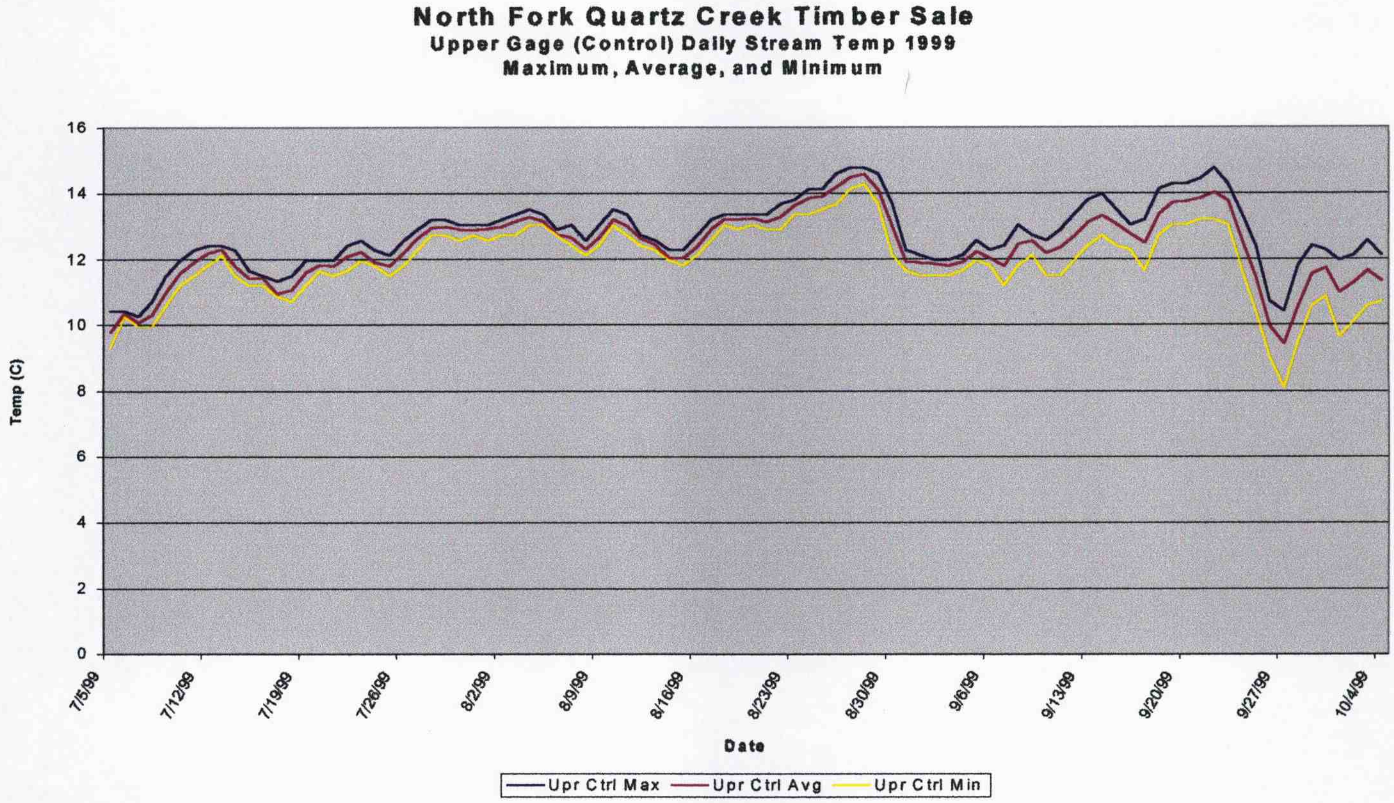

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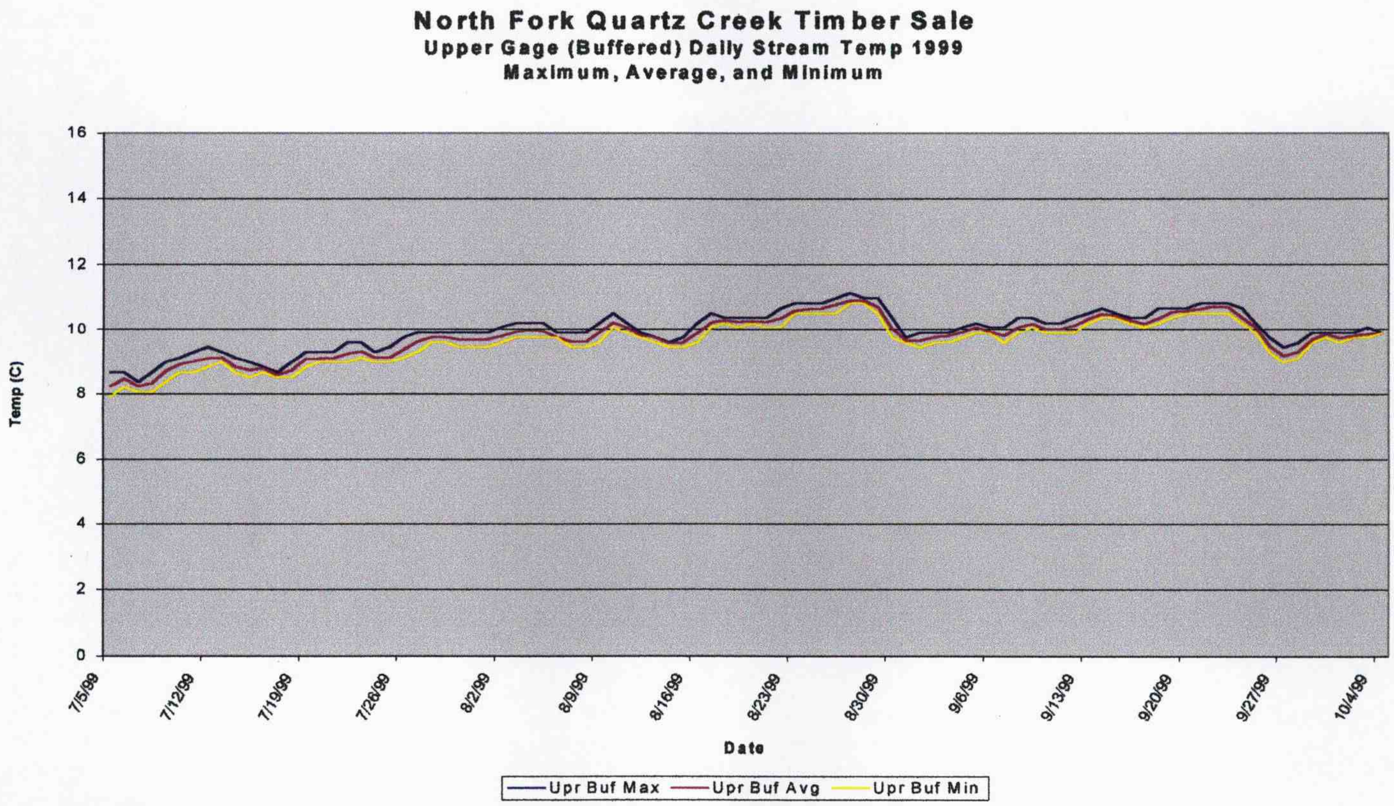

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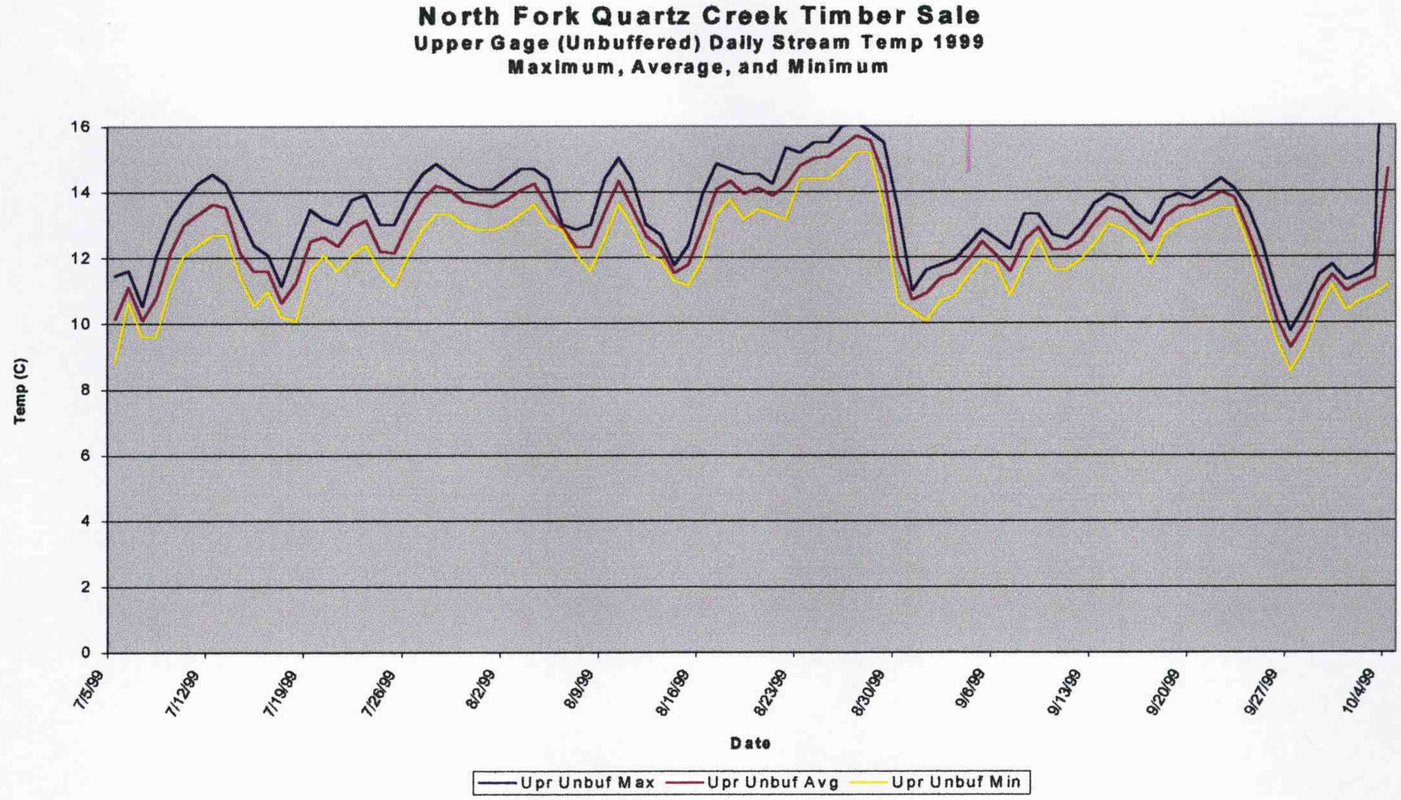

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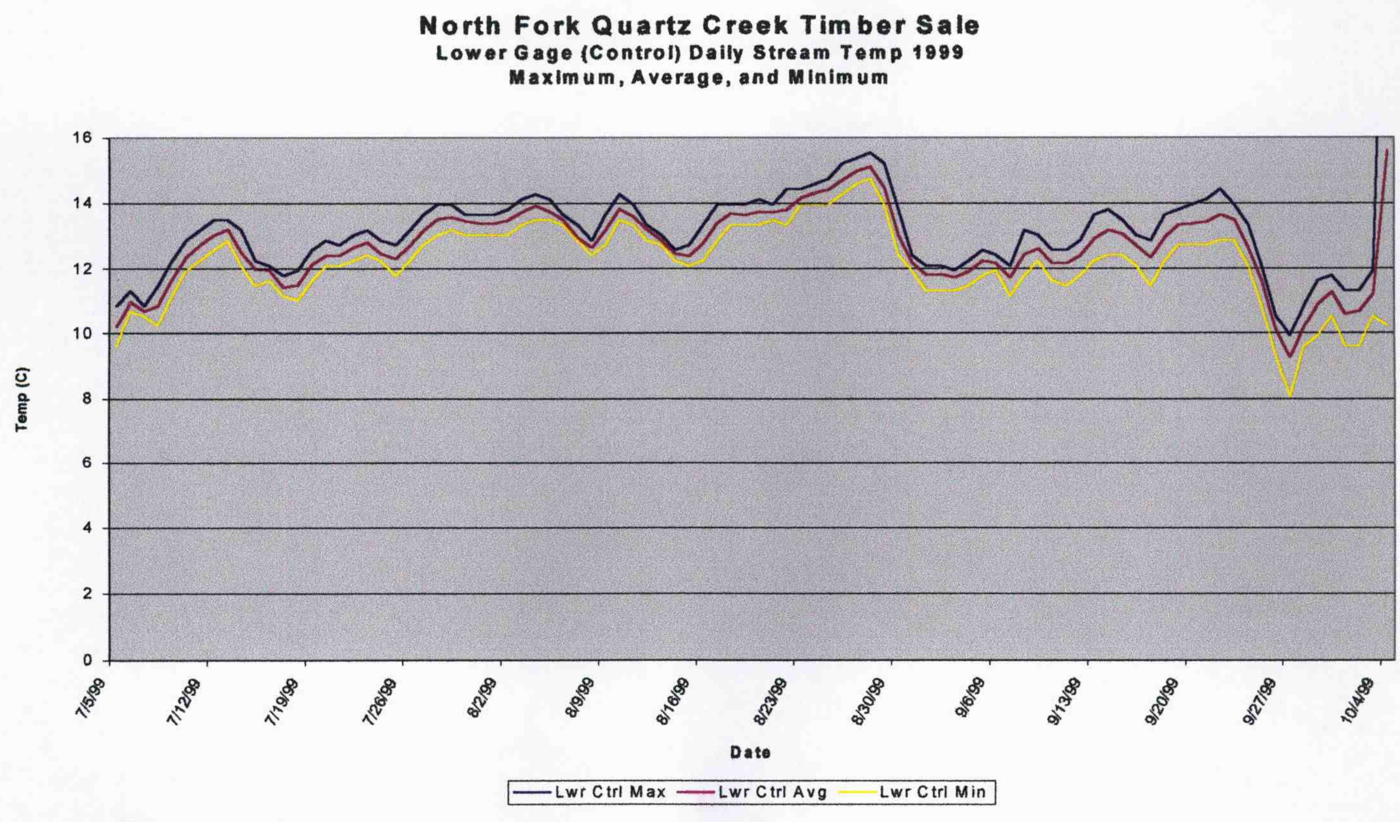

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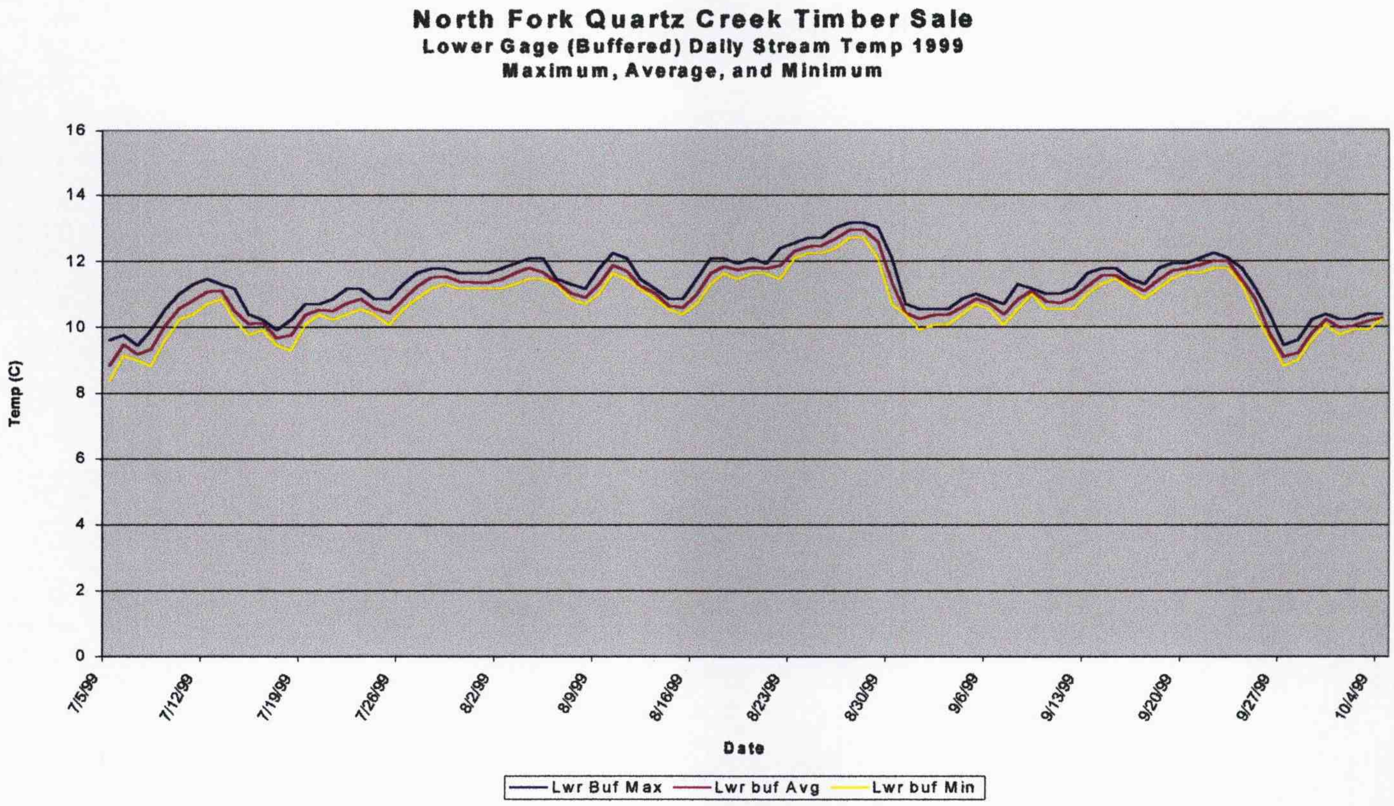

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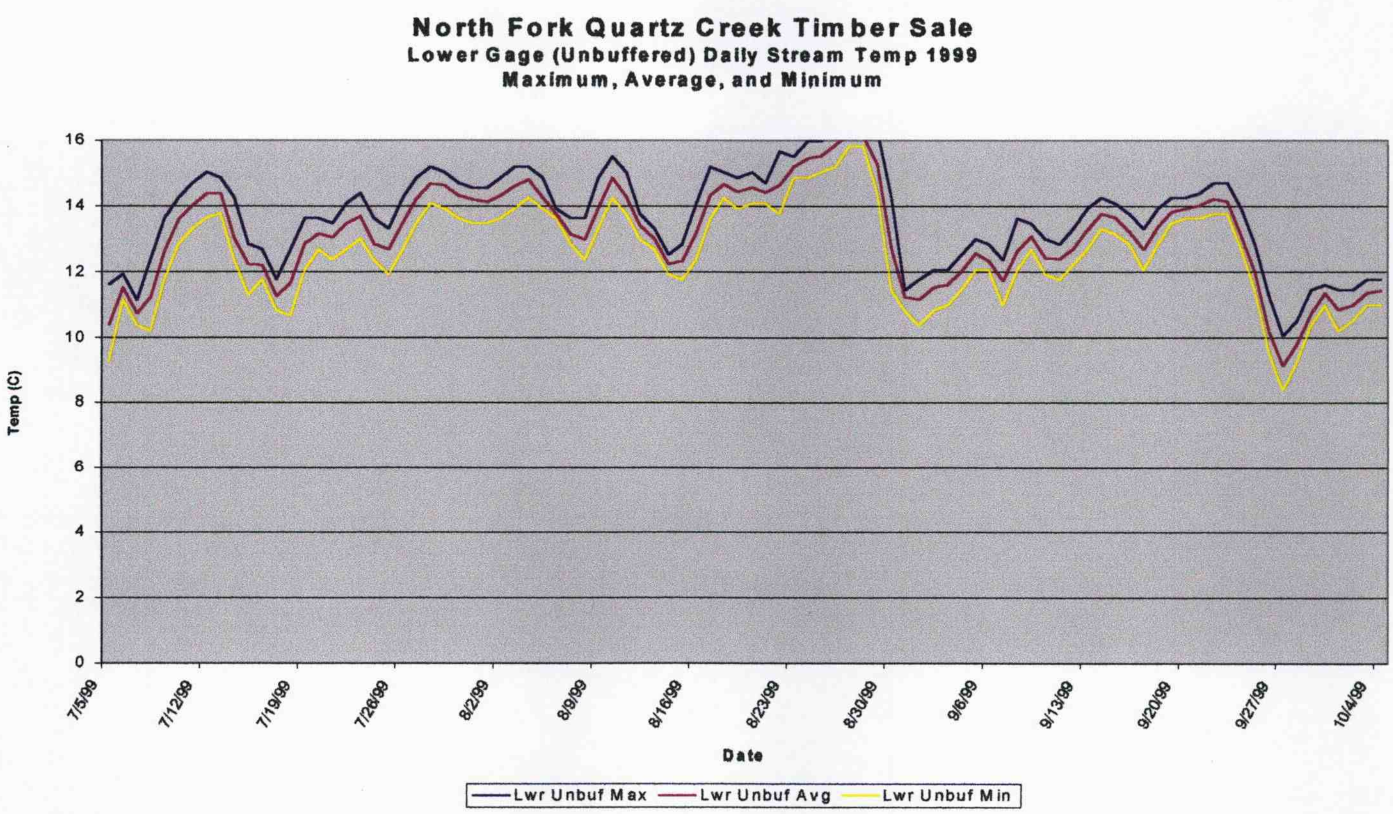


Figure V.20

4. *BRF 2000 Stream Temperature (Max, Avg, and Min)*

Stream temperature data for the summer of 2000, provided in figures V.21 – V.29, is consistent with stream temperature data for the summer of 1999, provided in the Appendix, taking in to account ambient air temperature, amount of insolation, and other natural occurrences for the 2 summers. Data for both summers was acquired prior to any logging prescription implementation. Analysis of data for 2 consecutive pre-harvest summers provides a valuable baseline when the time comes to evaluate post-harvest effects for this area and can provide clues about any natural disturbances that may have occurred between the 2 sample dates.

a. *BRF Upper Gage*

The *control* stream daily temperature data, shown if figure V.21, fluctuates widely in unison with air temperature data and displays a cooling trend from mid August and on, much more so than the *buffered* stream and slightly more than *unbuffered* stream. The *control* stream reaches a peak max temperature of 13.8°C in late July and early August, and then again for a week in mid September due to an increase in ambient air temperature. The *control* stream temperature ranged from 10 to 14°C from mid July to early September and from 8 to 12.5°C from early September to mid October. Ambient air temperature appears to have more influence on the *control* stream when compared to the *buffered* and *unbuffered* streams, but the relatively elevated fall stream temperature indicates a certain degree of protection from insolation. The diurnal swings are fairly minimal with at most a 1.5°C difference between max and min with the greatest difference experienced during peak air temperatures or during large cool air daily temperature variations.

The *buffered* stream data, shown in figure V.22, is much cooler and less influenced by air temperature than the *control* and *unbuffered* streams. The *buffered* stream max daily temperature range is a minimal 0.75°C, or 8 to 8.75°C, from mid July to early September with a small diurnal variation for this period. From mid September and on, significant shifts in air temperature appear to have more influence on the *buffered* stream, although the temperature range remains very small and the *buffered* stream temperature remains elevated into the fall season. Data indicates that this stream is a cool, well-insolated stream.

The *unbuffered* stream temperatures, shown in figure V.23, are approximately mid range between the warm *control* stream and the cool *buffered* stream. The *unbuffered* stream appears to be influenced by ambient air temperature, but less so than the *control* stream. The max daily stream temperature ranges from 10.5 to 12°C from mid July to early September and 9 to 11°C from early September to mid October. The largest diurnal swings occur during times of max air temperature and large cool air daily variations similar to the *control* stream.

The late summer stream temperatures stay somewhat elevated for all 3 streams indicating a certain amount of protection from insolation. At the same time, the *control* and *unbuffered* streams are influenced by daily air temperature variations. In contrast, the upper gage *buffered* stream seems perfectly insolated until late September when daily air temperature swings are most drastic.

A faulty max temperature spike is evident in October on all 3 upper gage graphs. Upper gage data for 2000 matches very well with upper gage data for 1999.

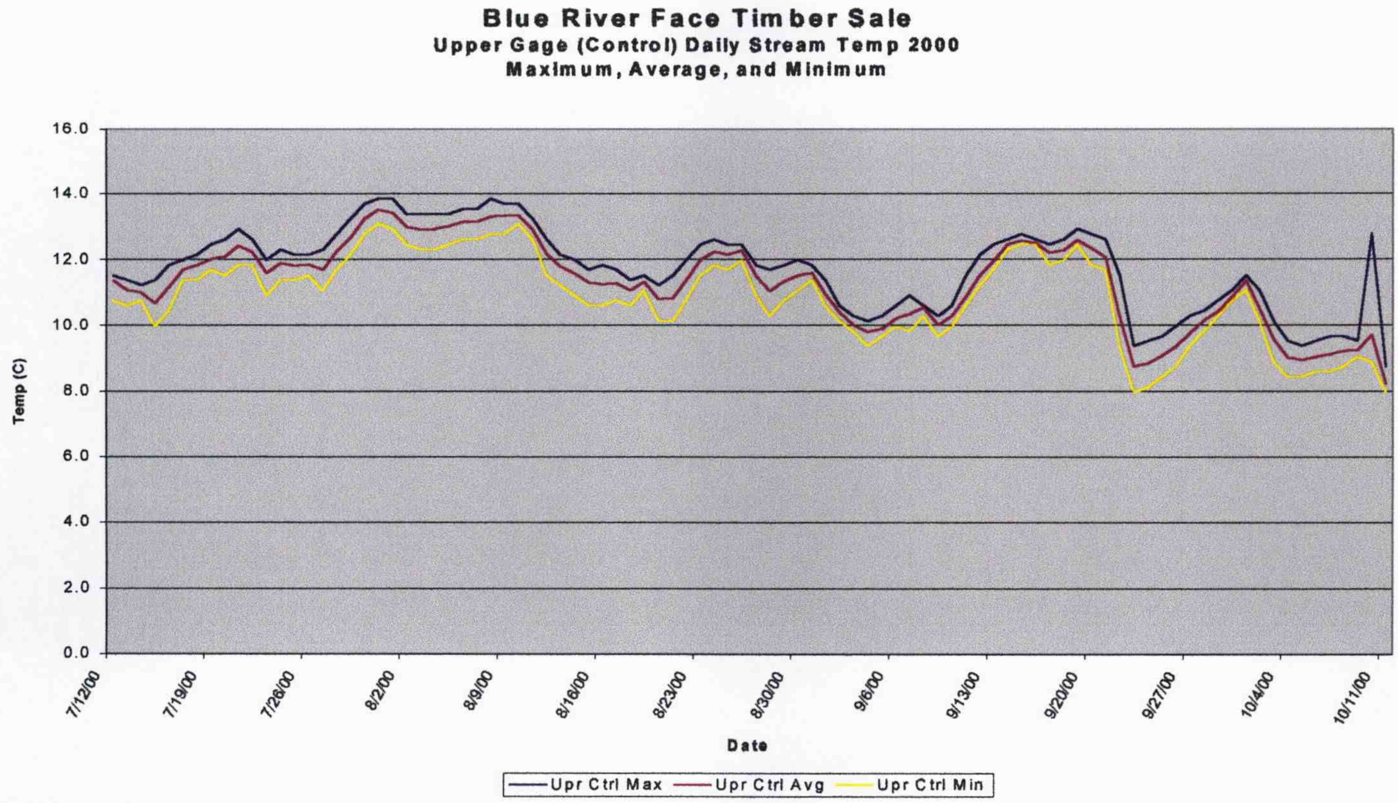


Figure V.21

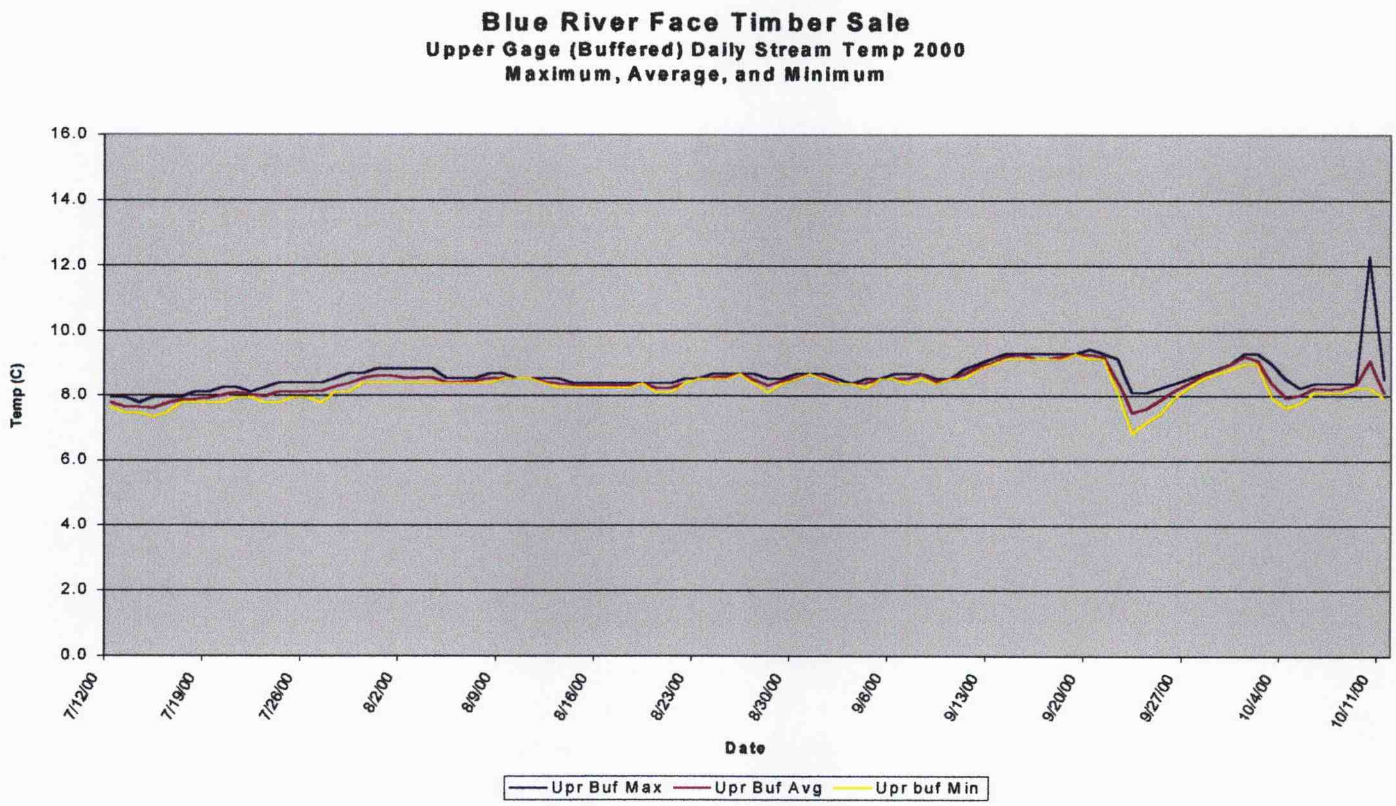


Figure V.22

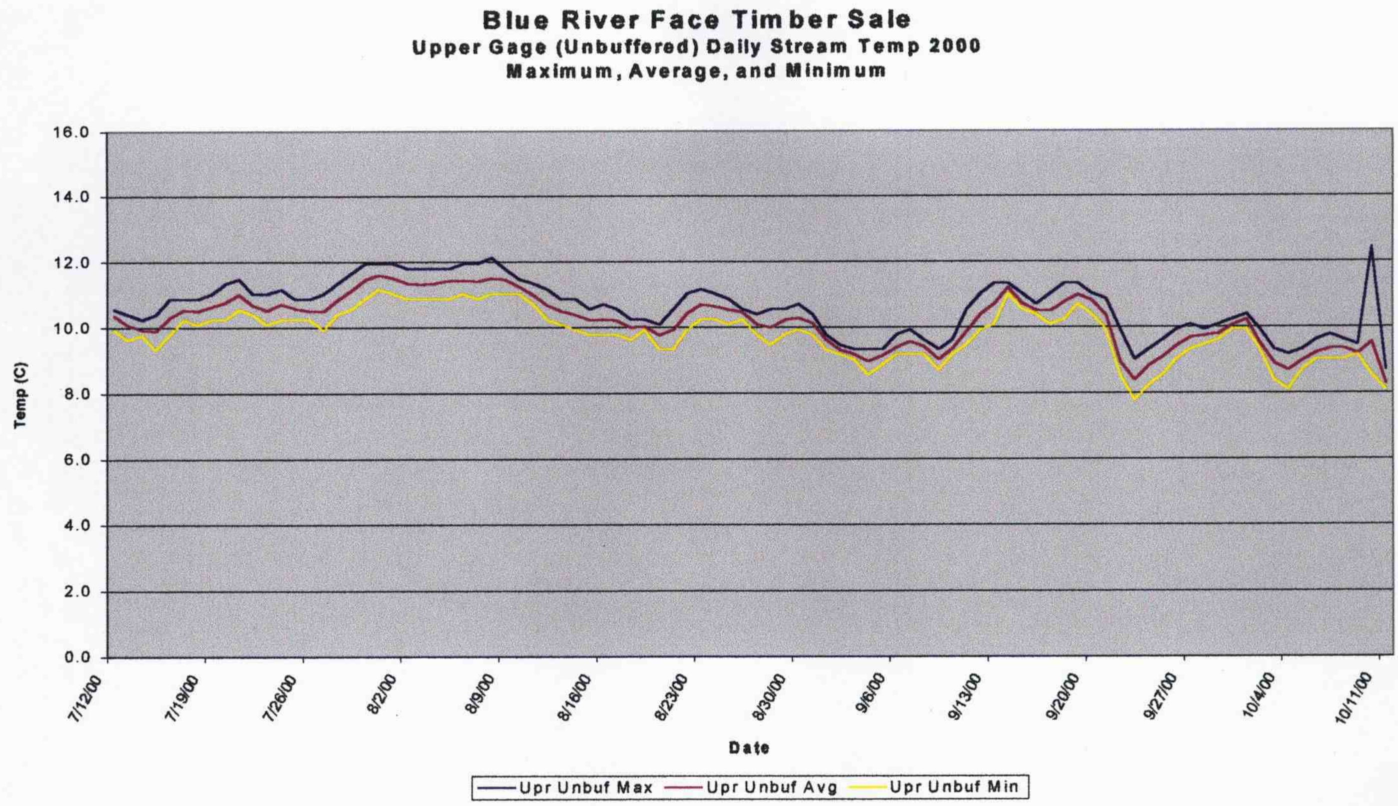


Figure V.23

b. *BRF Middle Gage*

The *control* stream middle gage data, provided in figure V.24, is almost identical to that of the upper gage with temperatures slightly higher as the stream flows to a lower elevation. The middle gage experiences the same daily and diurnal fluctuations due to air temperature and runs about 0.3˚C warmer than the upper gage.

The *buffered* stream data, provided in figure V.25, shows considerably more diurnal and daily variation throughout the summer and a significant increase in the influence of daily air temperature variations in the fall. The middle gage reveals a 2 to 2.5˚C overall temperature increase when compared to the upper gage.

The *unbuffered* stream data, provided in figure V.26, is similar to upstream with a very slight increase in overall temperature and a decrease in diurnal variation.

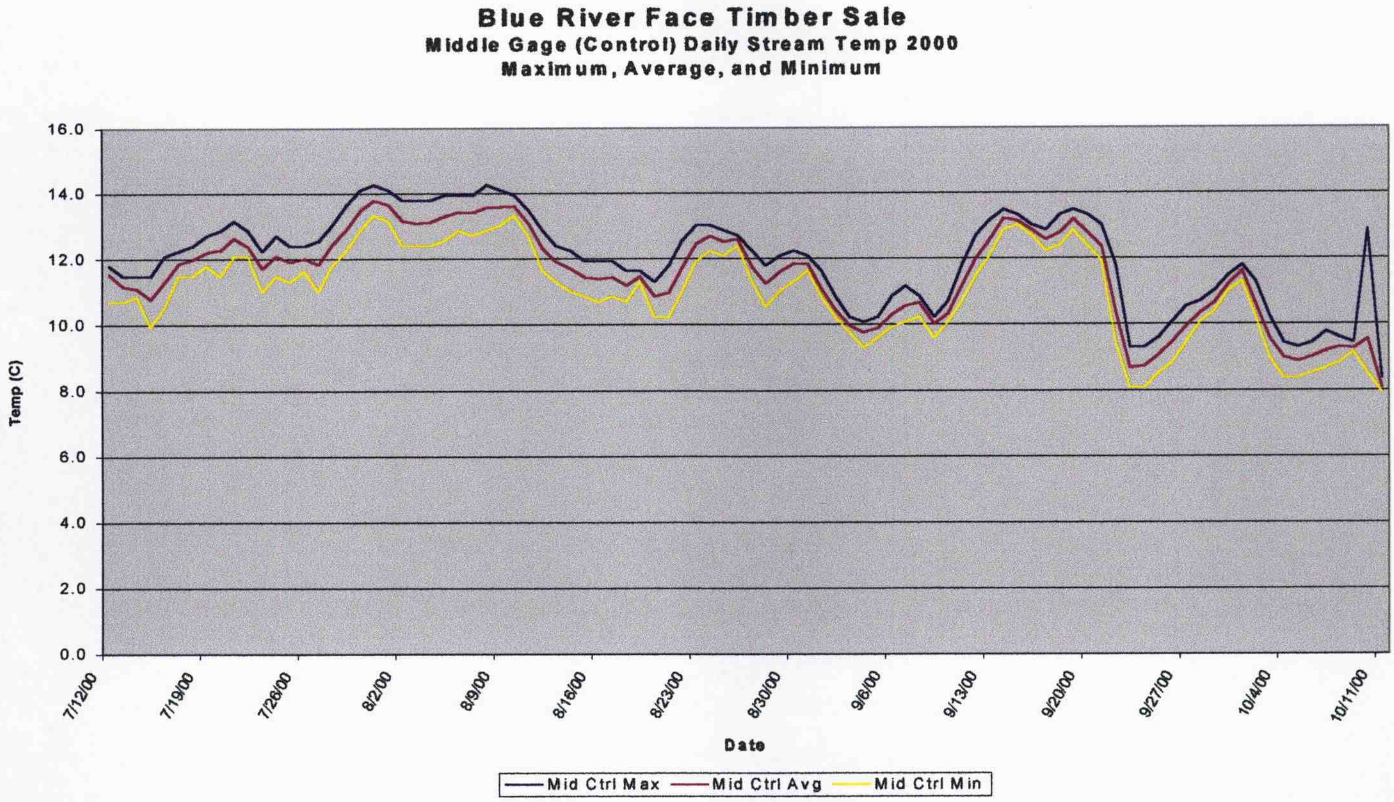


Figure V.24

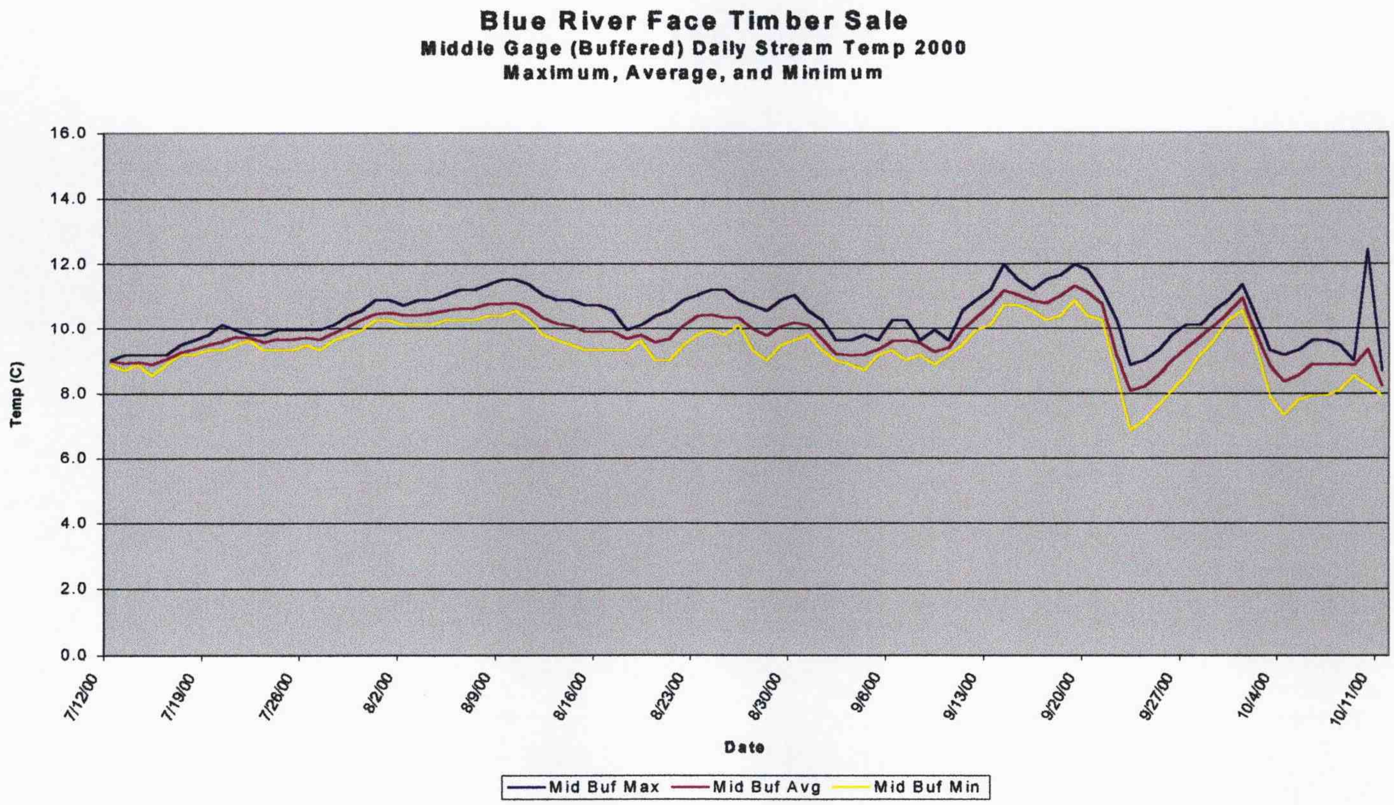


Figure V.25

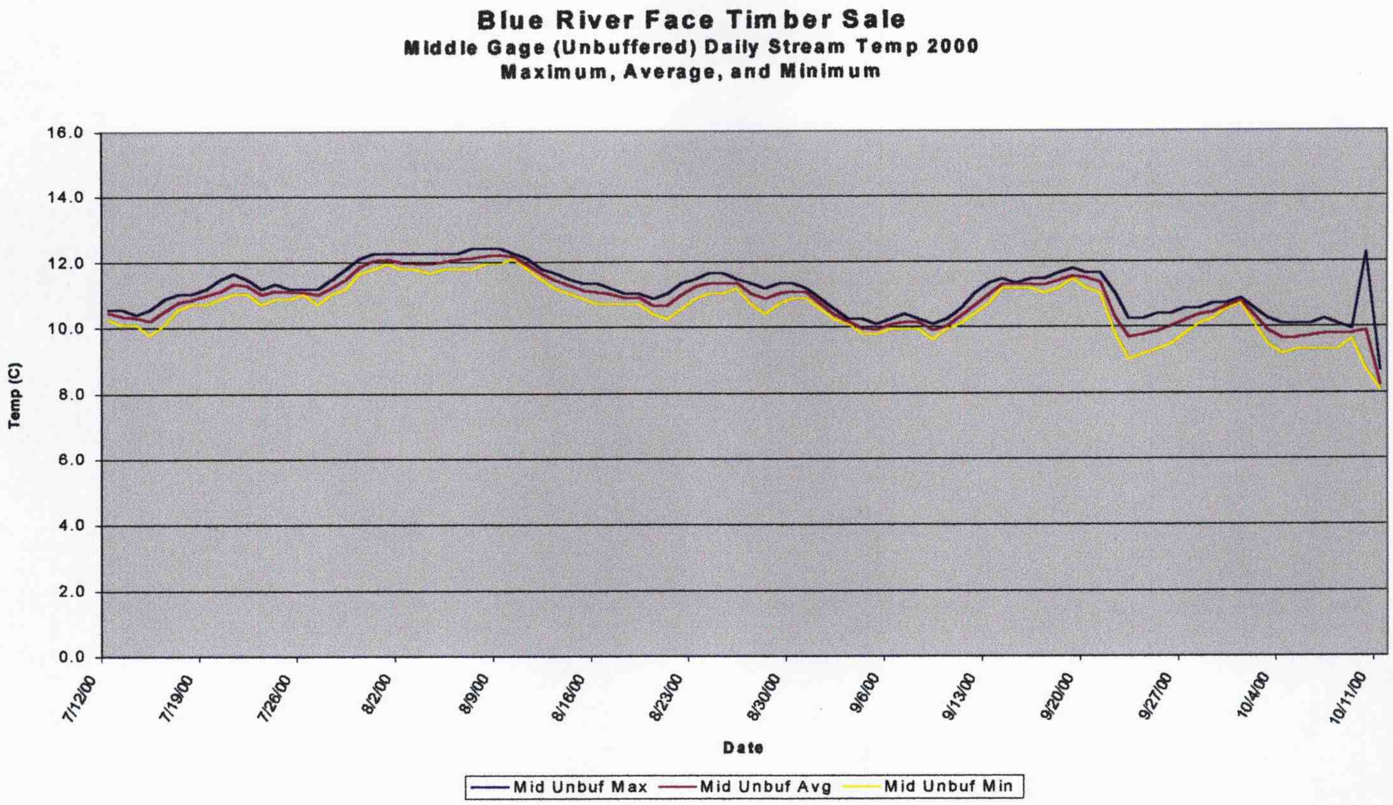


Figure V.26

c. *BRF Lower Gage*

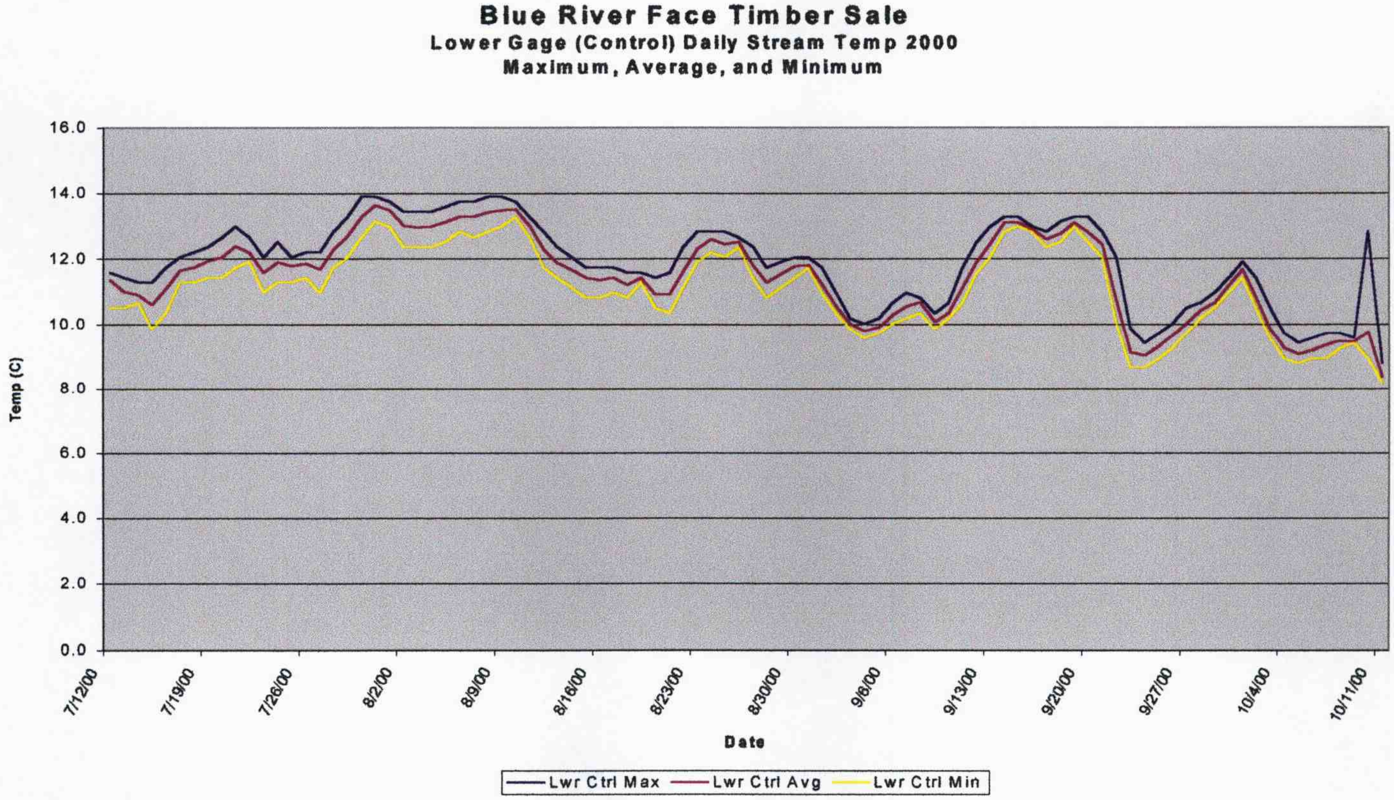
The *control* stream data, provided in figure V.27, is practically identical to data for the upper and middle gages, but appears to have cooled slightly from late July to early August when compared to middle gage data. It appears that the middle gage is most influenced by ambient air temperature highs in late July with slightly higher maximum temperatures than the upper and lower gages. Perhaps the middle gage placement is slightly more susceptible to ambient air influences or other stream cooling influences are at work between the middle and lower gage.

The *buffered* stream data, provided in figure V.28, looks quite different from the non-fluctuating data of the upper gage. For July and August, the lower gage shows the widest diurnal spread and follows ambient air temperature variations closely. The max stream temperature ranges from 10 to 12.5˚C from mid July to early September and from 9.5 to

13°C from early September to mid October. The largest diurnal spread is about 1.5°C and occurs during the hottest air temperatures in late July.

The *unbuffered* stream data, provided in figure V.29, shows that the stream is warming slightly as it flows to a lower elevation with a peak temperature of 12.75°C at the beginning of August. The lower gage shows a wider diurnal spread than the middle gage and similar to the upper gage.

The upper gage *buffered* data must have been gathered near a very cool spring. A significant increase in diurnal and daily variation occurred for data taken at the middle and lower gages. A faulty spike in max data is evident in late fall for lower gage data and middle gage data above.



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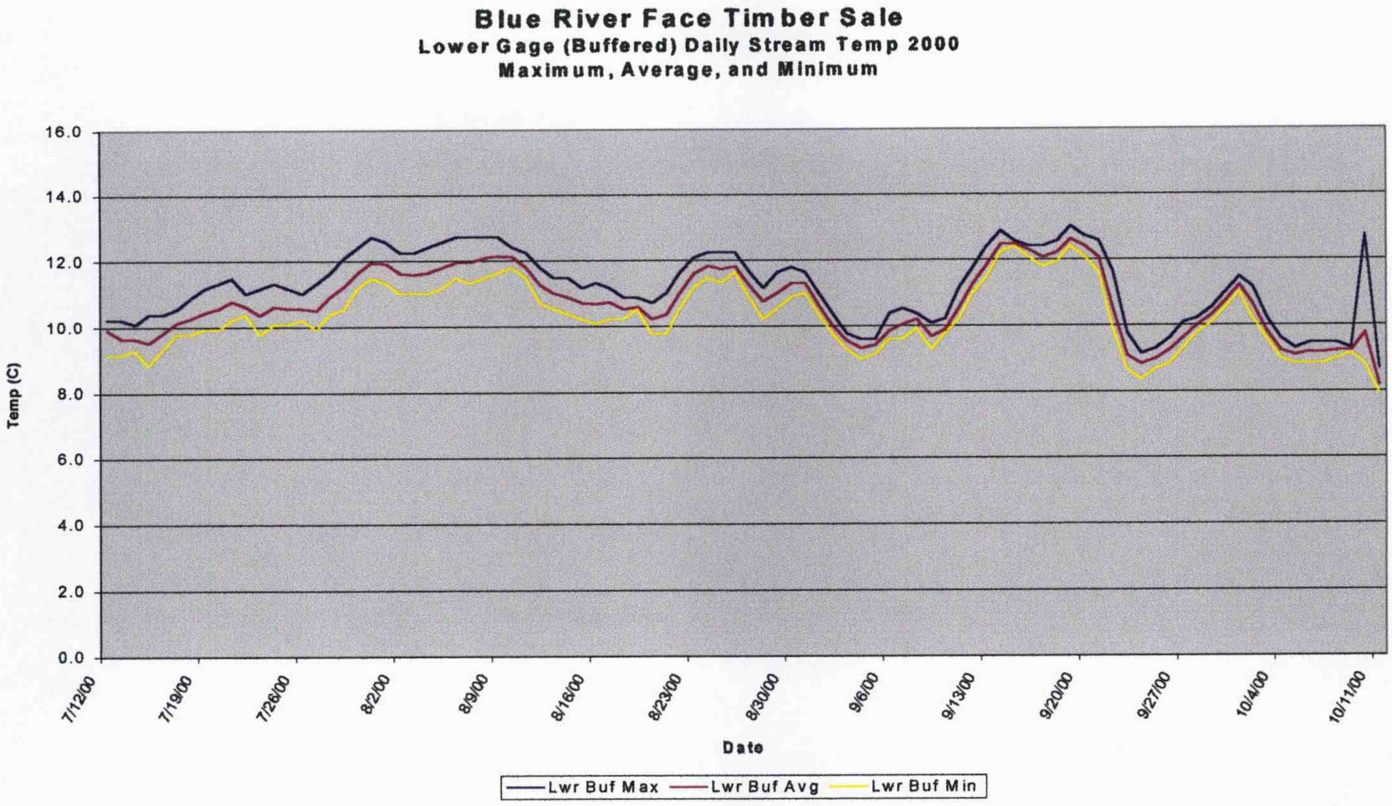


Figure V.28

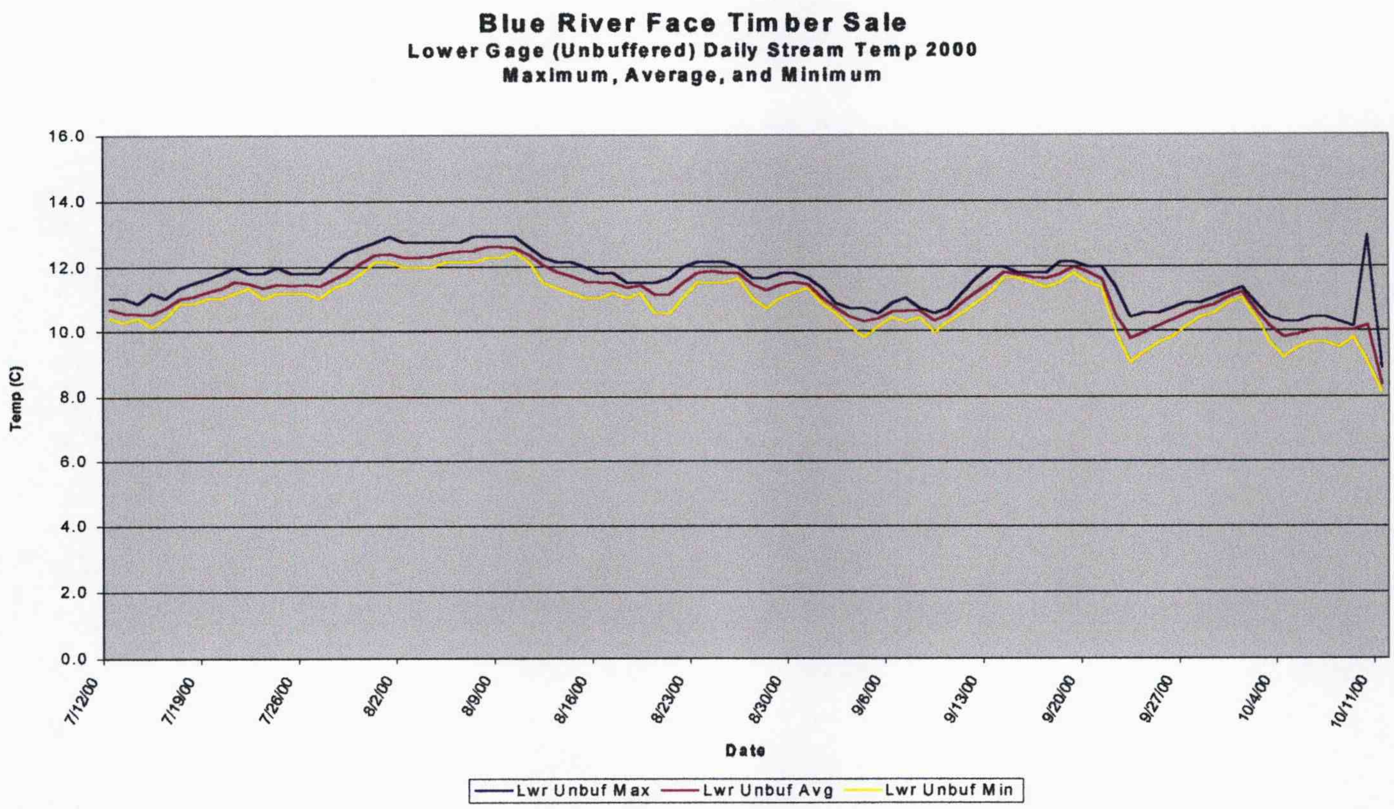


Figure V.29

5. *WM 2000 Stream Temperature (Max, Avg, and Min)*

Stream temperature data for the summer of 2000, provided in figures V.30 – V.41, appears consistent with stream temperature data for the summer of 1999, provided in the Appendix, taking in to account ambient air temperature and amount of insolation differences, and other natural occurrences for the 2 summers. The glaring exception is the data analyzed for lower gage control "X" data for the summer 2000. All *control* data at every other gage location for 1999 and 2000 does not reach near the high temperatures or the wide diurnal variations of lower gage control "X" for 2000. Either the data capture is suspect or some unknown influence dramatically impacted the temperature at this location. Data for both summers was acquired prior to any logging prescription implementation. Analysis of data for 2 consecutive pre-harvest summers provides a valuable baseline when the time comes to evaluate post-harvest effects for this area and can provide clues about any natural disturbances that may have occurred between the 2 sample dates.

a. *WM Upper Gage*

The control "X" stream data, provided in figure V.30, displays minimal diurnal variation with a max temperature range from 9 to 12°C and a high that is reached in early August. The daily stream temperature variation throughout the summer follows the air temperature variation closely with stream temperature remaining fairly elevated as air temperatures fall from early September to mid October.

The "A" stream data, provided in figure V.31, shows a rather cool stream with a wide diurnal variation of about 2°C in early August and max high temperature of 10.2°C that is not reached until mid September. The max temperature range is from 7 to 10.2°C and fall stream temperature remains elevated. The "A" stream minimums dip below 6°C in

September and are 2°C lower than any minimum temperature for control "X" stream. Overall, the "A" stream runs 2°C cooler than the control "X" stream and is much more susceptible to daily highs and lows.

The "B" stream data, provided in figure V.32, is very similar to stream "A" with a wide diurnal spread and a max temperature range from 7 to 10°C. Highs are reached in early August and again in mid September. Minimum temperatures dip well below 6°C from early September to mid October.

The "C" stream data, provided in figure V.33, starts at its warmest temperatures in mid July, reaching 13.3°C, and then slowly trends downward throughout the summer and into fall. The diurnal shift is about 1 to 2°C in early summer and decreases from there on. Stream "C" shows similar patterns to the other streams, but is the only graph to show a comparatively steep cooling trend from early summer to late fall.

Stream "X", "A", and "B" show similar ambient air temperature influences with "A" and "B" running significantly cooler than control "X" and with significantly wider diurnal variation. Stream "C" starts out 2 to 3°C warmer than the other 3 streams, but the continuous stream "C" cooling throughout the summer causes "C" max stream temperature to drop below "X" max stream temperature and near as cool as "A" and "B" in the fall. Data seems to indicate that the "C" is not that well insolated. Stream "A" and "B" appear comparatively cool, but affected by daily high and low temperatures. The control "X" stream does not appear to be significantly affected by daily high and low temperatures, but is consistently the warmest stream of the upper gage group. Again, upper gage 2000 data matches extremely well with upper gage 1999 data provided in the Appendix.

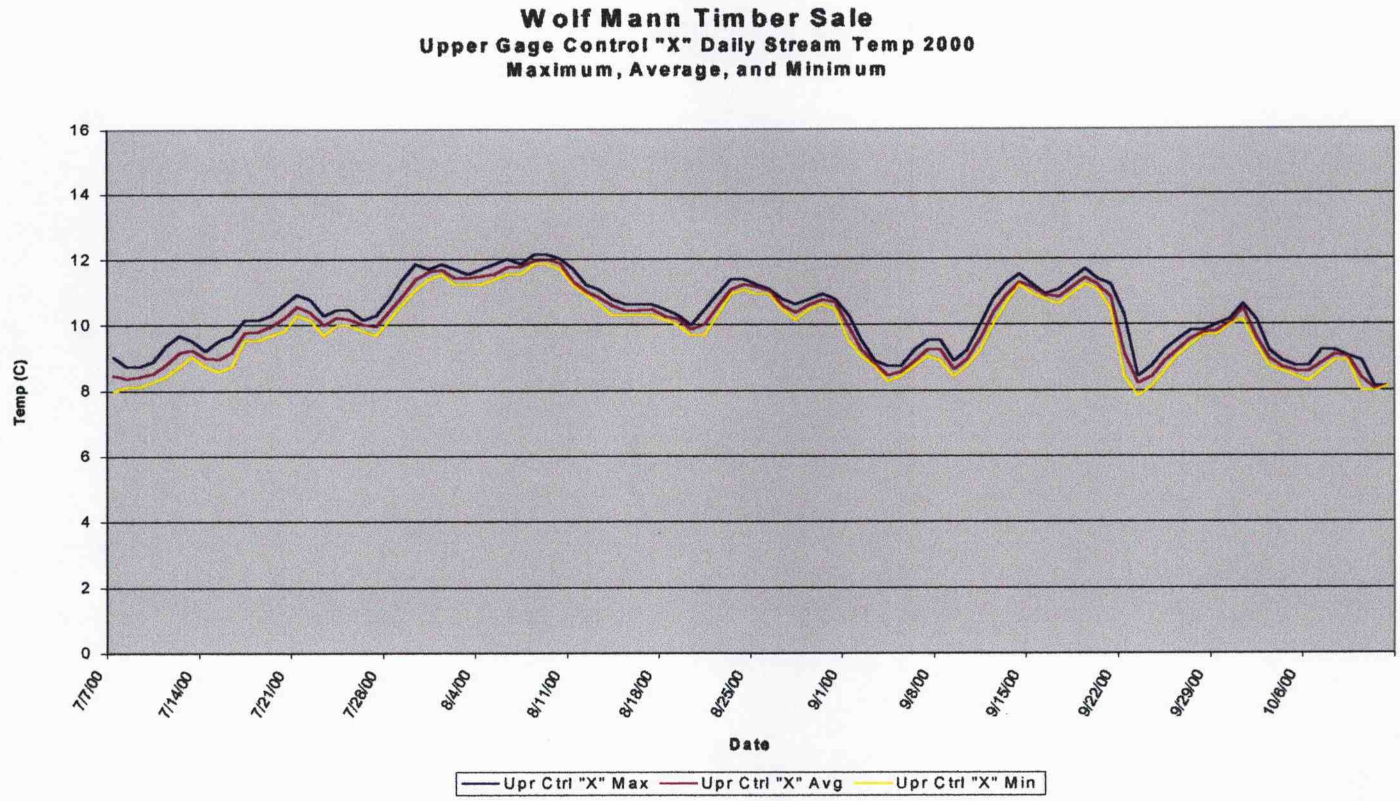
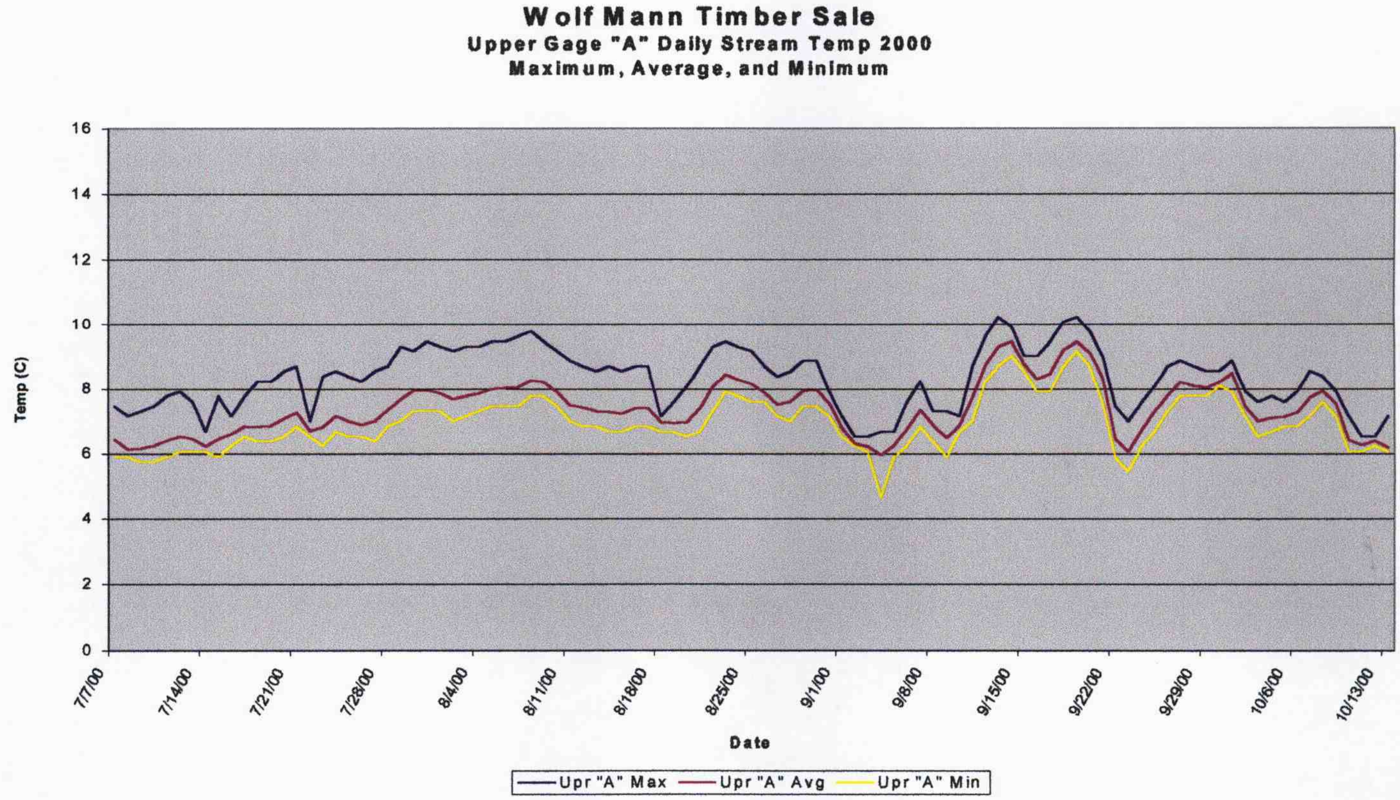


Figure V.30



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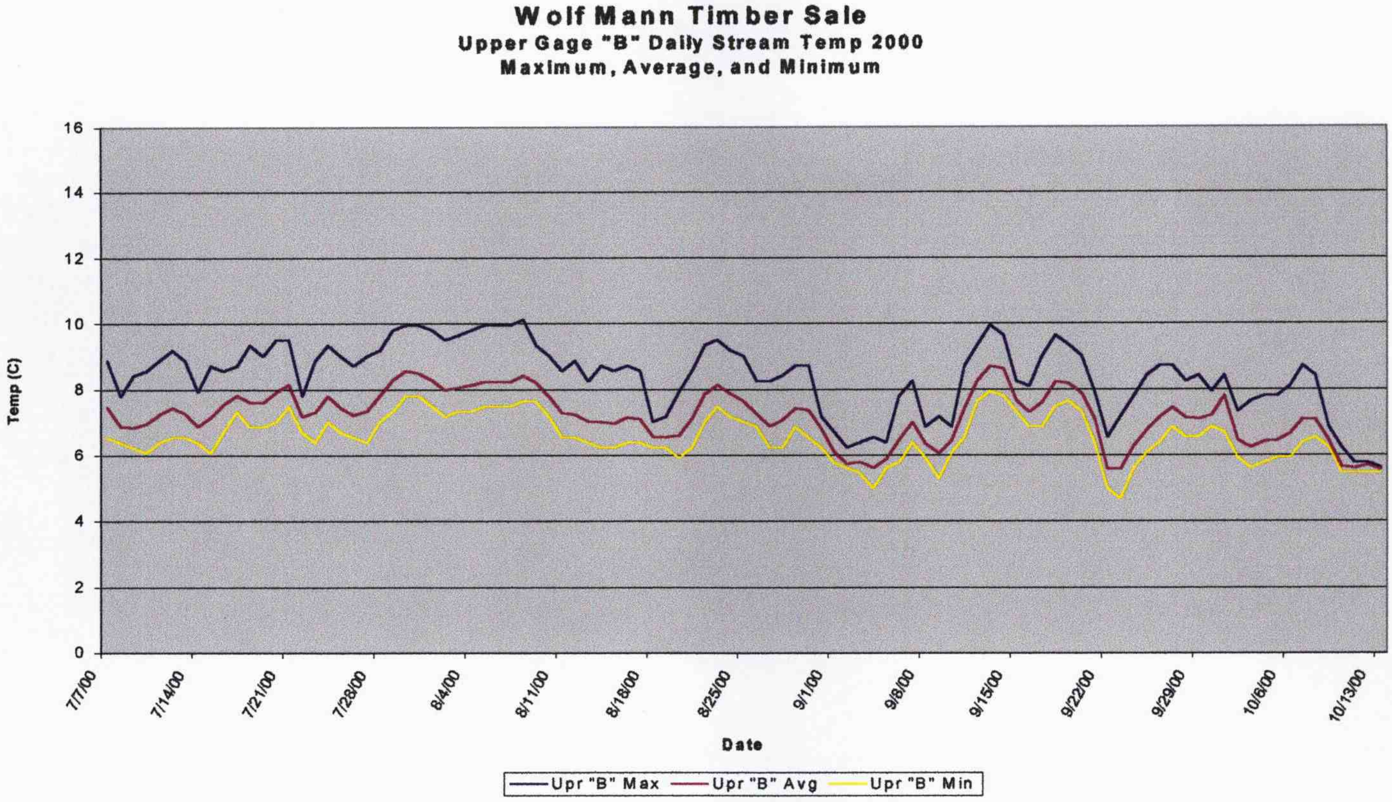

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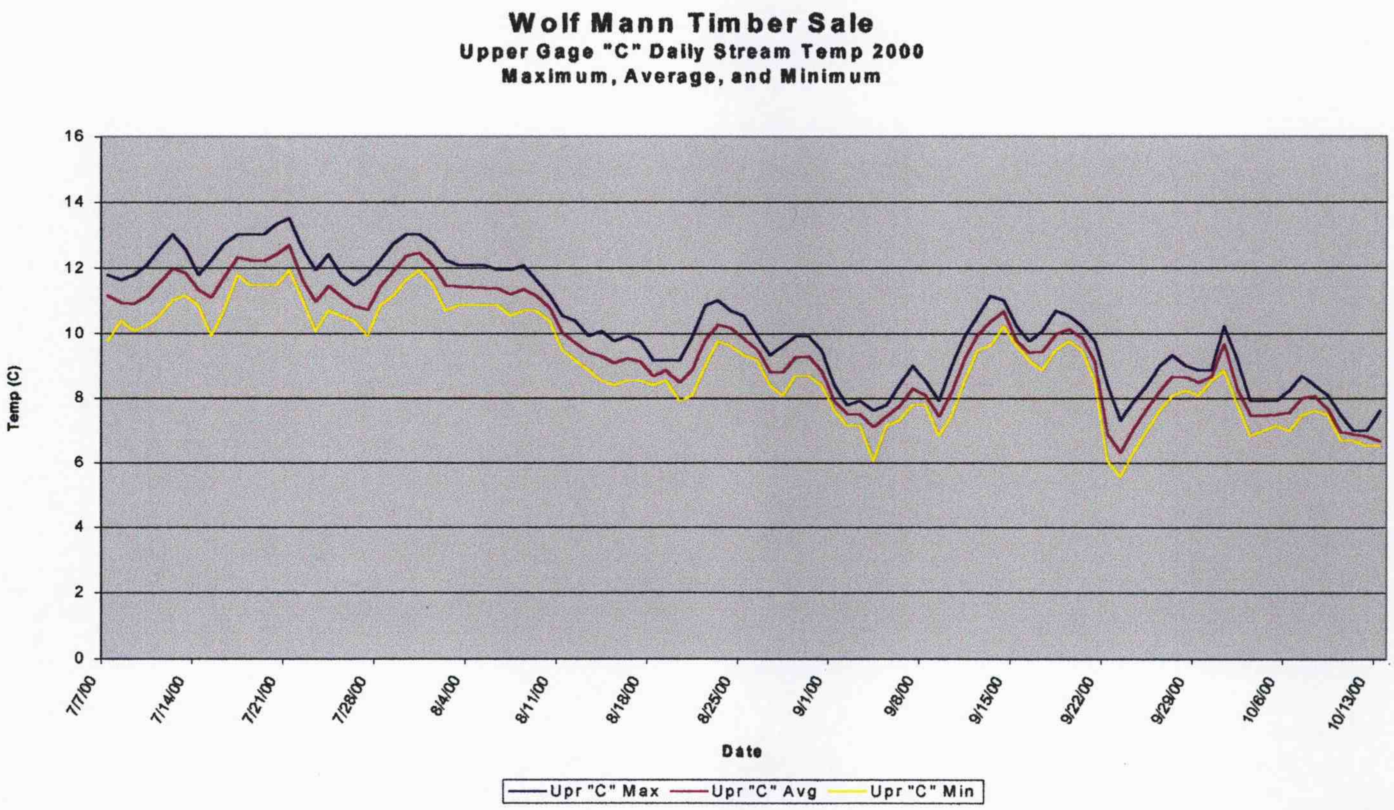


Figure V.33

b. *WM Middle Gage*

The control "X" stream data, provided in figure V.34, shows a peak high temperature in late July of 13°C, which is about 1°C warmer than the upper gage. The summer temperatures range from 8.5 to 13°C with both the upper and middle gage displaying minimal diurnal variation.

The "A" stream data, provided in figure V.35, runs 2 to 3°C warmer than the upper gage with large daily and diurnal fluctuations throughout the summer and minimums dropping near 6°C in early September. The data shows an overall temperature increase of at least 2°C as stream flows from the upper to the middle gage. The upper gage appears to be located near a cold source.

The "B" stream data, provided in figure V.36, shows a similar 2 to 3°C increase from the upper gage with peak temperatures reached in early to mid August and a diurnal spread of 2°C. Again, stream "A" and "B" display very similar characteristics and effects from ambient air temperature and insolation.

The "C" stream data, provided in figure V.37, shows a 3 to 4.5°C increase in max temperature when compared to the upper gage and huge diurnal and daily fluctuations. The max peaks at 16°C in late July and a minimum of 5.75°C is reached in late September with a max and min range of about 8°C. The max temperature peaks again to 15°C in mid September before finally falling to near 12°C in late September.

The middle gages displayed the typical warming observed when streams run to lower elevation. The control "X" was near "A" and "B" temperatures with a smaller diurnal and daily variation. The "C" stream was the warmest with a much wider diurnal spread.

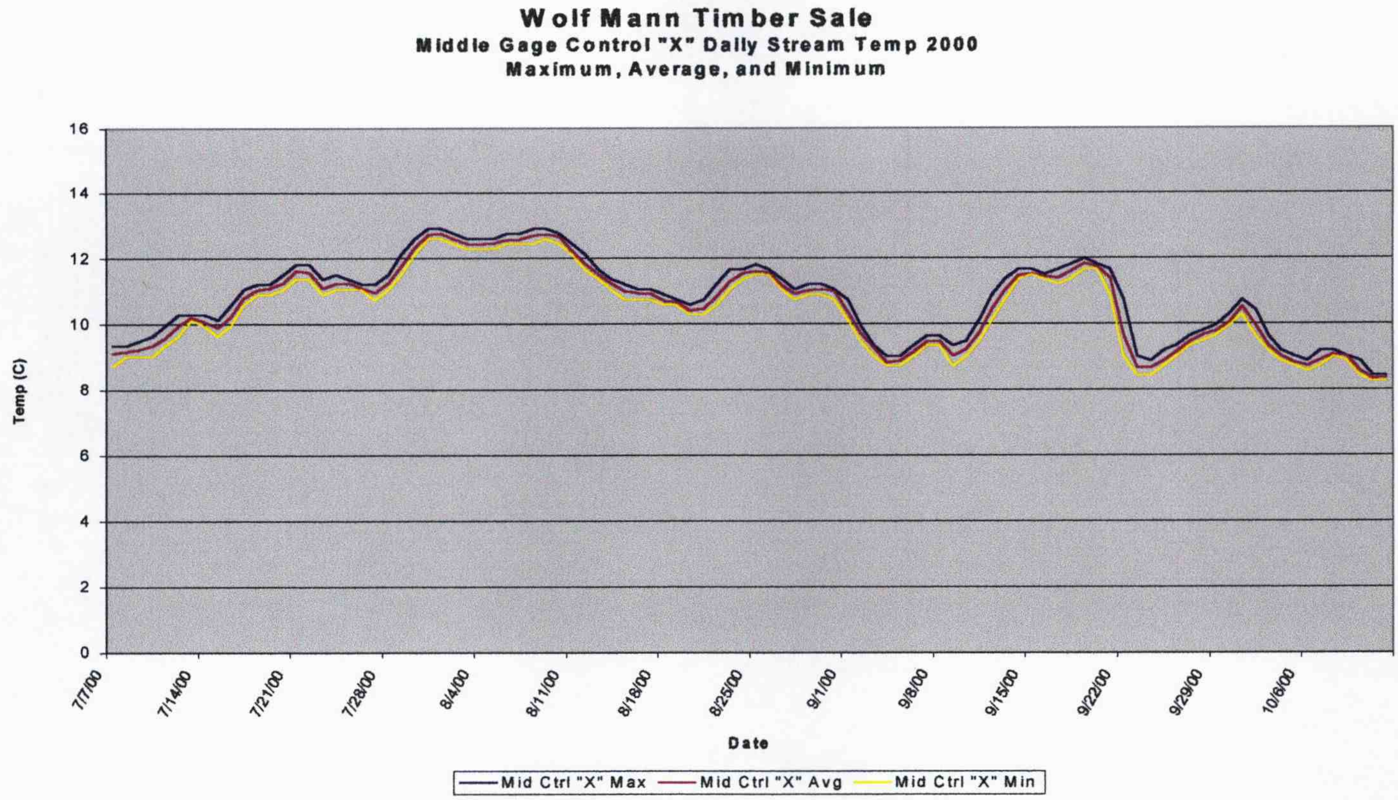
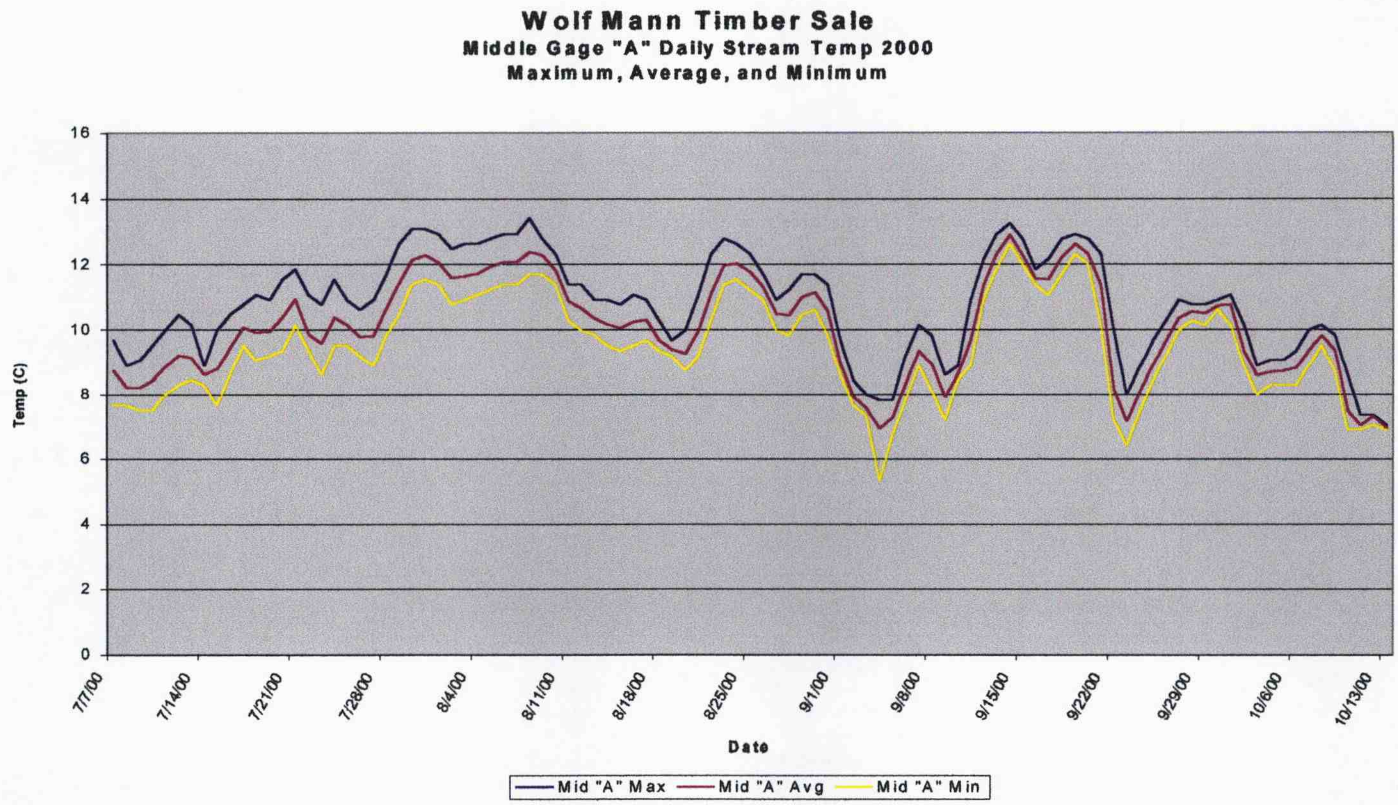


Figure V.34



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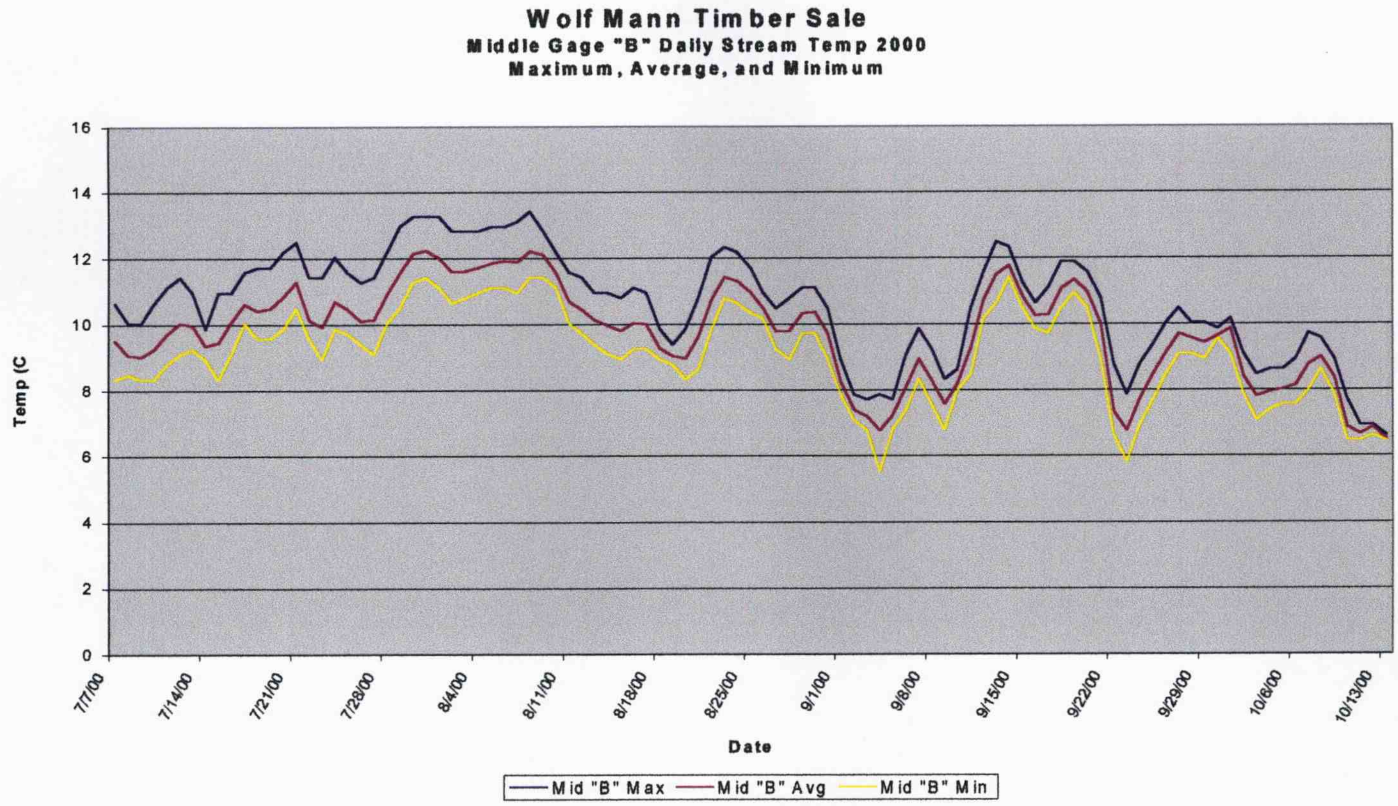

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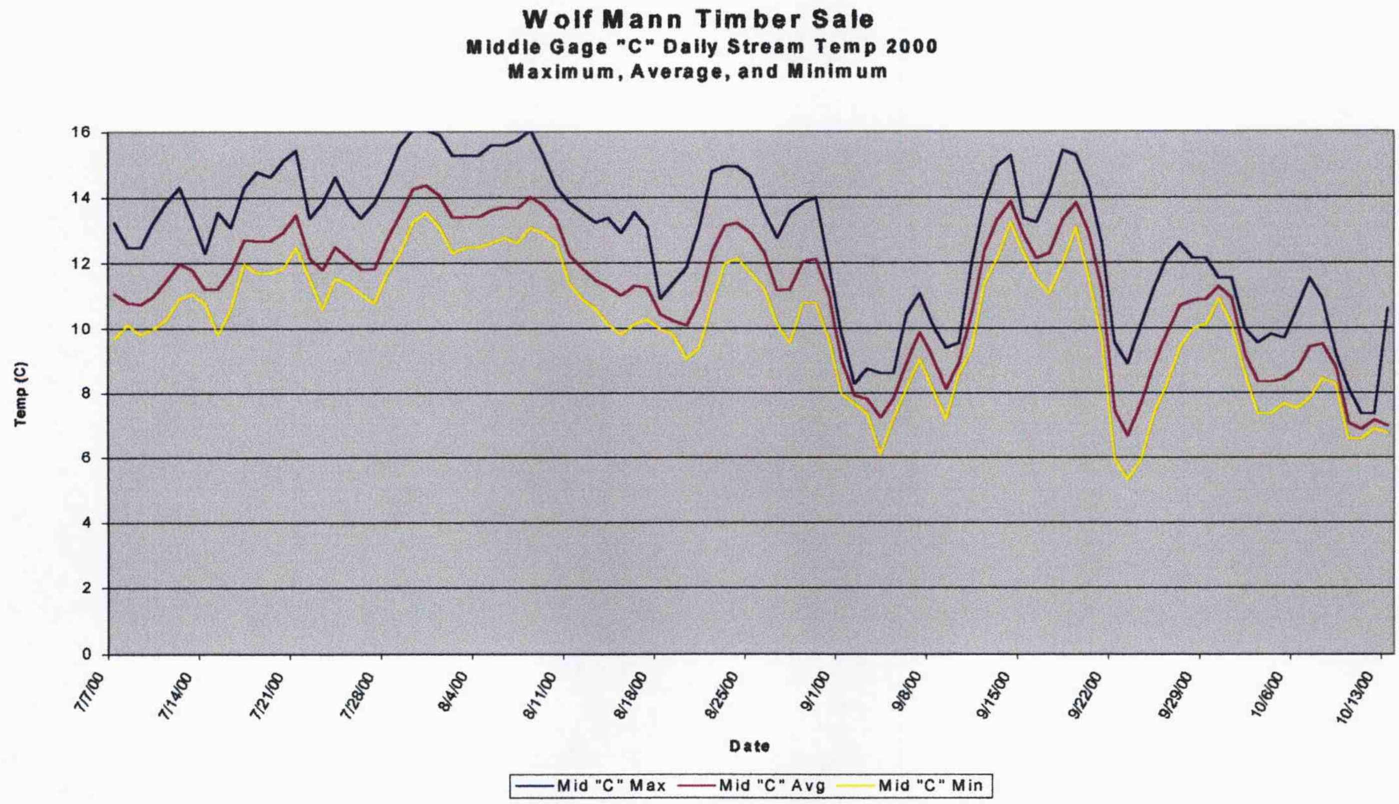


Figure V.37

c. *WM Lower Gage*

Again, the control "X" stream data, provided in figure V.38, appears suspect after analyzing the upper and middle gages. It would seem that the lower gage has become exposed to ambient air or resides in a very shallow pool of water particularly when compared to lower control "X" 1999 data provided in the Appendix.

The "A" stream data, provided in figure V.39, is very similar to middle gage data, but the lower gage has slightly less pronounced daily temperature fluctuations. A peak temperature of 13.5°C is reached in early August and a low of 6°C is reached in early September. Peak temperatures are again reached in mid September during a weeklong period of 22°C air temperature.

The "B" stream data, provided in figure V.40, is very similar to stream "B" middle gage and stream "A" lower gage in daily fluctuation and overall temperature. Stream "B" lower gage shows slightly less diurnal variation and runs slightly warmer than stream "B" middle gage in the fall months. This stream reaches a high temperature of 13.5°C in late July and early August and a low of 6°C in early September.

The "C" stream data, provided in figure V.41, is very similar in overall daily fluctuation to upstream middle gage temperatures, but shows a smaller diurnal variation and slightly less influence from daily ambient air temperature variations. The middle gage max temperature runs about 1°C warmer in late summer and early fall when compared with the lower gage. The lower gage appears less affected by daily fluctuations and daily extremes when compared to the upstream gage.

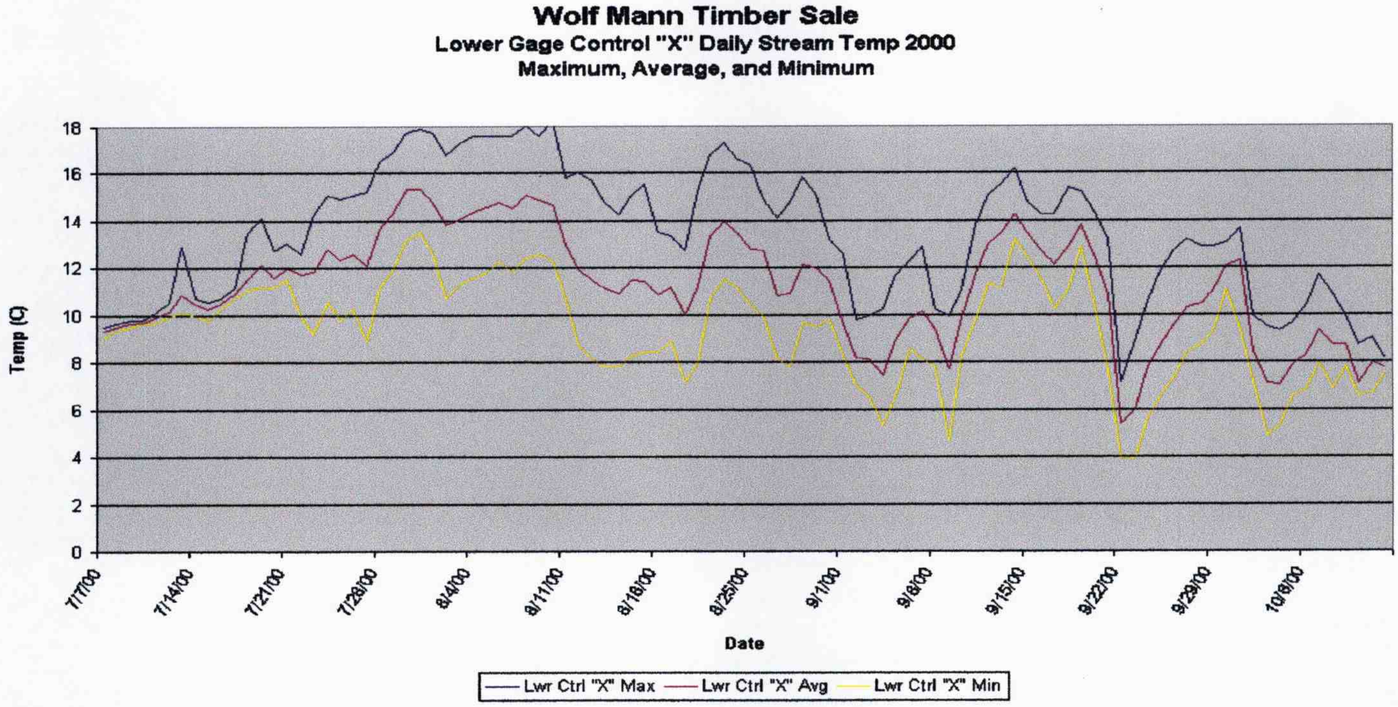
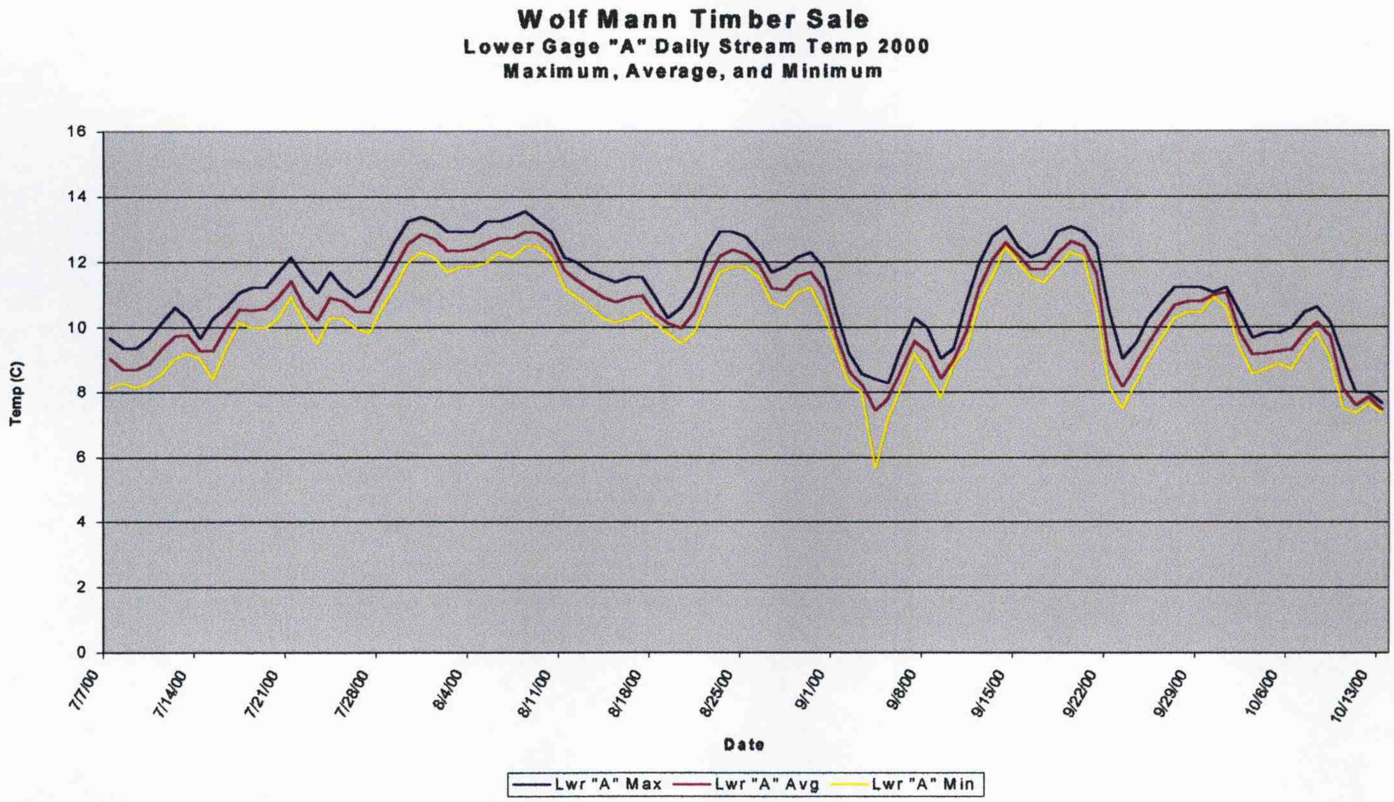


Figure V.38



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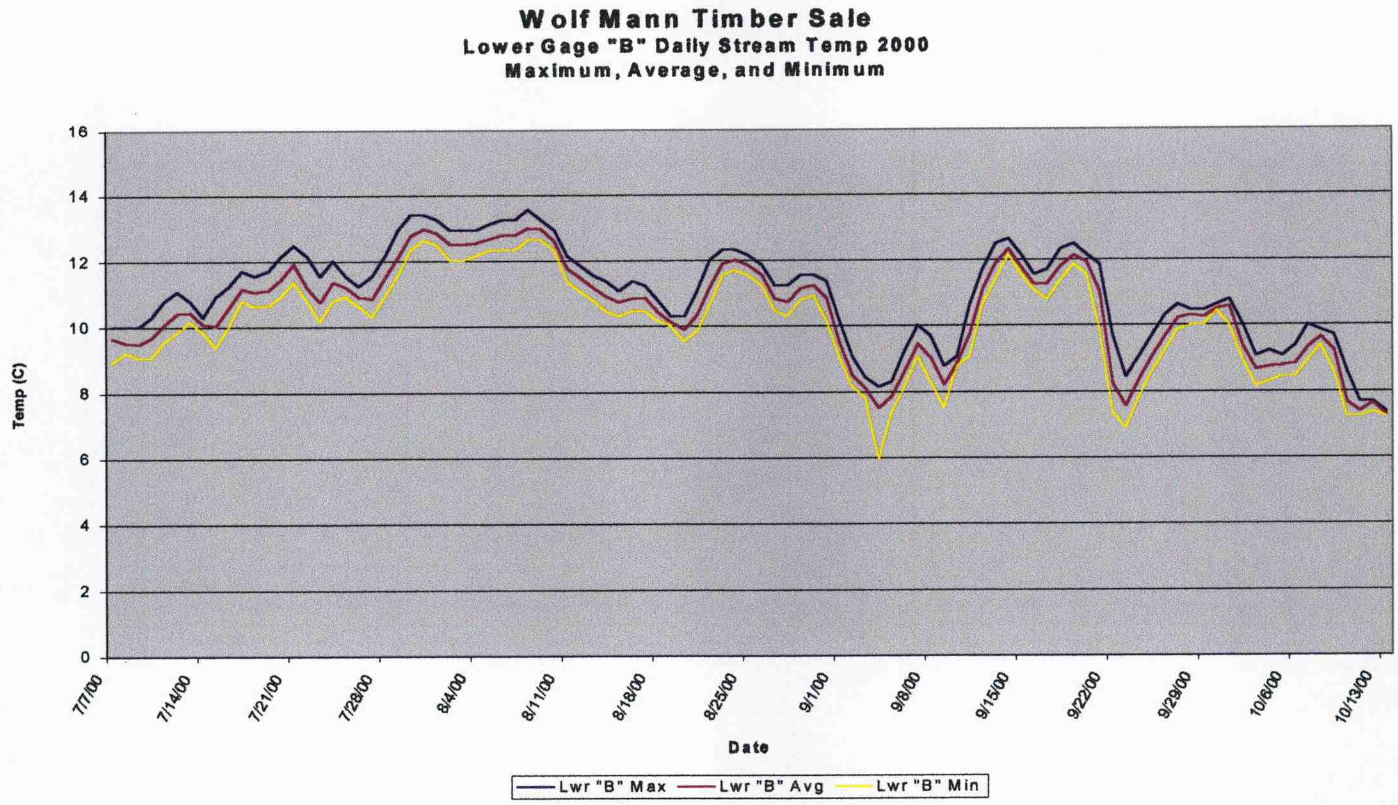

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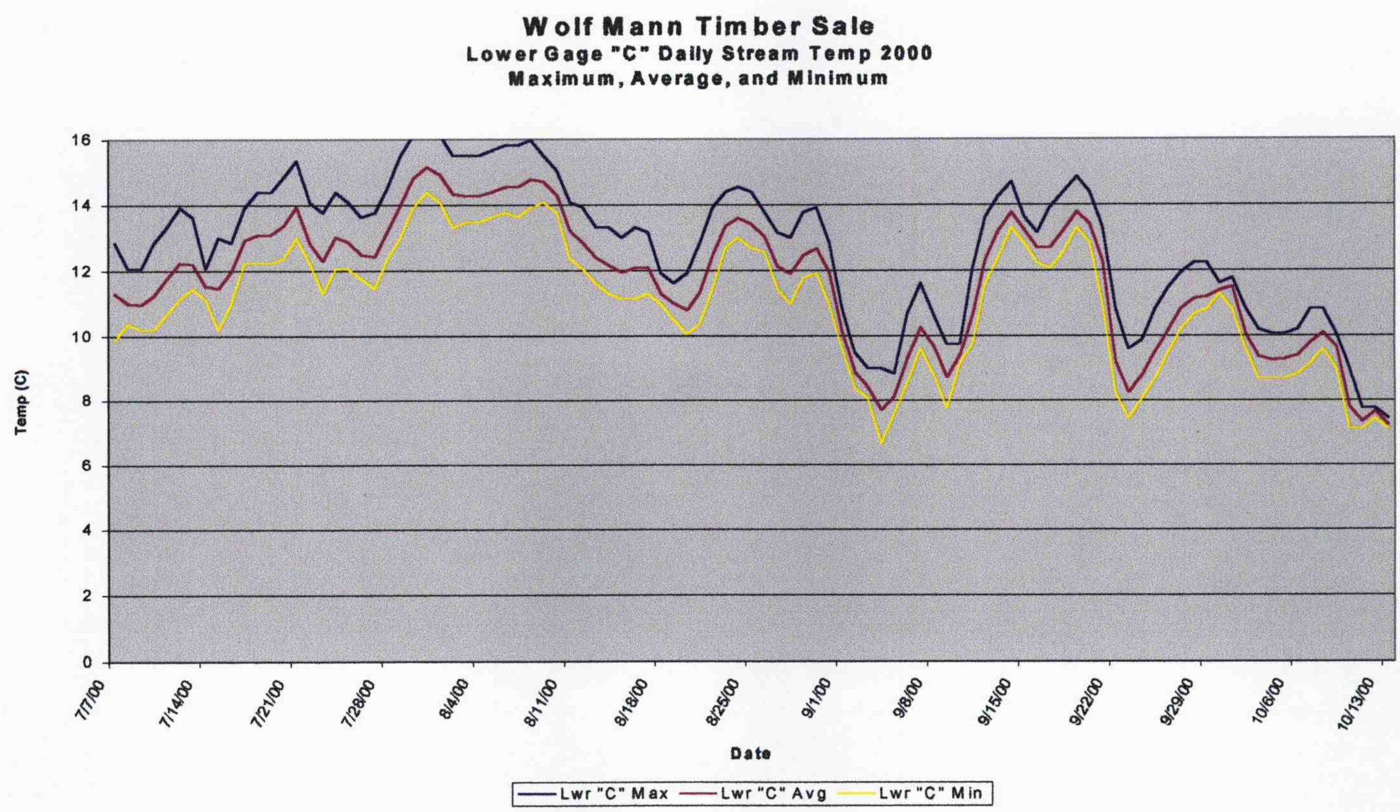

Figure V.41

VI. CONCLUSIONS

A. North Fork Quartz Creek

The (*control – buffered*) comparison, pre and post-harvest, displayed the most significant changes in stream temperature, but there were no glaring signals indicating a direct link to the logging implementation. The upper gage (*control – buffered*) data indicates no significant impact to *buffered* stream temperature from early July to early August, but does indicate some *buffered* stream warming from mid August through the fall. This is applicable to all upper gage max, avg, and min temperature difference graphs. However, the lower gage data appears to indicate that the post-harvest *buffered* stream is cooler from early July to early August and fairly even with pre-harvest data from mid August and on. So, the upper and lower gages appear to yield some contrasting conclusions. The *buffered* 2000 data does exhibit more diurnal and daily temperature fluctuation than the *buffered* 1999 data, which can indicate more influence from ambient air and insolation. The summer 2000 air temperatures did stay warmer than 1999 air temperature data making both the *control* and *buffered* 2000 streams warmer than 1999 data indicates.

The lower gage *control* 2000 stream ran warmer than the lower gage *control* 1999 stream while the *buffered* streams for the 2 summers were relatively the same during this time frame. So, actually the warmer *control* 2000 stream resulted in the *buffered* 2000 stream appearing cooler on the temperature difference graphs.

The pre and post-harvest data gathered only provides minimal evidence of *buffered* stream warming following logging implementation. Warmer 2000 air temperatures tended to complicate any clear signals. Data does provide some evidence of a 0.5 to 1°C increase in post-harvest *buffered* stream temperature. There does not appear to be any clear evidence of harvest impact on the *unbuffered* stream.

In general, the *control* stream runs about 2 to 3°C warmer than the *buffered* stream and 0.25 to 1.25°C cooler than the *unbuffered* stream. The pre-harvest stream temperature disparity between the prescribed sites, along with an initially warm control stream can tend to disguise harvest impacts on selected streams.

Another interesting observation evident in all of the 1999 (max, avg, and min) graphs, provided in section V and in the Appendix, is the upward stream temperature trend from early to late September during an extremely flat air temperature period. Maximum stream temperatures rose as much as 2°C during a period when maximum daily air temperature remained constant. This can be seen in 1999 data for NFQC, BRF, and WM.

B. Blue River Face

The data presented for the 2 consecutive summers will serve as a good baseline for future studies. Individual stream temperature differences, from one summer to the next, appear to correlate well in comparison and with air temperature data provided.

The *control* stream did not show the typical warming pattern when flowing from upstream to lower elevation. Max temperatures and widest diurnal variation were evident at the middle gage with the stream cooling slightly at the lower gage. The *control* stream showed considerable daily fluctuation and middle gage data peaked at 14.2°C in early August. The relatively flat upper gage *buffered* stream data was about 3.5 to 5°C cooler than the *control* stream with negligible daily and diurnal fluctuation evident until late September with a max temperature of 9.2°C. The upper gage *unbuffered* stream showed much of the same daily and diurnal variation as the *control* stream, but ran about 2°C cooler throughout the summer with a max temperature of 12°C in early August.

As mentioned previously, the *control* stream temperatures did not change significantly from the upper to the lower gage. The *unbuffered* stream generally warmed by 1°C upon arrival at the lower gage. However, the *buffered* stream changed dramatically from gage to gage. The *buffered* stream upper gage started as a flat line and warmed by about 2.5 to 3°C while showing a significant increase in diurnal and daily variation. At the lower gage, the *buffered* stream temperature patterns and overall temperatures were quite similar to the *control* and *unbuffered* streams. Therefore, the lower gages for the 3 logging prescriptions should provide good clues when studying the impacts of future forest harvest.

C. Wolf Mann

Stream "X", "A", and "B" show similar ambient air temperature influences with "A" and "B" running significantly cooler than control "X" and with significantly wider diurnal variation. Stream "C" starts out 2 to 3°C warmer than the other 3 streams, but the continuous stream "C" cooling throughout the summer causes "C" max stream temperature to drop below control "X" max stream temperature and near as cool as "A" and "B" in the fall. Data seems to indicate that the "C" is not that well insolated. Stream "A" and "B" appear comparatively cool, but affected by daily high and low temperatures. The control "X" stream does not appear to be significantly affected by daily high and low temperatures, but is consistently the warmest stream of the upper gage group. The control "X" stream peaks at 12°C in early August while the "A" stream nearly reaches 10°C in early August and peaks at 10.2°C in mid September. Stream "B" peaks at 10°C in early August and again in mid September. The "C" stream peaks at 13.7°C in mid July and decreases relatively quickly throughout the rest of the summer.

The most significant temperature change occurred at the middle gage data. While the control "X" stream warmed by 0.5 to 1°C, the "A", "B" and "C" stream temperatures increased by as much as 3 to 3.5°C and display very wide diurnal variations. The changes in data at the lower gage were less significant.

All streams appear to maintain elevated temperatures into the fall indicating a fair amount of forest cover. However, stream "C" did exhibit high temperatures in early summer then trend cooler in contrast to the other streams. Again, summer 2000 data matches extremely well with summer 1999 data provided in the Appendix.

VII. References

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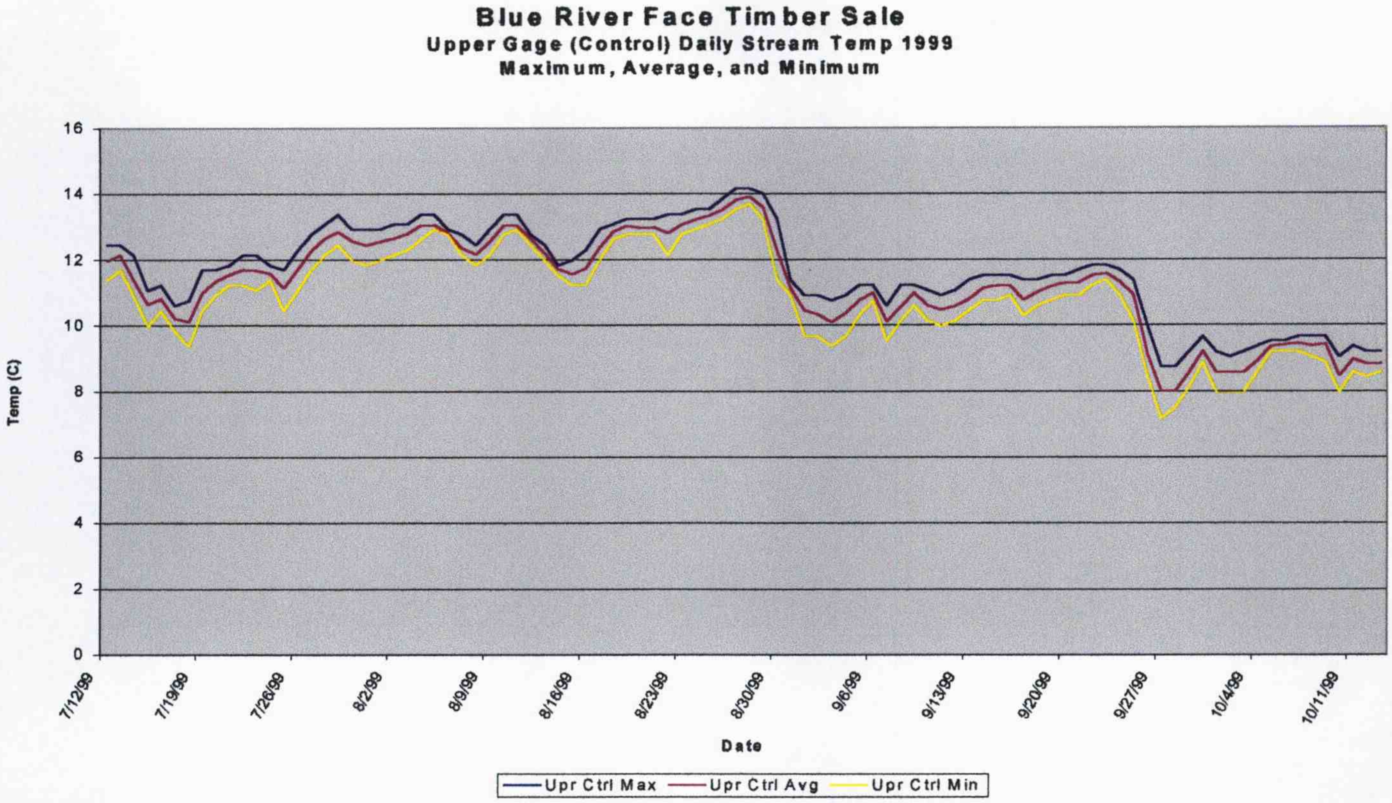
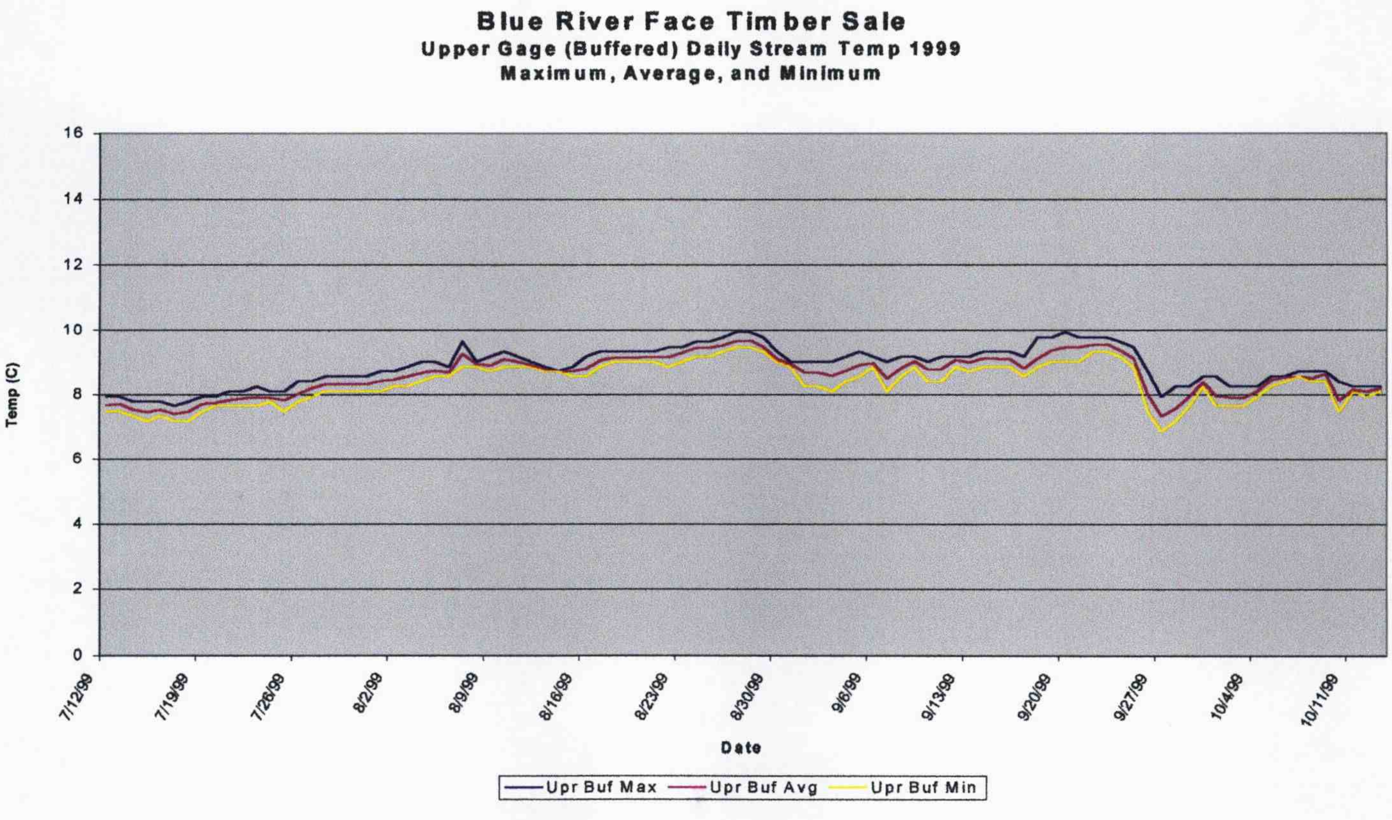
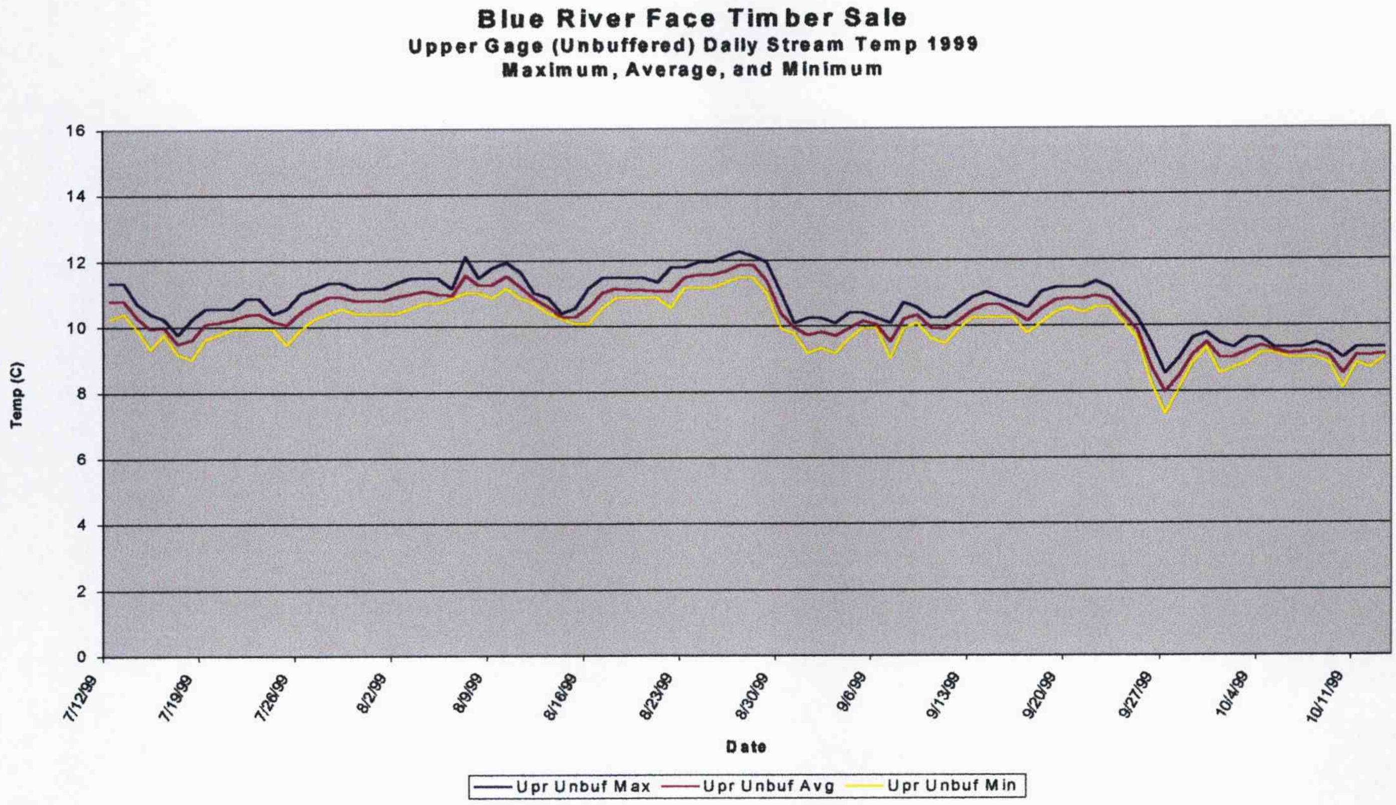
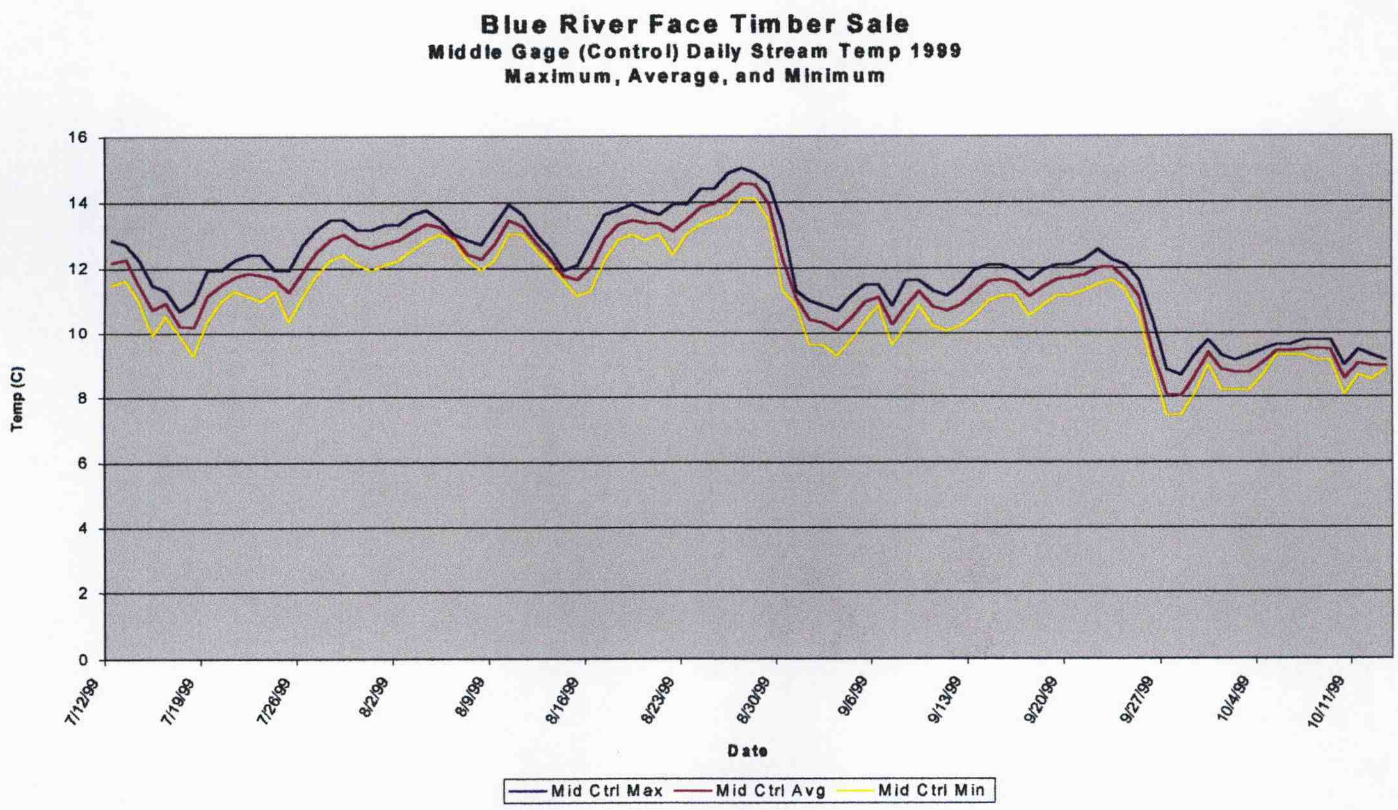
VIII. APPENDIX Blue River Face 1999 Data



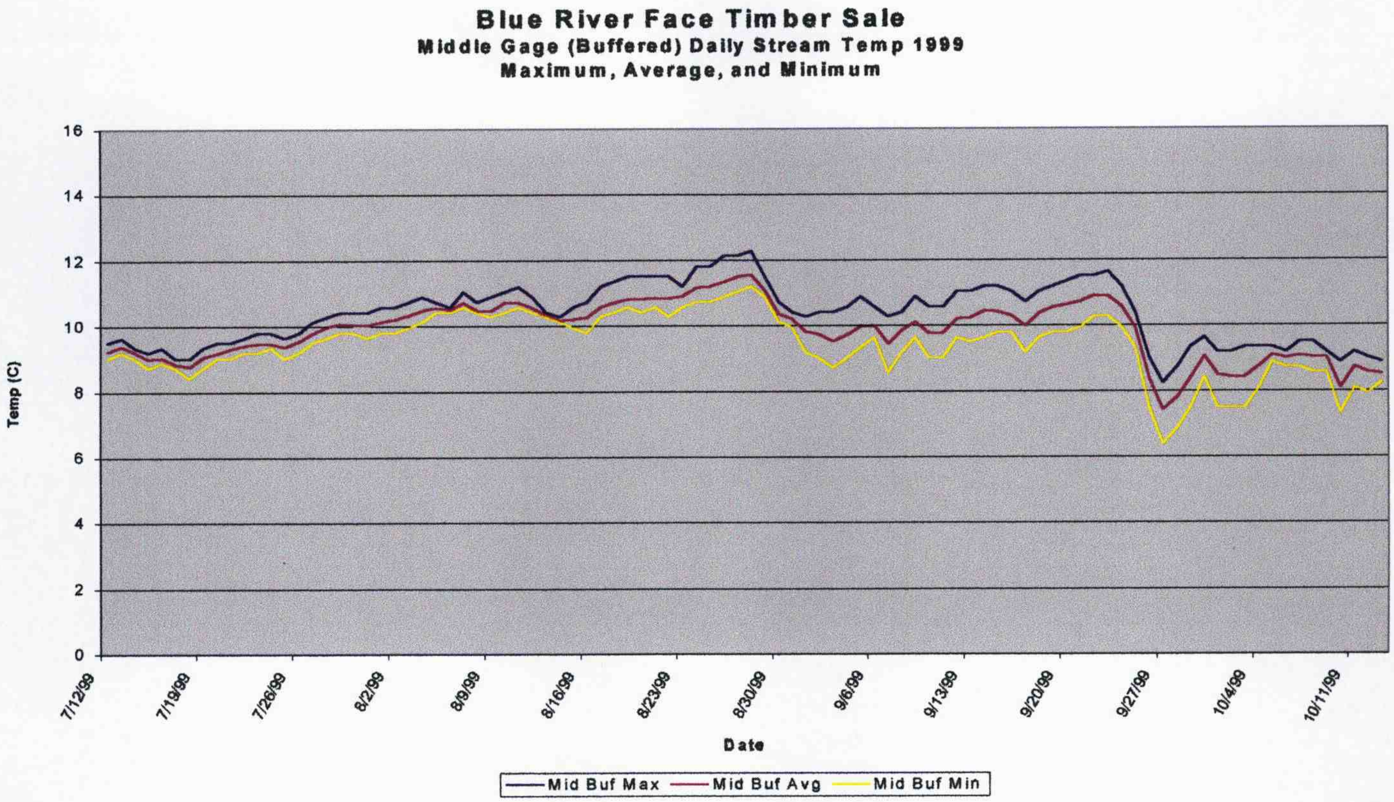


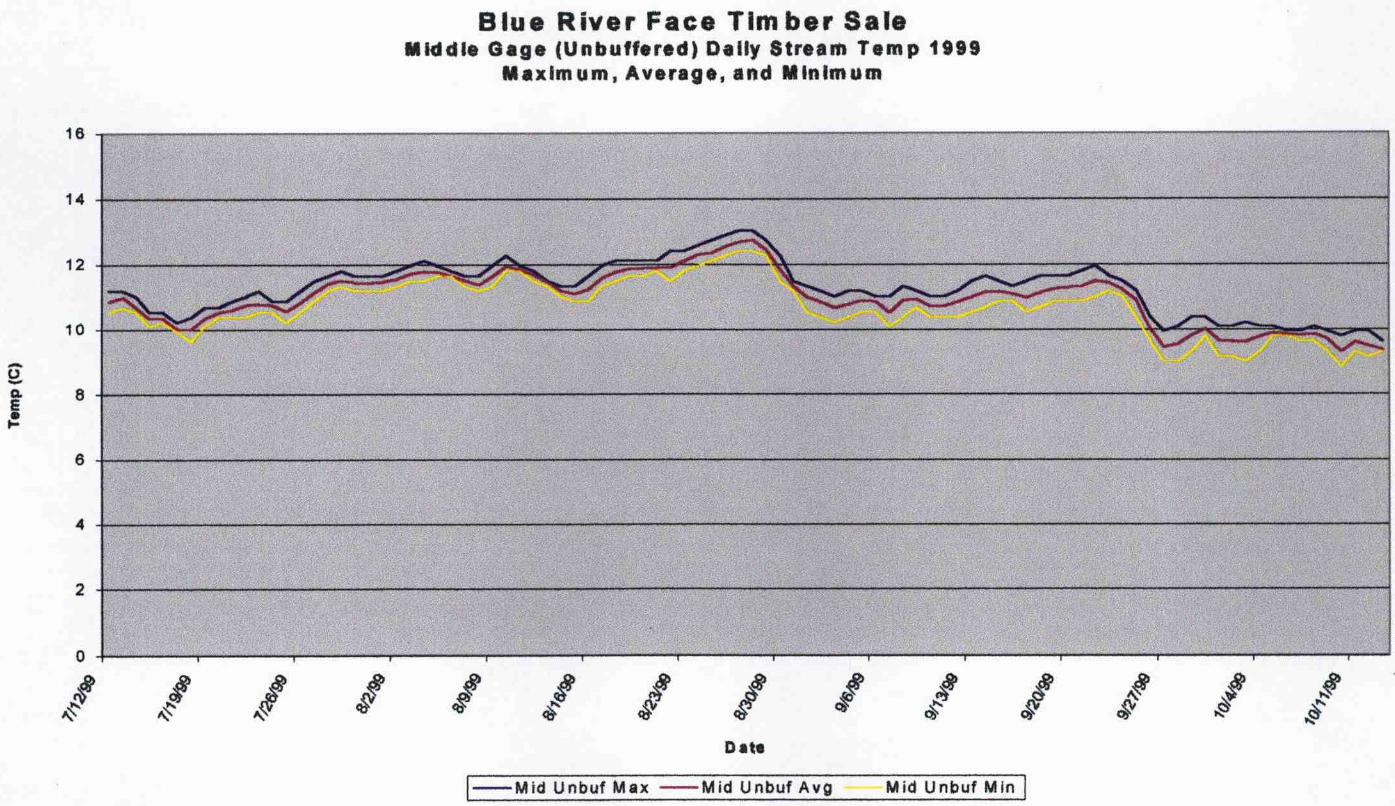
Figures BRF.1 and BRF.2



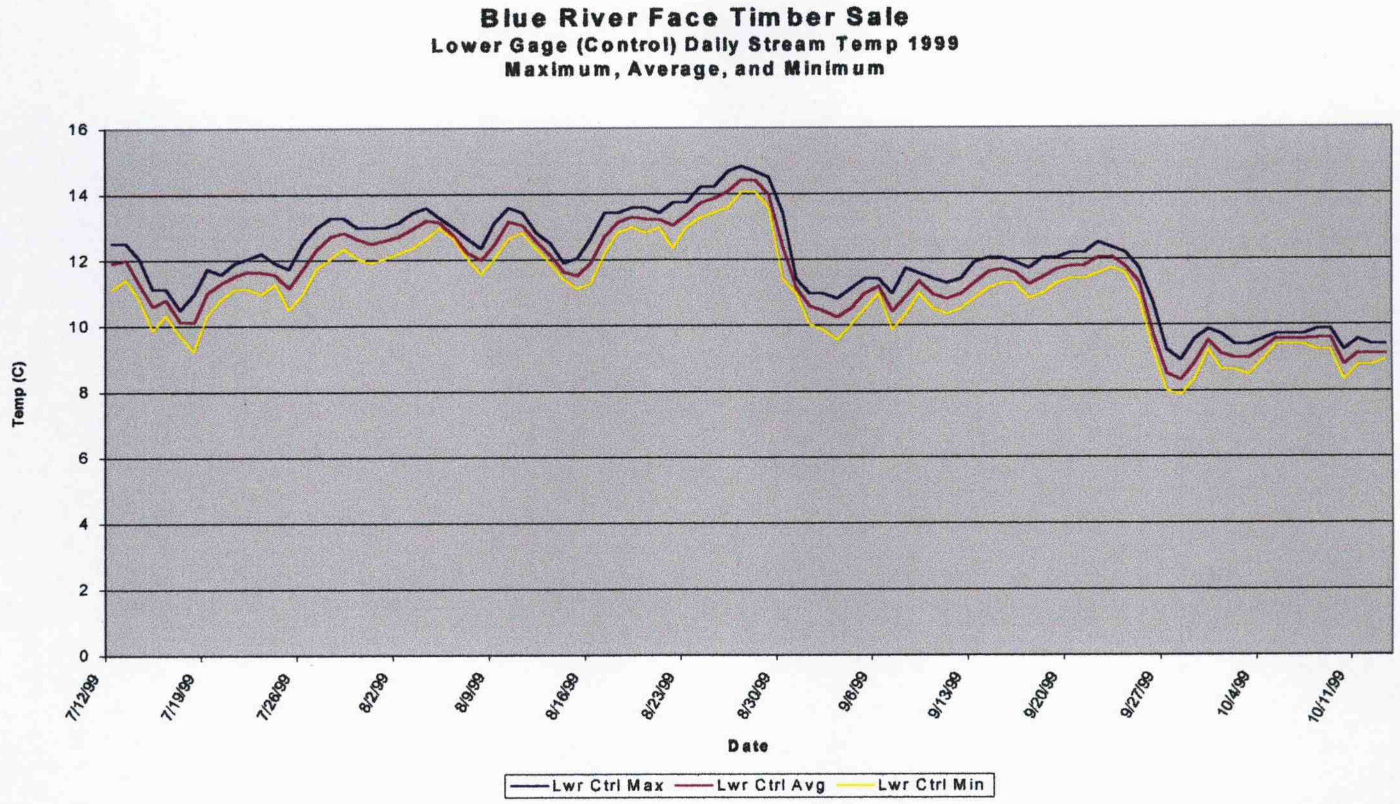


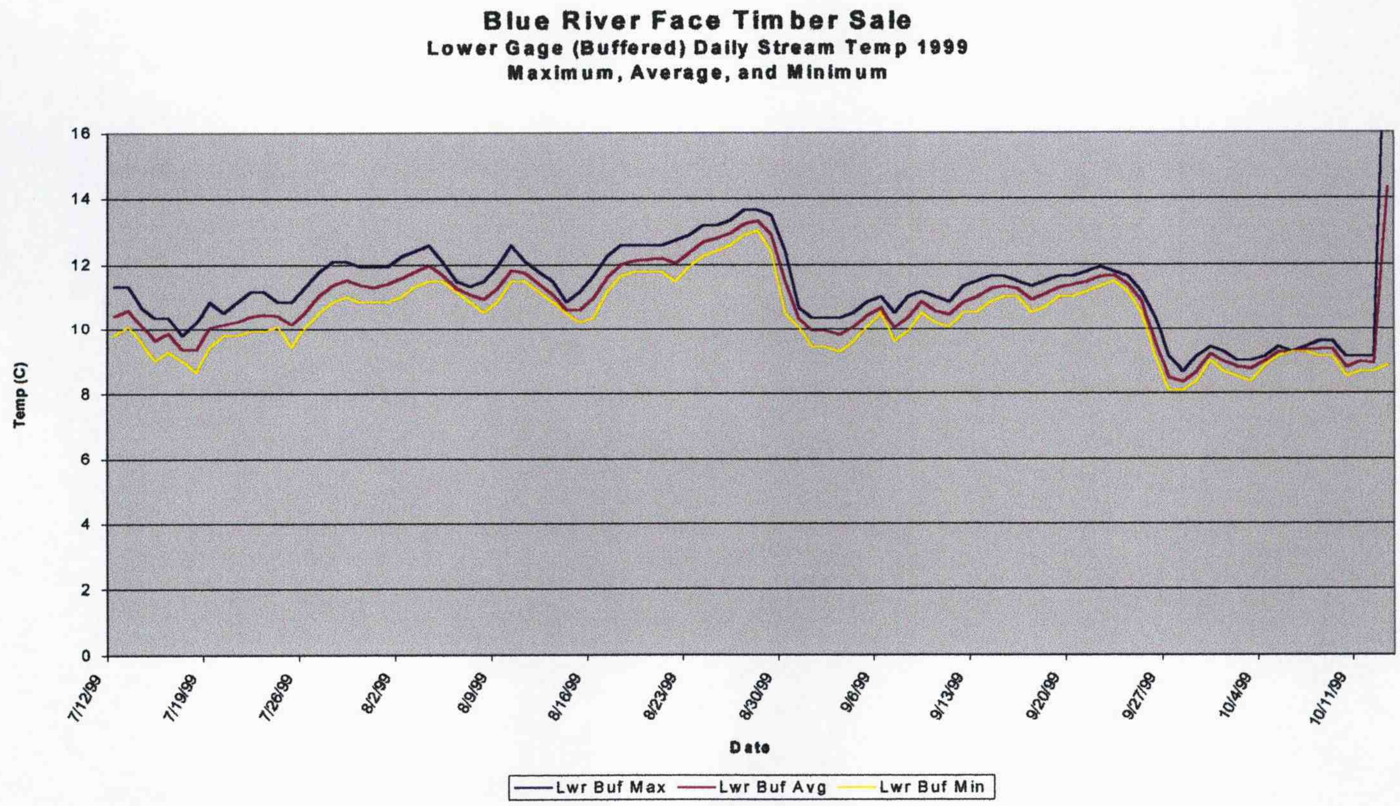
Figures BRF.3 and BRF.4





Figures BRF.5 and BRF.6





Figures BRF.7 and BRF.8

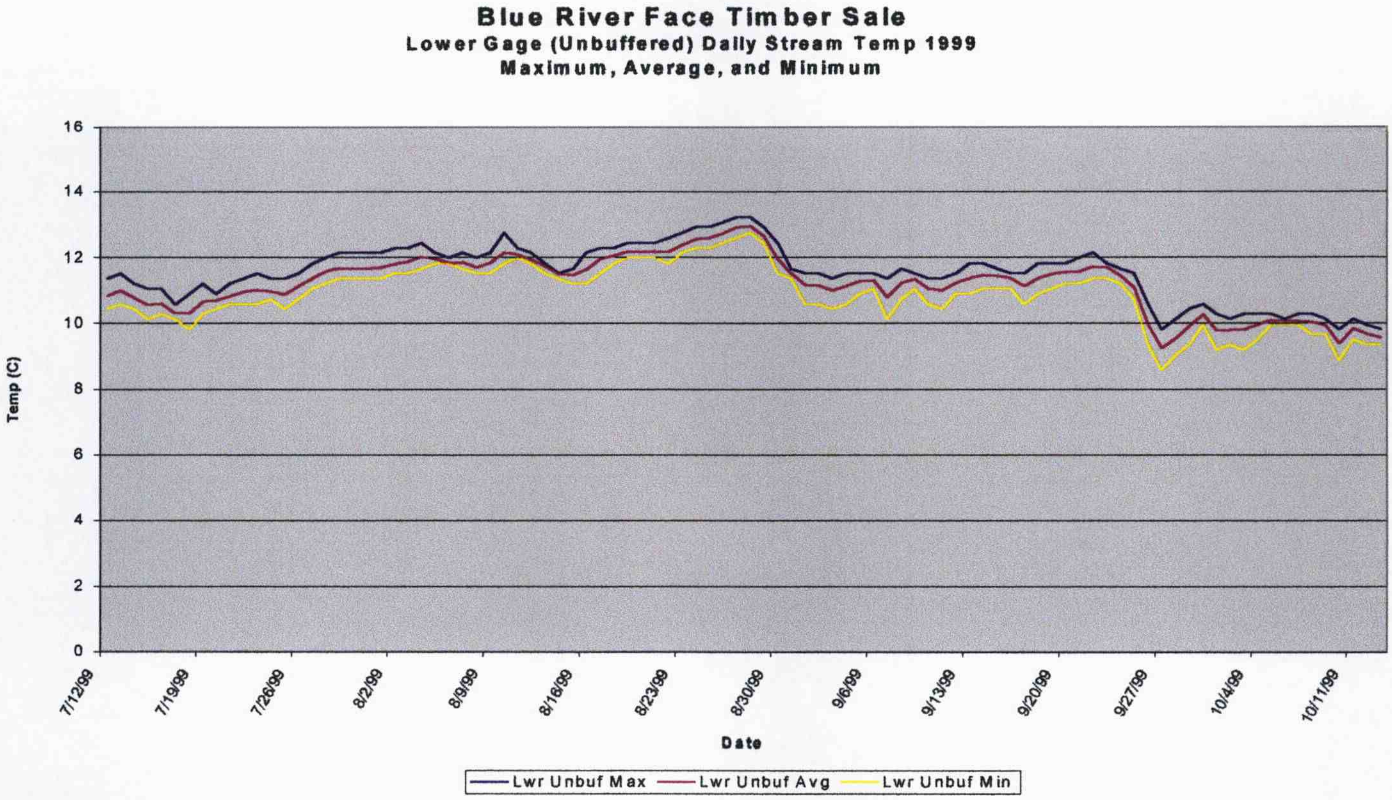


Figure BRF.9

Wolf Mann 1999 Data

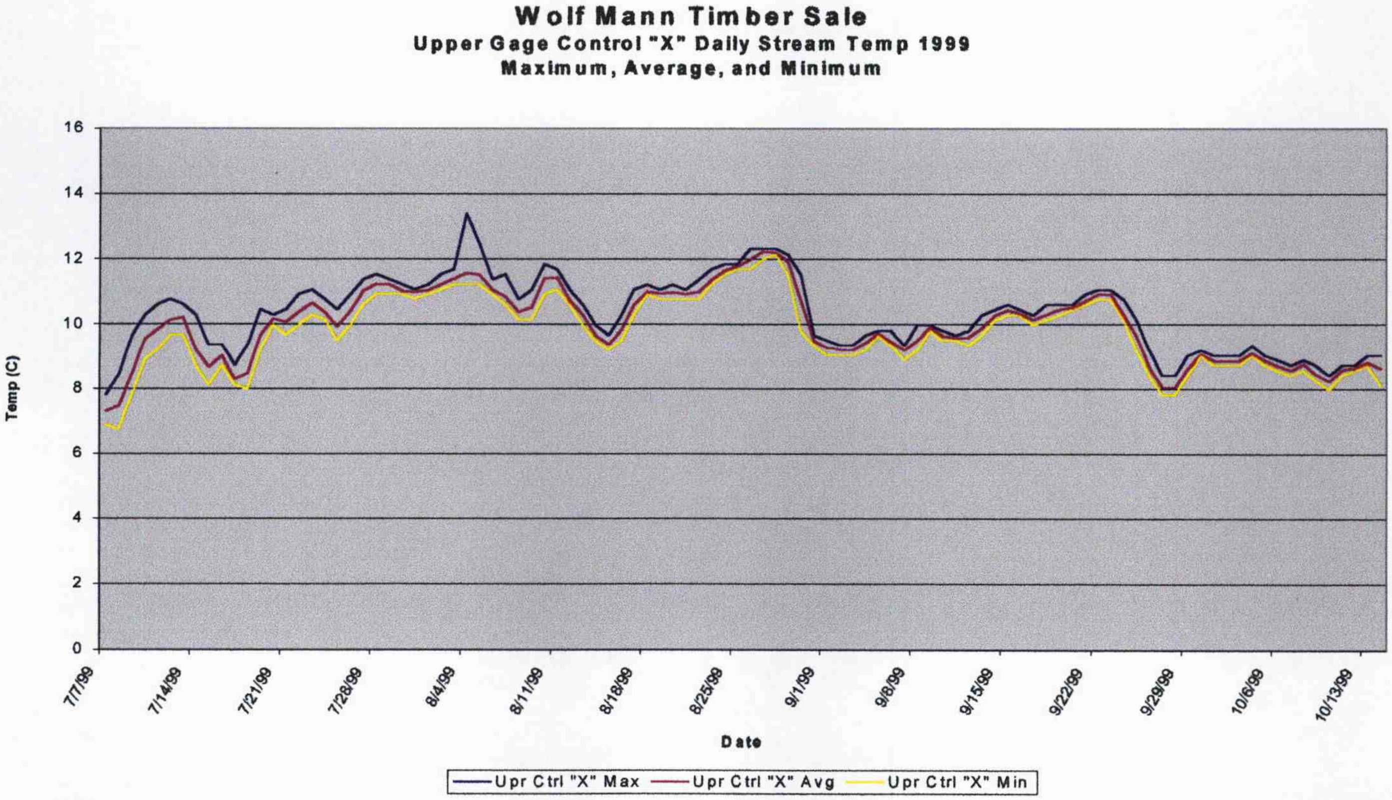
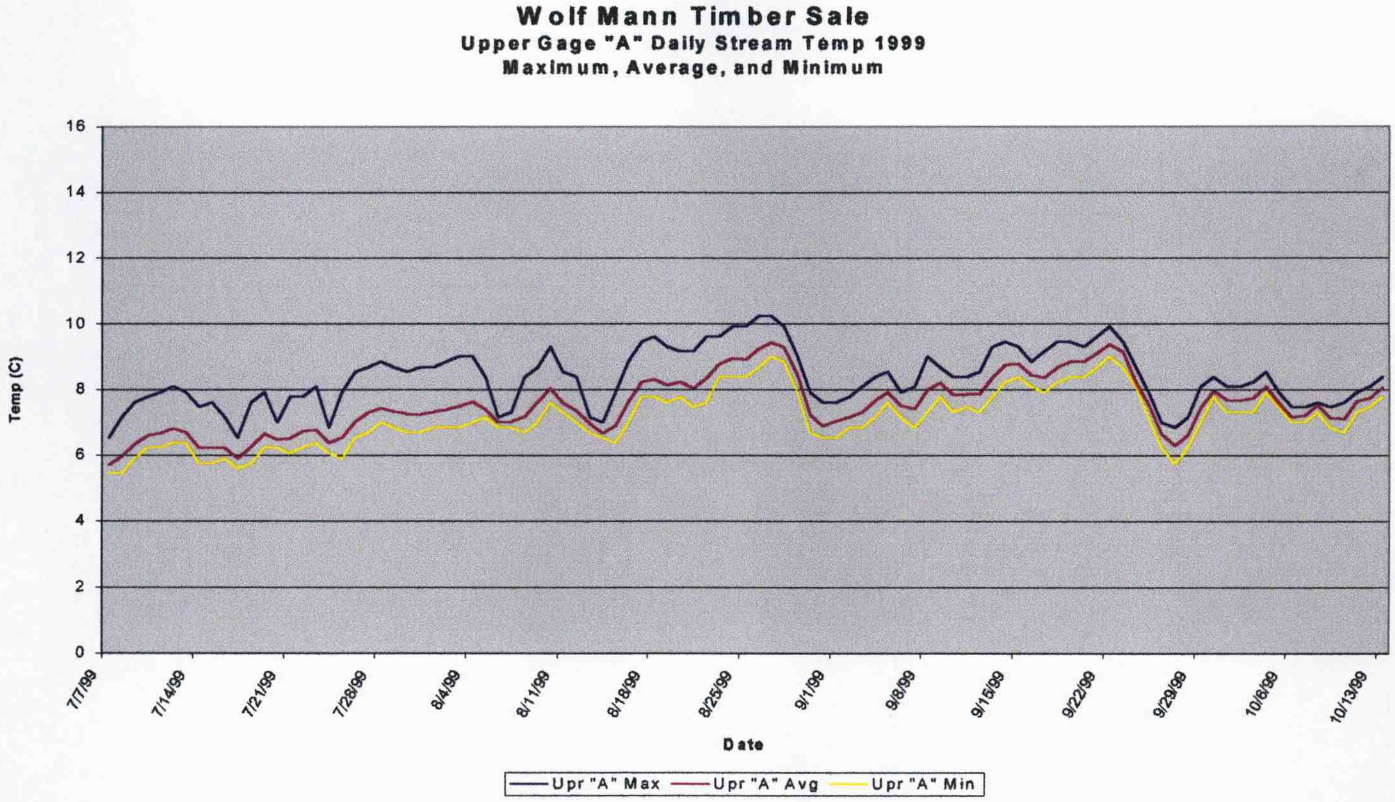
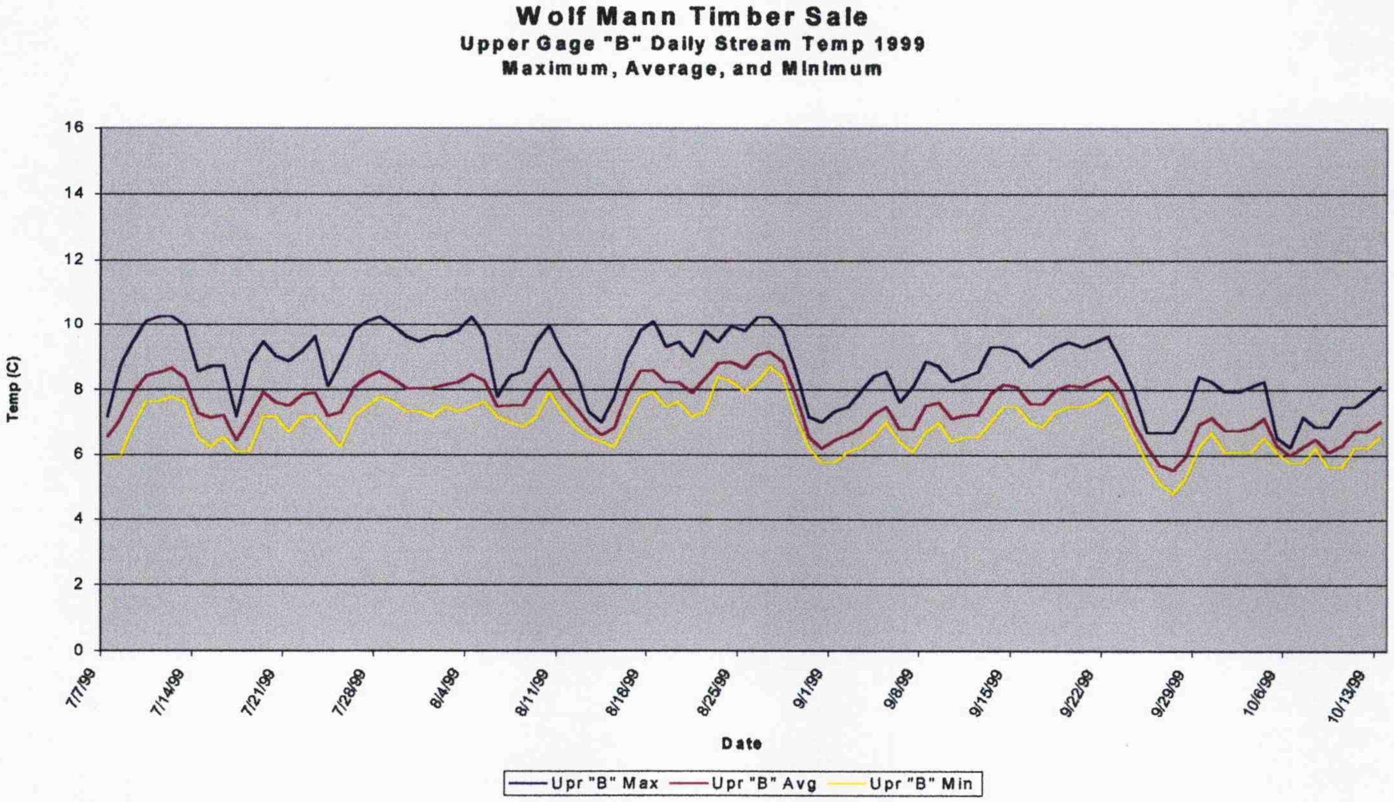
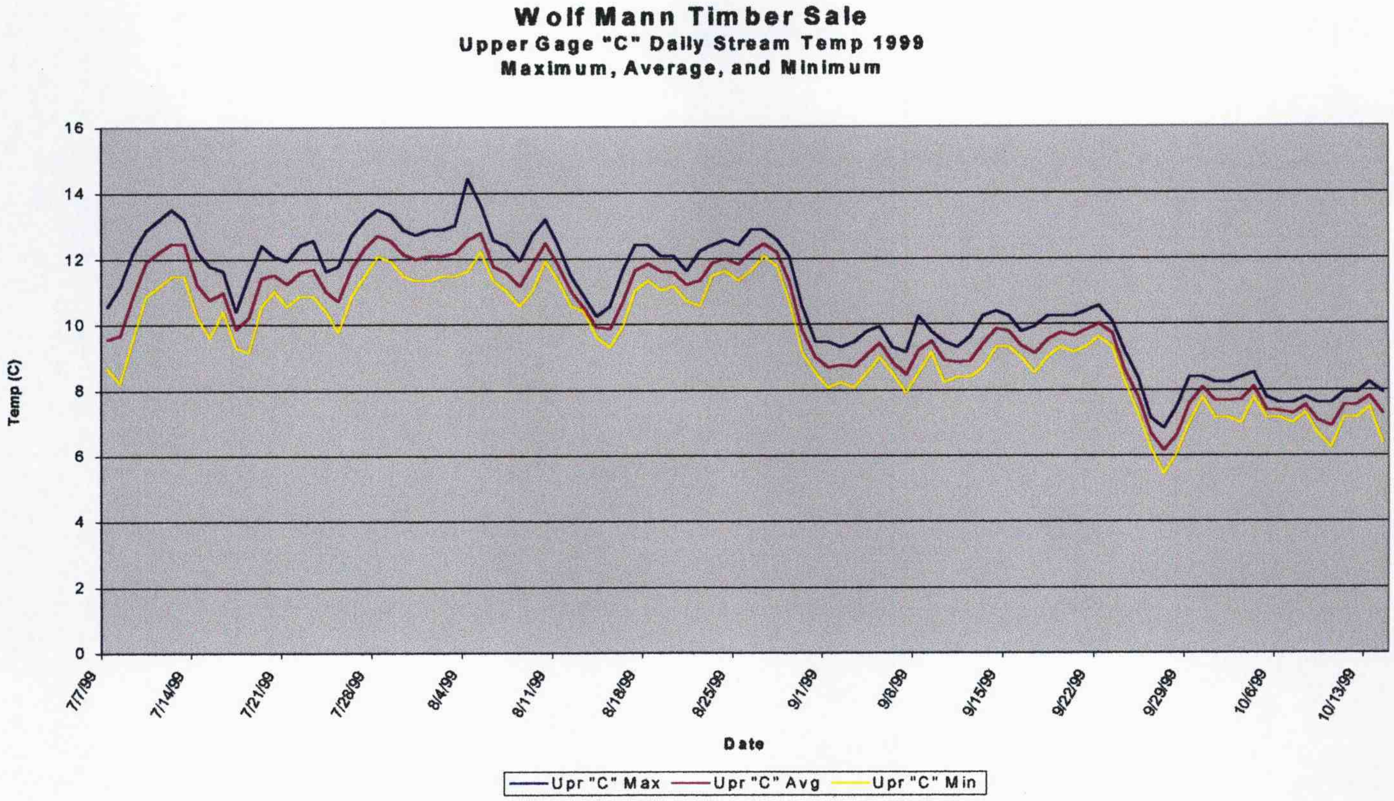


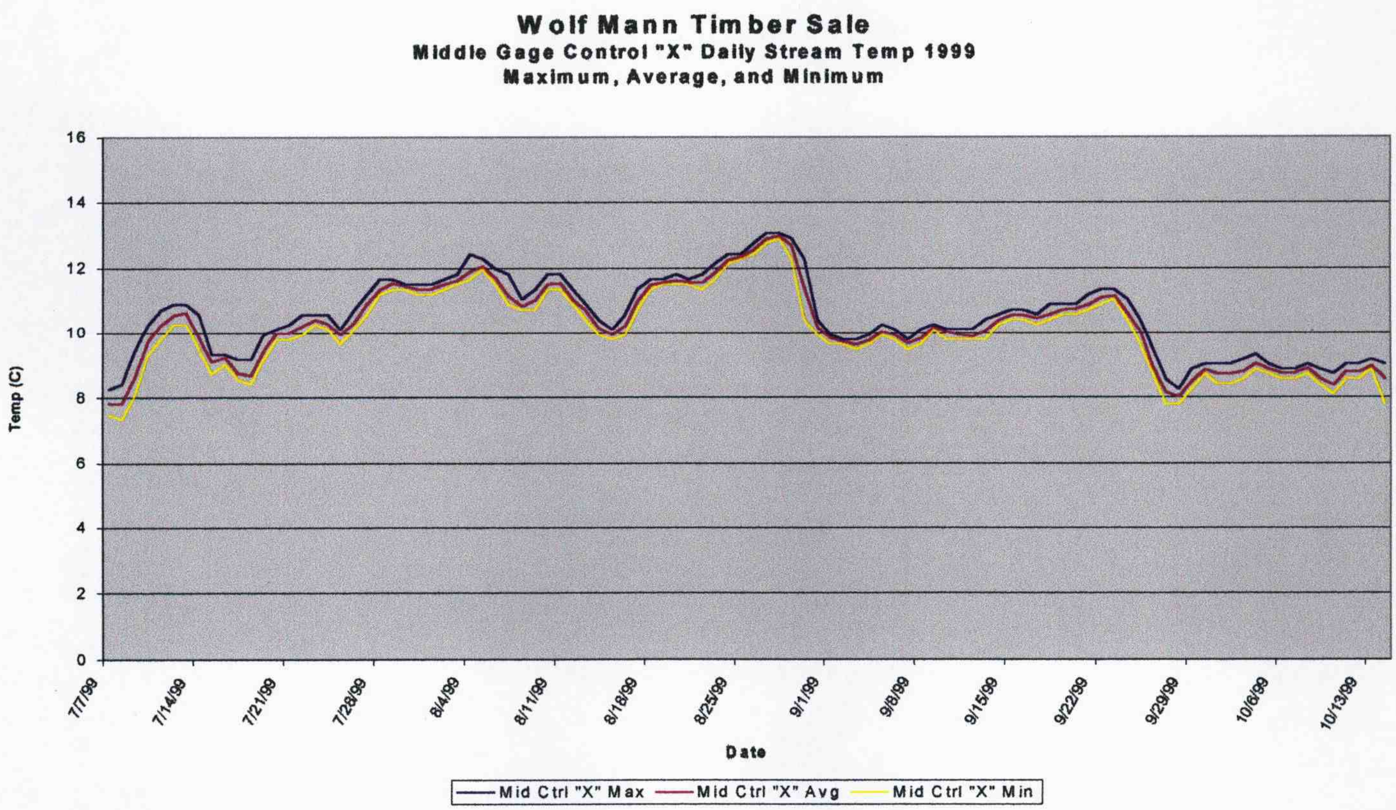
Figure WM.1



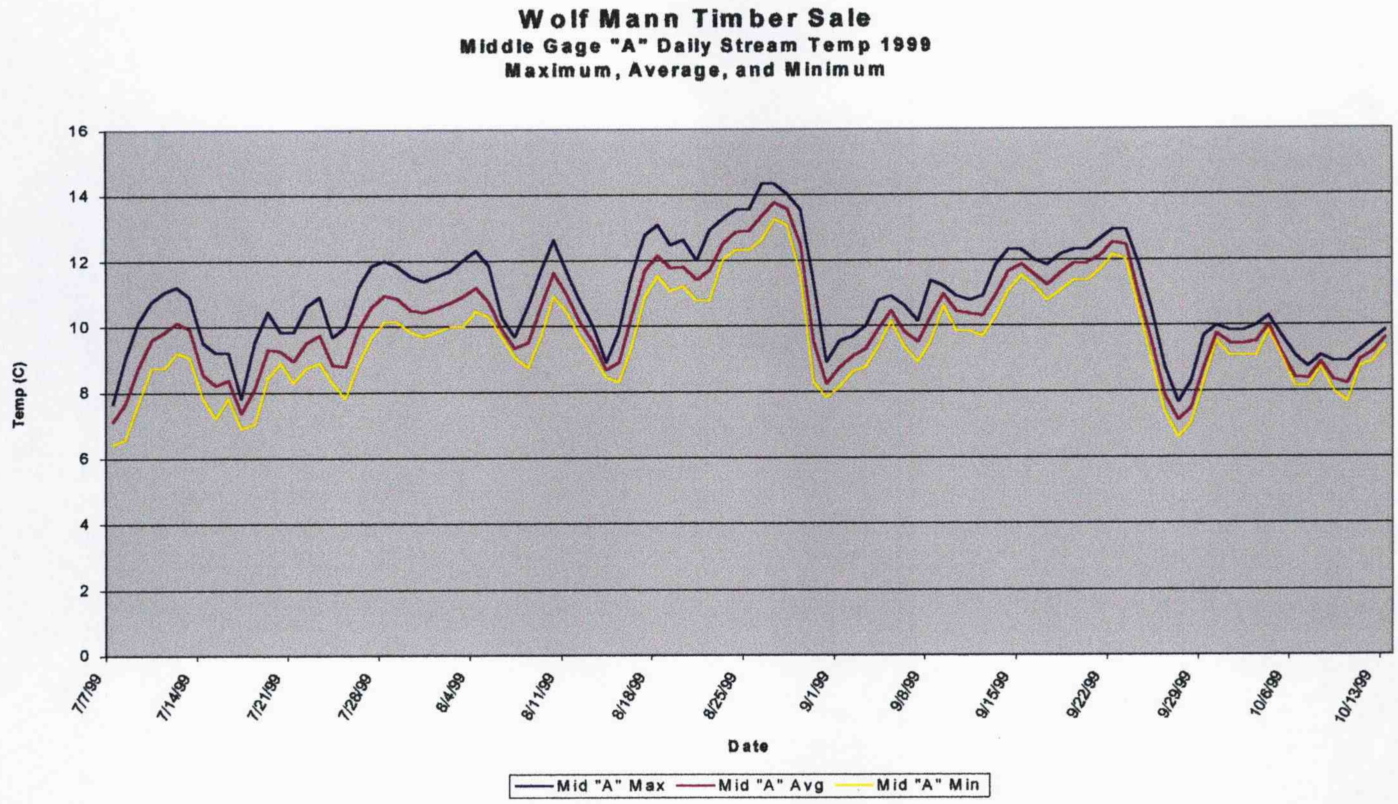


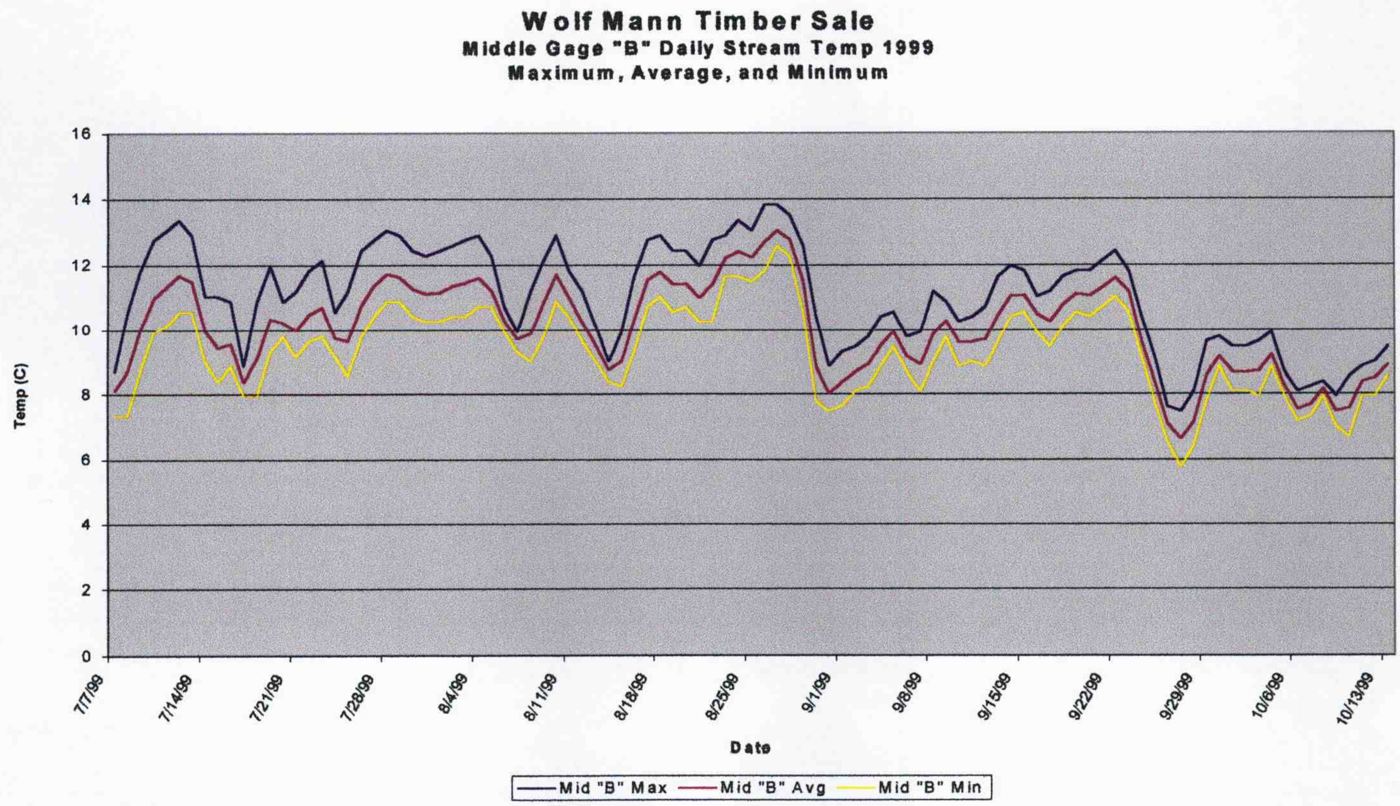
Figures WM.2 and WM.3



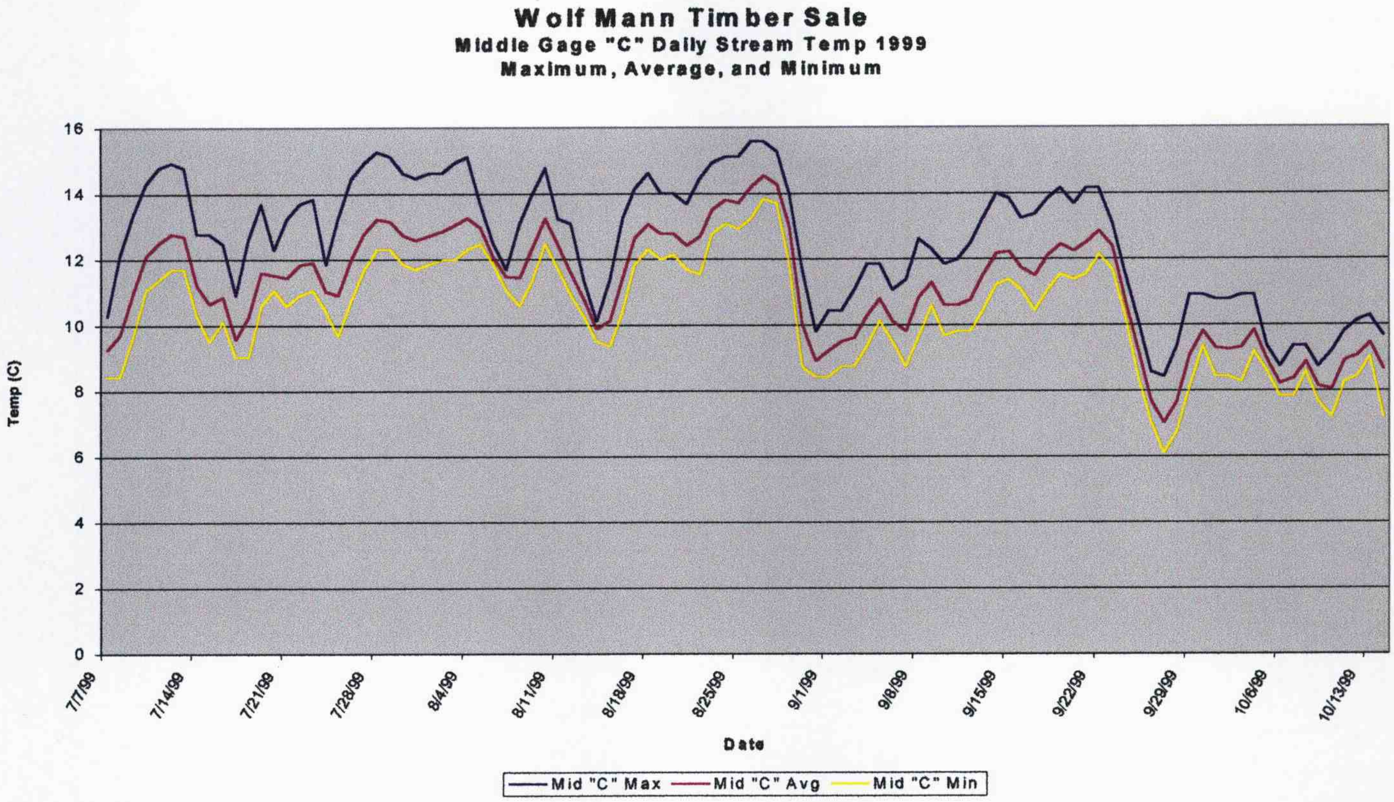


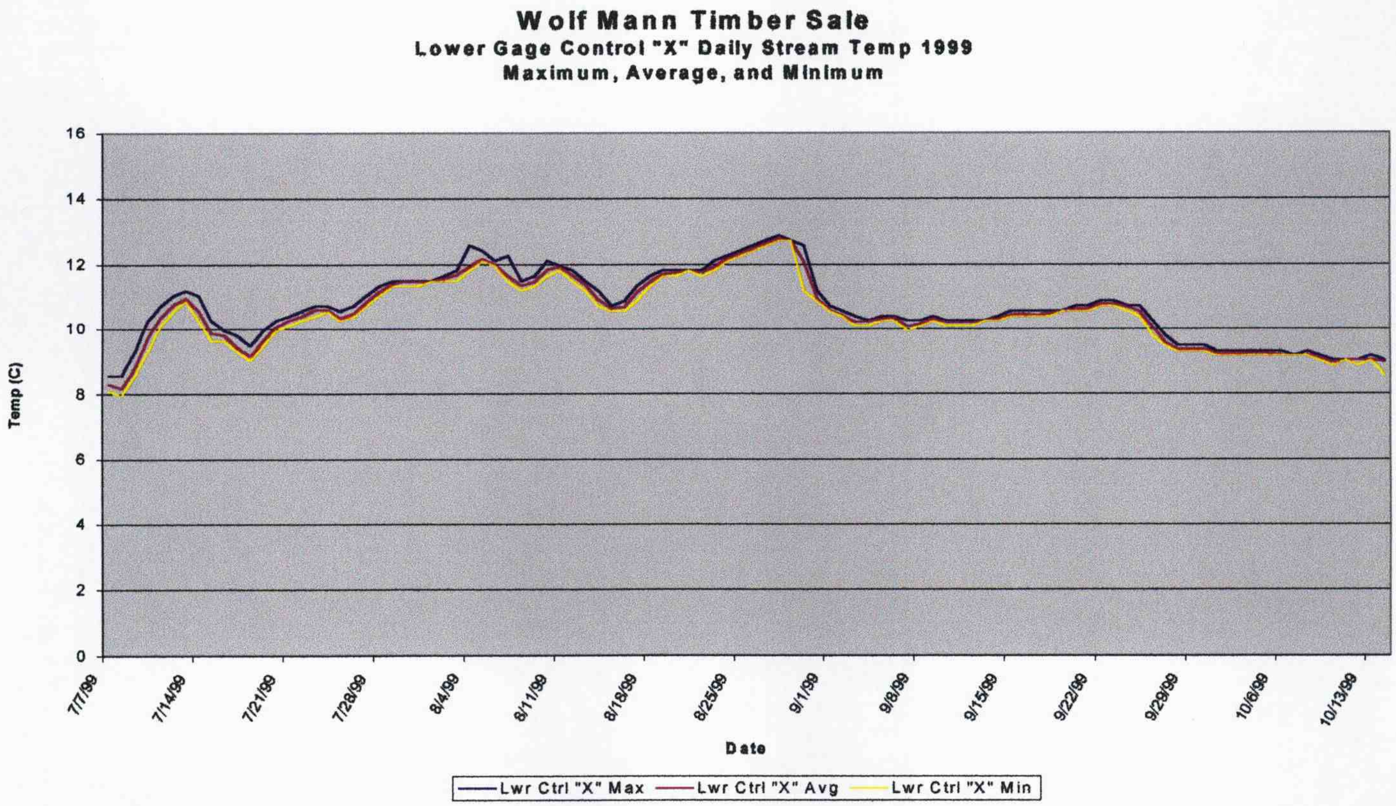
Figures WM.4 and WM.5



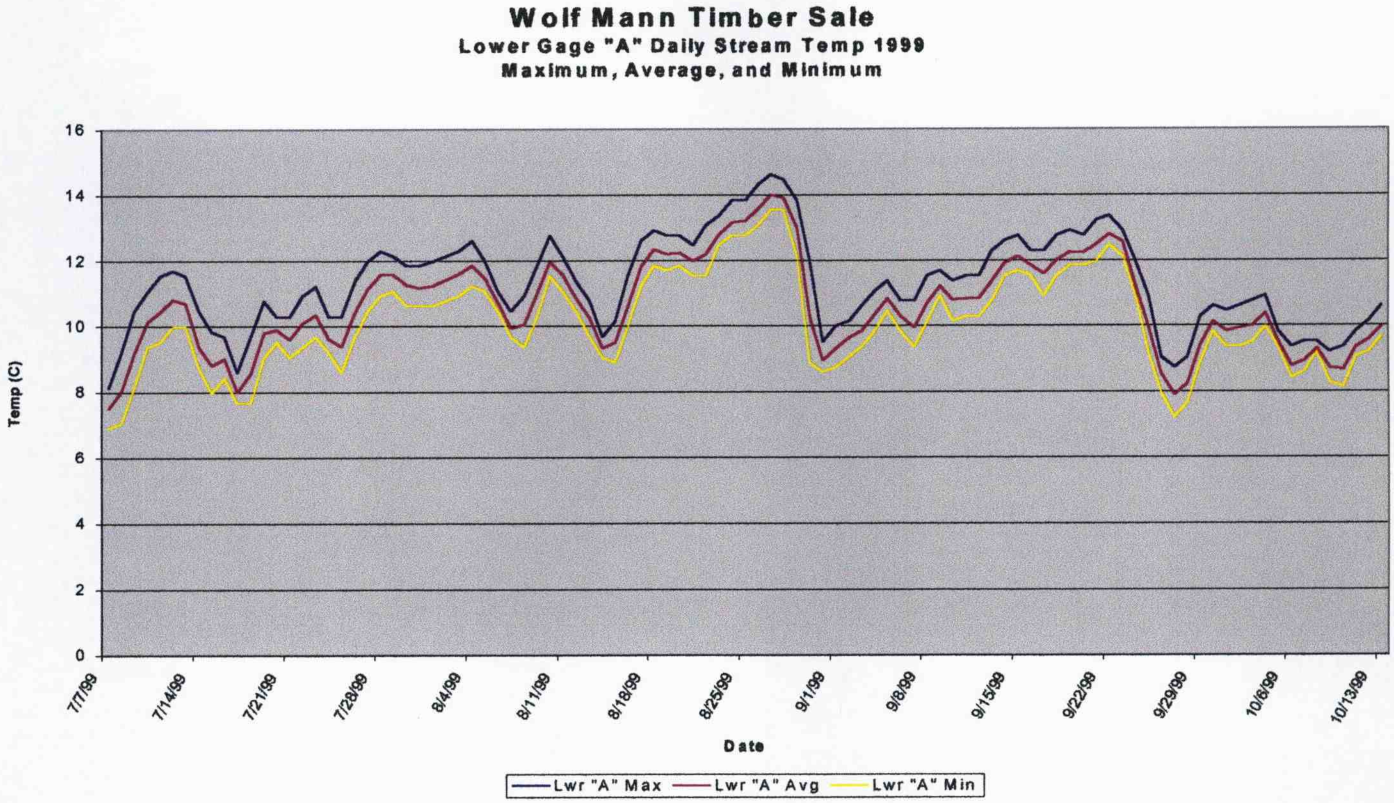


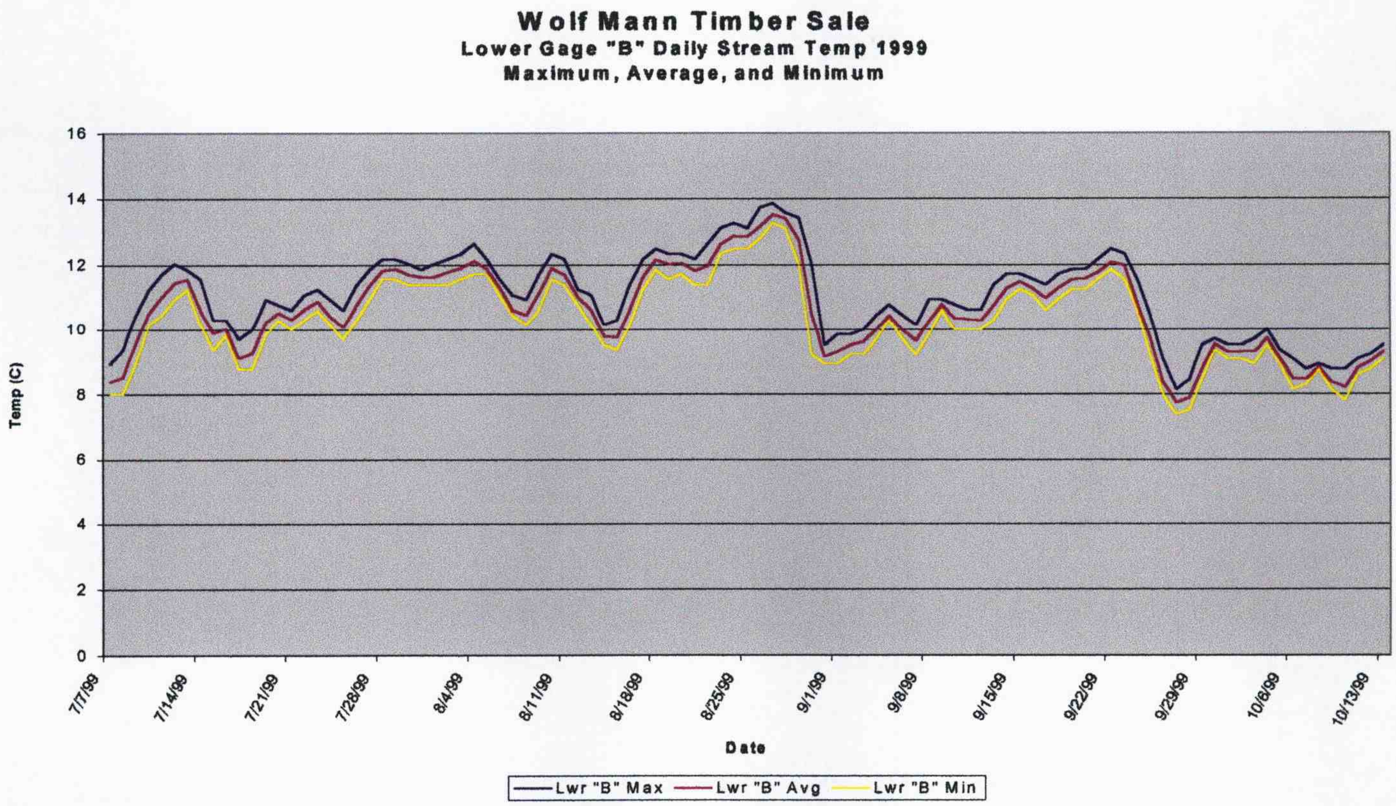
Figures WM.6 and WM.7





Figures WM.8 and WM.9





Figures WM.10 and WM.11

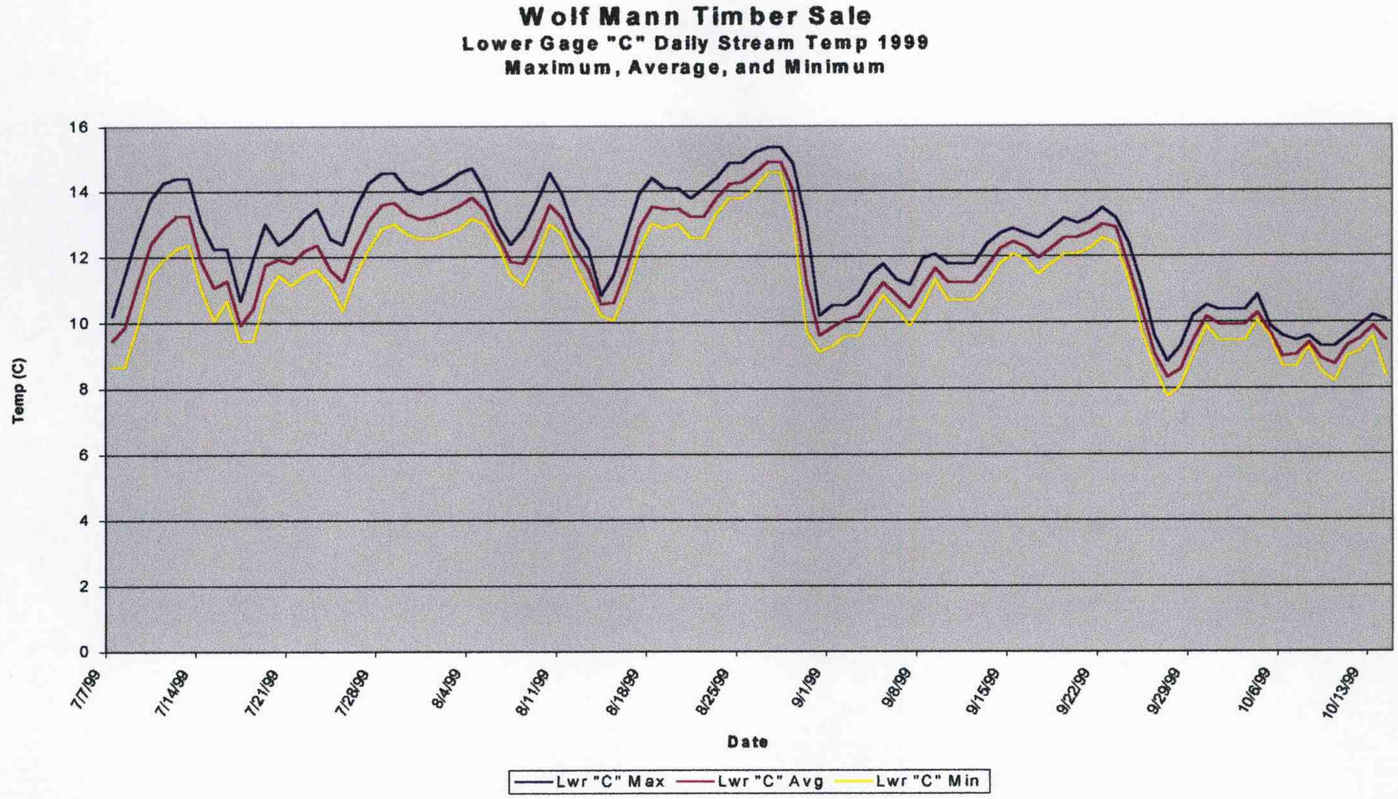


Figure WM.12

NFQC Middle Gage Data 1999

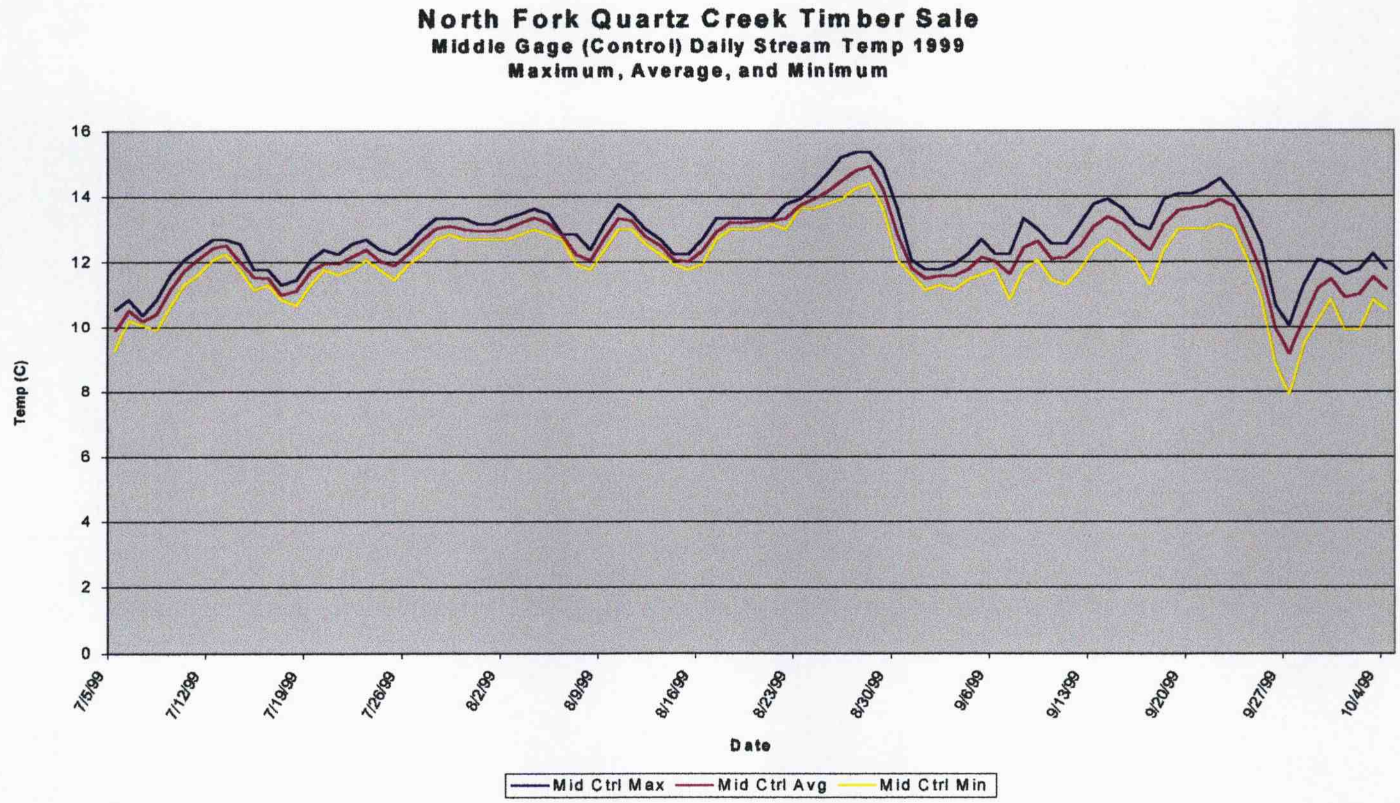
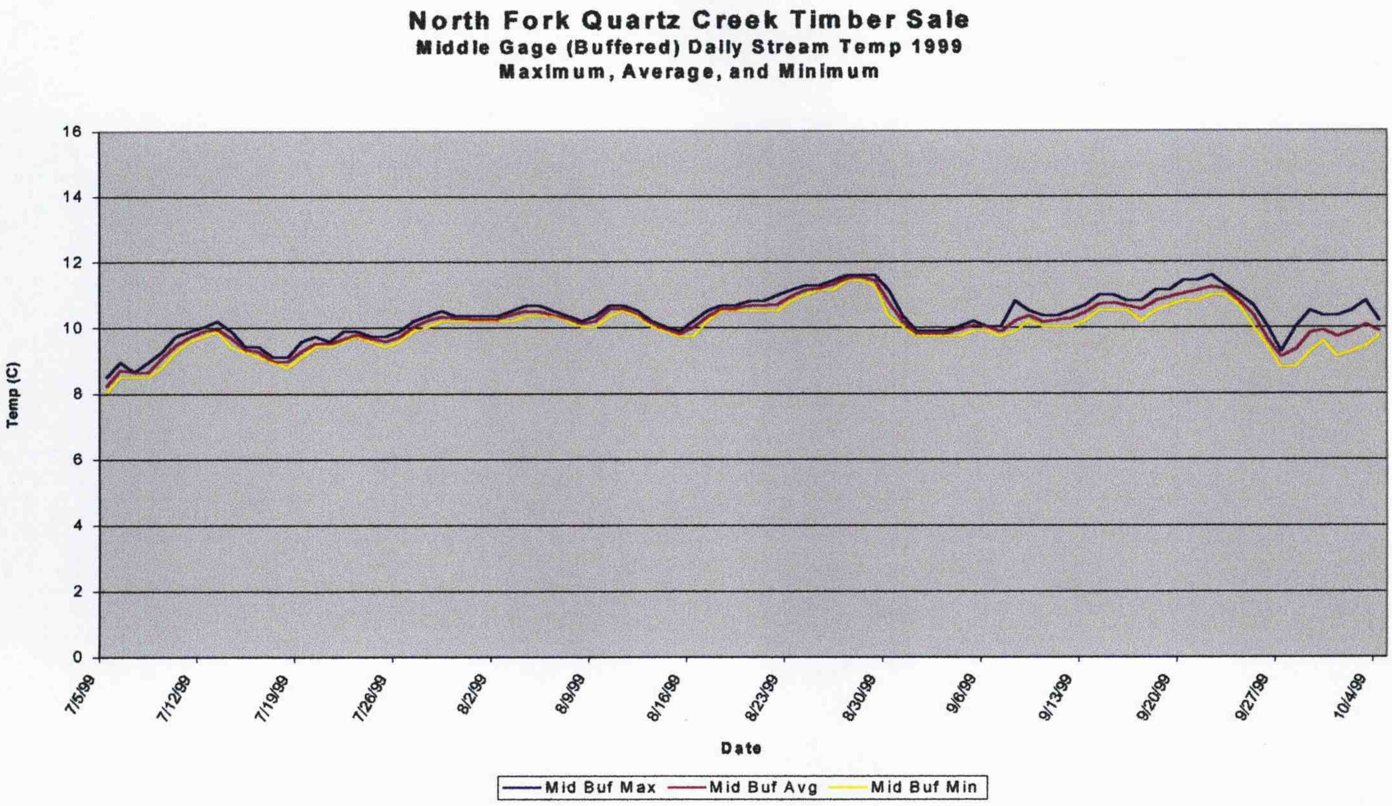
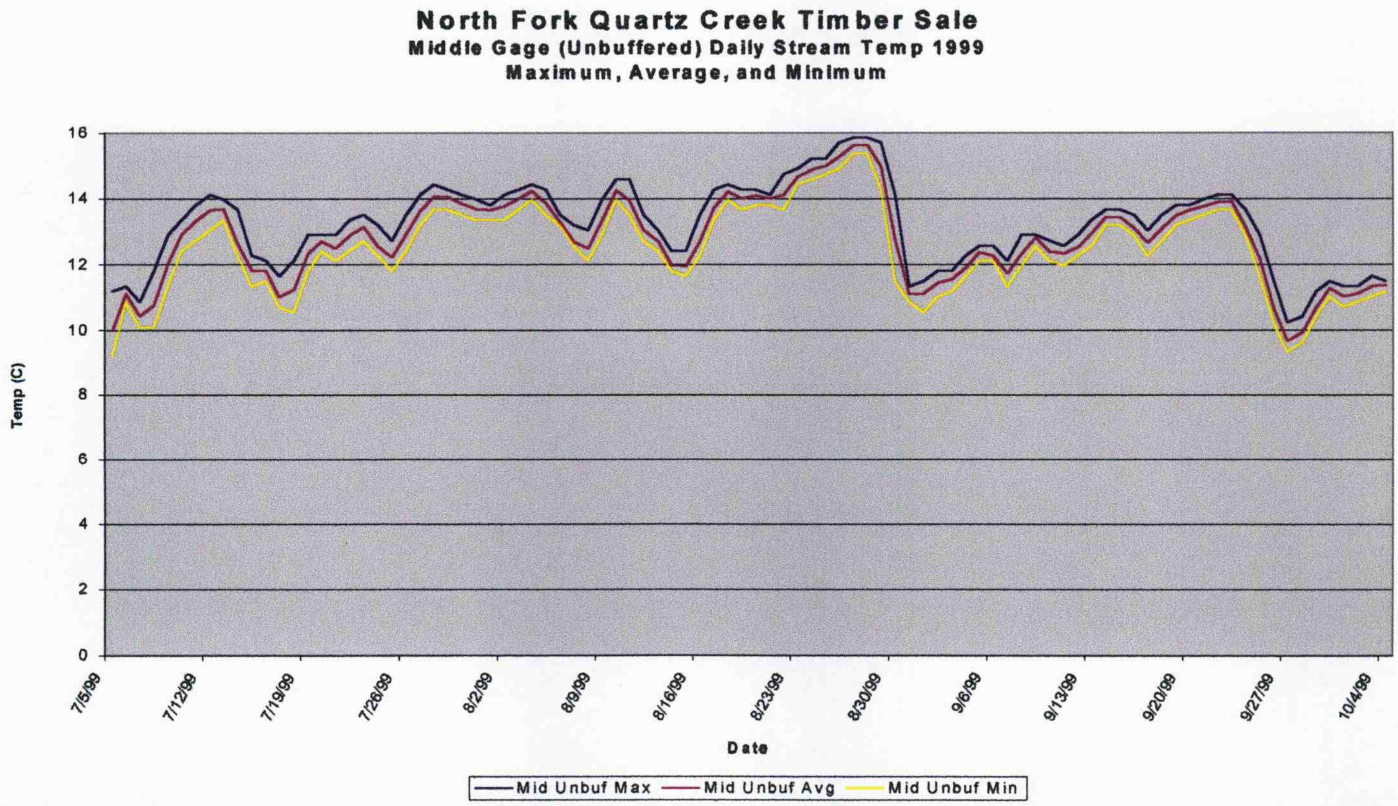


Figure NFQC.1





Figures NFQC.2 and NFQC.3