Ontario Ministry of Natural Resources Hearst District Thermal Regime Stream Assessment

by

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Ontario Ministry of Natural Resources, Hearst District
Thermal Regime Stream Assessment

Lisa Gibbons

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ABSTRACT

Gibbons, L.M. 2001. Thermal Regime Stream Assessment in the Hearst Ministry of Natural Resources District, Hearst, Ontario.

Key Words: forest management, stream thermal stability, fish habitat, habitat protection, forest operation impacts, riparian area.

Forest ecosystems today are continually under pressure from a variety of special interests including timber operations. A goal of the Ontario Ministry of Natural Resources to aid natural ecosystems by providing forest management guidelines is to assist foresters with timber operations. The Timber Management Guidelines for the Protection of Fish Habitat were developed to mitigate the harmful influences of timber operations on fish habitat and water quality.

Knowledge of a stream's thermal regime is important for assessing the effectiveness of the Area of Concern when applying the guidelines. Currently, the lack of this information in the Hearst MNR District led to the attempted use of a stream thermal stability model. The model was developed to allow users to collect only a single stream temperature at 1600hr on a day when temperatures exceeded 24.5°C. Fifty-one stream segments were studied and temperature data were collected with automated Hobo8 loggers. The thermal stability model proved unsuccessful as the model could not be calibrated for this district.

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1.0 INTRODUCTION

Conflicts between commercial logging and fish habitat may arise as the result of competing interests within the framework of the multiple use of forest ecosystem concept. The demand for timber must be met but minimizing the negative impacts with relation to fish habitat is also a requirement. The *Timber Management Guidelines for the Protection of Fish Habitat* serve to assist managers in protecting fish habitat in Ontario during the planning and implementation of timber operations (OMNR 1988). These guidelines are an aid for developing management strategies that protect both fish habitat and water quality. The desired outcome of the strategy is to protect ecosystems that support fish populations at normal historic levels. Forest operations such as construction of roads, location of landings, harvesting, and mechanical site preparation can be modified to protect fish habitat in streams as well as other sensitive areas with rare plant and animals.

1.1 RATIONALE

The OMNR is responsible for implementing the *Timber Management Guidelines for the Protection of Fish Habitat* (OMNR 1988). However there currently is a lack of information about fish species and fish habitat within many of the regions. The fish species of concern for the Area Biologist in the Hearst

District is brook trout, *Salvenlinus fontinalis* (Mitchill 1814). The present work focuses on the identification of brook trout habitat, which is classified as coldwater. The lack of data with regard to the location of fish habitat and species within the numerous streams in the Hearst Forest is a concern when trying to apply the guidelines. The lack of financial support and time pressure has led the Hearst District to try to apply a rapid assessment to the streams to determine the thermal regime. In southern Ontario a thermal stability model, *A Simple Method to Determine the Thermal Stability of Southern Ontario Trout Streams* (SMST) (OMNR and DFO n.d.) was developed. The objective of the present study was to apply this thermal stability model to the Hearst District to classify the thermal regime of a stream. Module 6, based on SMST protocol was used. The Area Biologist did not believe any streams in the Hearst District were warm water streams. The desired outcome was to have the ability to walk up to a stream and take one single temperature measurement at a specified time of day to classify the stream as cool or cold water. This outcome is desirable as personnel without significant training could perform this task, and numerous streams could be classified quickly at low cost.

1.2 OBJECTIVES

The goal of the study was to determine if Module 6, from *Southern Ontario Stream Procedural Manual* (SAPSO) (Stanfield *et al.* 1999), based on *A Simple Method to Determine the Thermal Stability of Southern Ontario Trout Streams* (SMST)(OMNR and DFO n.d.) could be calibrated and applied to the

Hearst District in northern Ontario to allow for a simple single point observation classification of streams.

1.3 REPORT LAYOUT

The report is divided into three sections. Section I introduces the report, explains the rationale for the study, and describes the layout of the report. Section II reports on the responsibilities of MNR personnel with regard to fish habitat management, and outlines through a literature review, some of the implications of forest operations on fish habitat, and how the current guidelines address these impacts. Section III describes the setting, objective, methods, results, and discussion of the study. Also, recommendations and some possible future management schemes are discussed in this section.

2.0 LITERATURE REVIEW

2.1 MNR RESPONSIBILITY and BROOK TROUT

2.1.1 Timber Management Guidelines for the Provision of Fish Habitat

One of the goals of the Ontario Ministry of Natural Resources is "to provide opportunities for continuous economic and social benefits to the people of Ontario through the development and conservation of Ontario's natural resources." (OMNR 1988). The *Timber Management Guidelines for the Protection of Fish Habitat* is a tool to help achieve this goal and to help forest managers protect fish habitat from stream bank damage, sediment inputs, temperature change and other ecological impacts that may arise from timber extraction.

The guidelines differentiate stream habitat as either warm, cool, or cold water streams, and thereby classify streams for different fish species. According to the OMNR (1988), cold water species such as brook trout:

- are less tolerant of high temperatures and temperature fluctuation,
- are sensitive to removal of shade,
- have more stringent requirements for dissolved oxygen,
- spawn in gravel,
- spawn in small streams, and
- spawn in the autumn.

Therefore the classification of the thermal regime of a waterbody is required to ensure that management of a waterbody protects sensitive aquatic life native to the stream. The OMNR, Fish and Wildlife Branch (1998) defines a waterbody segment or an aquatic resource area to be coldwater if any one of the following apply:

- it contains salmon, trout, whitefish and/or scuplin species; or
- it contains benthic invertebrates such as *Agapetus* spp. or *Glossosoma spp.* of the family Glossosomatidae;
- it possesses thermal characteristics of a cold water stream based on the water temperature data standards (OMNR and DFO n.d.); or
- it possesses thermal characteristics of a cold water lake where on August 31, the hypolimnetic water temperature is <15°C and the dissolved oxygen is >4 ppm.

Table 1 outlines the guidelines for each thermal regime and timber modification process within the Area of Concern (AOC) (OMNR 1988). The Fisheries Act is the federal act that is the main legislative body for the protection of fish habitat in Ontario that is administered by the OMNR (DFO 1998). This act forbids operations that can result in harmful alterations, disruptions or destruction of fish habitat. Areas of concern include: spawning grounds, nurseries, rearing, food supply and migration areas on which fish rely on indirectly or directly. Table 2 outlines several other federal and provincial legislations that aid in fulfilling the goal to protect fish habitat. Specific modifications of harvesting operations in the guidelines that protect coldwater fish habitat are outlined in Table 3.

Table 1. Summary of Timber Management Guidelines for the Protection of Fish Habitat (OMNR 1988)

Operations Within Areas of Concern					Modifications to Timber Management	
Fish Habitat	Slope	Width of AOC*	Roads	Landings	Harvest Options	Mechanical Site Preparation
1. Lake Trout Lakes, Self-Sustaining Brook Trout Lakes, Aurora Trout Lakes,	0-15% 16-30% 31-45% 46-60%	30m 50m 70m 90m	No	No	·No harvesting ·Selection cutting on restricted basis; avoid damaging banks, keep debris away, avoid erosion	No
2. Other Lakes	As Above	As Above	No	No	·No harvesting ·Selection cutting on restricted basis ·Shelterwood limited clear cutting; do not cut near critical fish habitats or roads	Restricted; minimize exposure of mineral soil, orient furrows at right angles to slope
3. Coldwater Streams	As Above	As Above	Stream Crossings Only	No	Same as for #1, Lake Trout Lakes; maintain shade on both sides	No
4. Coolwater and Warmwater Streams	As Above	As Above	Stream Crossings Only	No	Same as for #2, Other Lakes; no shelterwood or clear cutting upstream of crucial fish habitats	Same as for #2, Other Lakes

* Width may have to be greater to reduce the risk of blowdown.

Table 2. Federal and Ontario provincial legislation pertaining to fish habitat protection (OMNR 1995, DFO 1998)

Jurisdiction	Act	Responsible Agency
Federal Legislation	Navigable Water Protection Act	Ministry of Transport Canadian Coast Guard
Provincial Legislation	Crown Forest Sustainability Act	Ministry of Natural Resources
	Forest Fire Protection Act	Ministry of Natural Resources
	Environmental Assessment Act	Ministry of the Environment
	Environmental Protection Act	Ministry of the Environment
	Ontario Water Resources Act	Ministry of the Environment
	Pesticides Act	Ministry of the Environment
	Ontario Heritage Act	Ministry of Culture and Communications

Table 3. Harvesting modifications for coldwater streams in Ontario (OMNR 1988)

	Modifications to Harvesting in AOC
1.	no road construction in area of concern except where necessary to cross the stream
2.	no landings in area of concern
3.	harvesting in area of concern should be restricted
4.	no mechanical site preparation within area of concern

2.1.2 Brook Trout

Brook trout, (Figure 1), are native to the eastern United States and Canada. Other common names include: aurora trout, brookie, coaster, common brook trout, mountain trout, mud trout, sea trout, speckled trout, speckled char, speck trout, and square tail. The identifying features of the brook trout are light worm-like markings and spots on dark background, some red and blue spots, a square tail; and a white leading edge on lower fins set off by black lines (OMNR 2000).

Brook trout are members of a group of northern species that require cooler temperatures than other trout such as rainbow (*Oncorhynchus mykiss*, Walbaun 1792) or brown trout (*Salmo gairdneri*, Linnaeus 1758). Water temperature is a key factor in determining suitable habitat for the brook trout, as typically they cannot survive at water temperatures outside of a narrow of parameter (OMNR 2000, Palmer 1986). Brook trout habitat usually encompasses cold, clear water with shade, logs, and rocks. Brook trout are most active in the morning and late afternoon and are carnivorous generalized feeders that eat aquatic insect larvae, insects, fish, mollusks, small mammals, snakes, and their own eggs and young. Brook trout spawn between August and December (Scott and Crossman 1985).

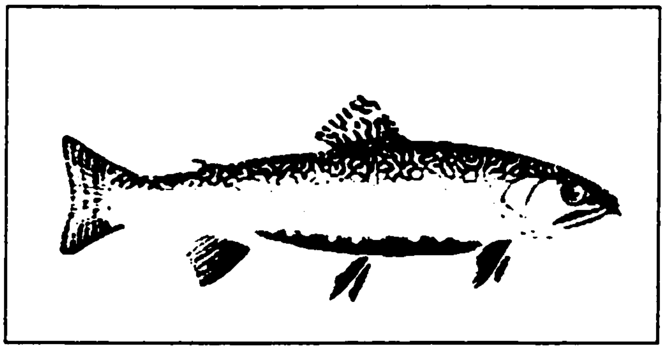


Figure 1. *Salvelinus fontinalis* (modified OMNR 2000)

2.2 FORESTRY OPERATIONS AND HYDROLOGY

Nearly all fish that inhabit freshwater are found at some time in streams (Hynes 1970) surrounded by forests. Therefore it is important to understand the impact of timber harvesting on streams. The most significant parameters of aquatic ecosystems affected by timber harvesting listed by Lynch *et al.* 1977 are:

1. water temperature,
2. stream flow,
3. turbidity and sedimentation,
4. organic material input, nutrient input, and
5. dissolved nutrients and mineral input

Deviation away any of these favorable parameters may have significant impacts on the fish population therefore Timber Management Guidelines for the Protection of Fish Habitat are intended to maintain the entire functioning stream ecosystem.

2.2.1 Forests and the Hydrological Cycle

The 17th century first saw the development of hydrological cycle theories, but until this time water was not regarded as being recycled in the environment and it was assumed that the oceans provided the streams with water (Allan 1995, Whitehead and Robinson 1993). Today, the process of recycling water through the environment is known as the hydrologic cycle, and forests play a critical role in this process.

The hydrologic cycle (Figure 2) describes the continuous cyclic flow of water from the atmosphere to the earth. The cycle is a series of storage places and transfer processes powered by solar energy (Anderson *et al.* 1976, Brown 1983, Allan 1995). Forests conserve water for streamflow, regulate the flow of springs, equalize streamflow, mitigate flood destruction, and prevent erosion (Verry 1986).

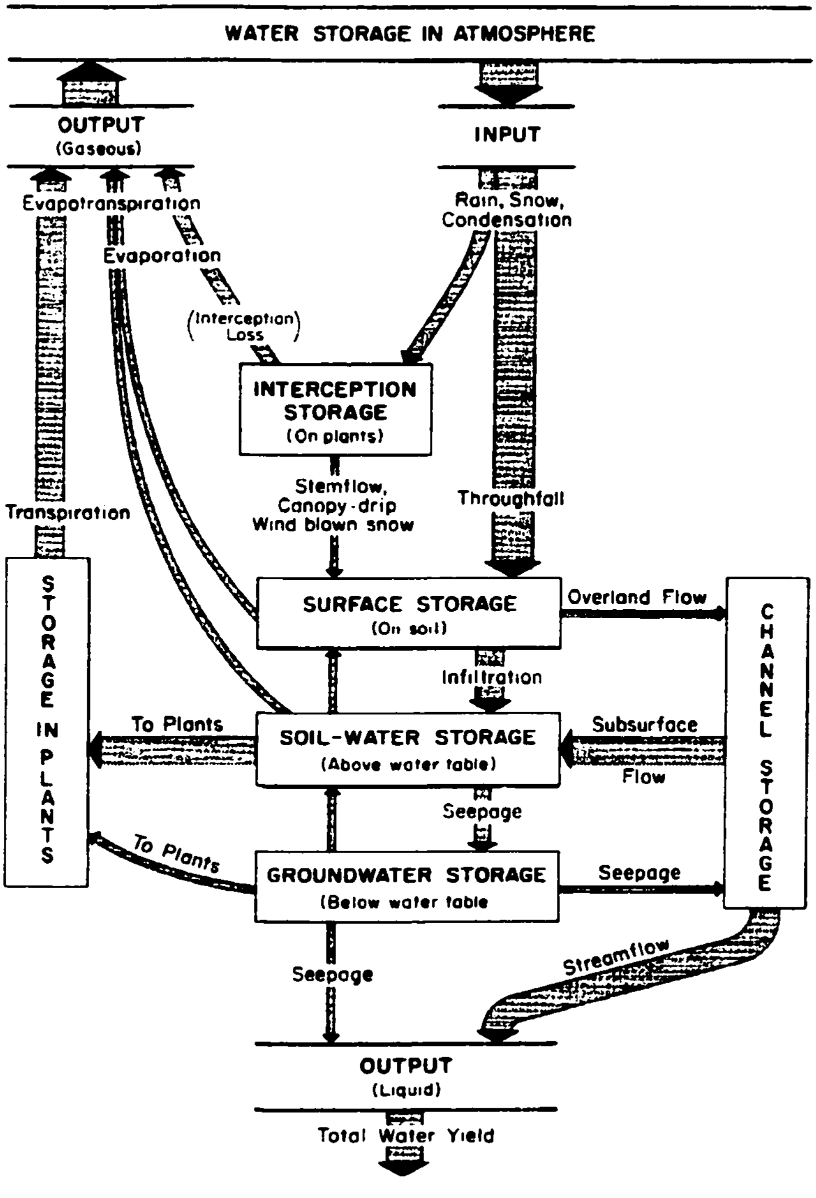


Figure 2. The Hydrologic Cycle (Anderson *et al.* 1976)

Forests and water are linked directly and interactions between the two occur continuously. Forests gain water from the environment through precipitation and infiltration. Precipitation that adheres to the forest canopy without reaching the forest floor is known as interception, the amount of which is a function of storm precipitation, duration, and intensity. Precipitation that is not intercepted can fall directly to the ground, drip from leaves, or branches (throughfall) or flow down the stems to the ground (stemflow).

The interception loss is the evaporation of precipitation off the leaves and stems of the tree. The infiltration capacity is the rate at which water enters the soil surface. The infiltration capacity of forested lands that exceed rainfall intensity can absorb overland flow from adjacent areas with low infiltration capacities (Anderson *et al.* 1976, Brown 1983, Allan 1995).

The water in the forest is exported in the geochemical cycle by evapotranspiration and transpiration (Kimmins 1997). Transpiration is the evaporation of water at the leaf surfaces, whereas evapotranspiration is the combined loss of water from transpiration (leaf surface) and evaporation (soil surface) (Brady and Weil 1996). Evapotranspiration is the evaporation of precipitation intercepted by the canopy, the vaporizing of water that reaches the leaf surface in transpiration, and the evaporation of moisture from bare areas, wetted forest floor, or snow cover. Evapotranspiration is usually greatest in warm wet climates and least in cold dry ones. Transpiration accounts for most of the vaporization loss from the forest.

Loss from the ecosystem also includes loss thru soil from overland flow and leaching (Anderson *et al.* 1976, Allan 1995) and this has a major effect on stream quality.

2.2.2 Water Temperature

Stream temperature plays a significant role in the geographical distribution and abundance of fish species and is a critical parameter in aquatic systems (Hynes 1970, Johnson and Jones 2000). The temperature variation of running waters is dependant mainly on seasonal and daily time scales and groundwater input (Allan 1995). The principal source of heat for a stream is solar energy directly hitting the stream surface. The removal of forest overstory cover and riparian vegetation causes an increase in maximum and minimum daily, weekly and seasonal temperatures and an increase in temperature range fluctuations because more direct sunlight can hit the streams surface (Chapman 1962, Brown and Krygier 1970, Swift and Messer 1971, Brazier and Brown 1973, Anderson *et al.* 1976, Lynch *et al.* 1977, Rishel *et al.* 1982, Brown 1983, Johnson and Jones 2000). Other sources of energy input outlined by Johnson and Jones (2000) are energy exchange by conduction between stream water and stream substrata, evaporation and sensible heat exchange with the atmosphere, and advection of water from deep groundwater sources and upstreams. Figure 3 shows mechanisms and factors influencing stream temperatures.

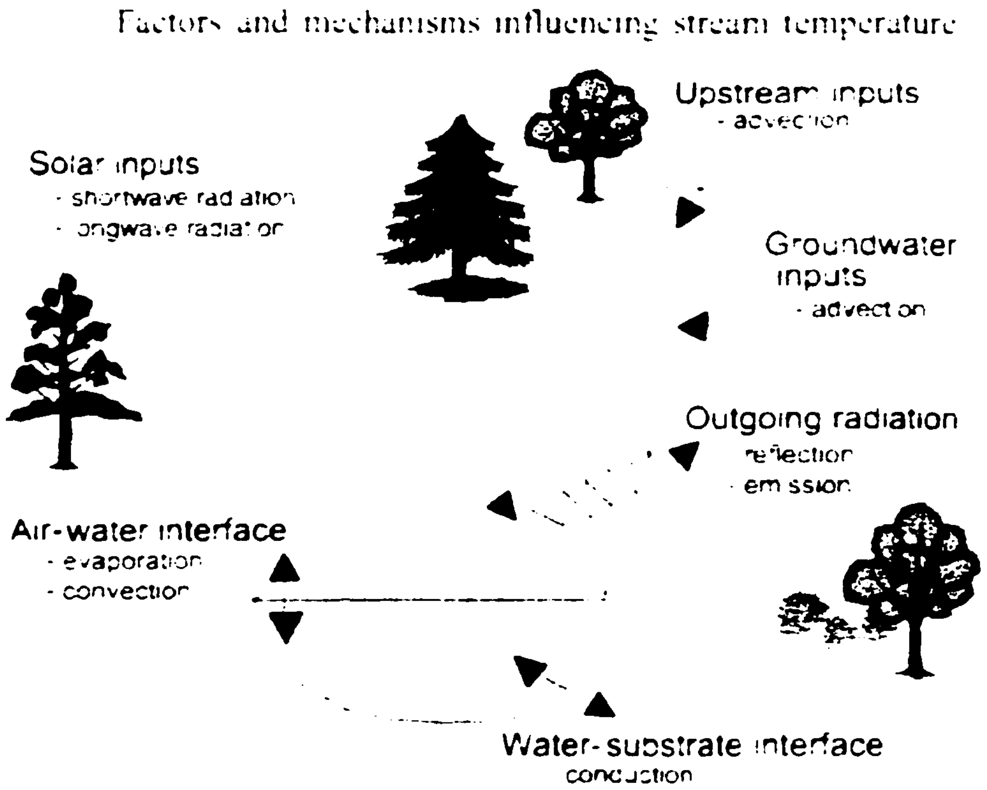


Figure 3. Factors and mechanisms influencing stream temperature (Johnson and Jones 2000)

The relationship between stream cover and trout habitat has been recognized for a long time (Boussu 1954). Temperature changes due to shade removal have significant implications for trout. These are changes in metabolic rate, hatching and development problems, and a decrease in vigor, growth rate, and resistance to diseases (Lynch *et al.* 1977). Increases in stream temperature can change the community structure and increases competition among all species. Changing the temperature also influences the dissolved oxygen content (Brown and Krygier 1970, Swift and Messer 1971, Lynch *et al.* 1977, Brown 1983, Johnson and Jones 2000), which influences the productivity of the stream and the survival, growth, and development of fish. In most cases changes in oxygen are not problematic, except for species such as brook trout, when their rate of metabolism rises very rapidly with temperature. Oxygen concentrations fall because the gas is less soluble in warmer waters, and the oxygen consumption of the fish is higher. Any conditions that slightly decrease the oxygen are deleterious for brook trout (Hynes 1970, Swift and Messer 1971, Allan 1995).

2.2.3 Streamflow

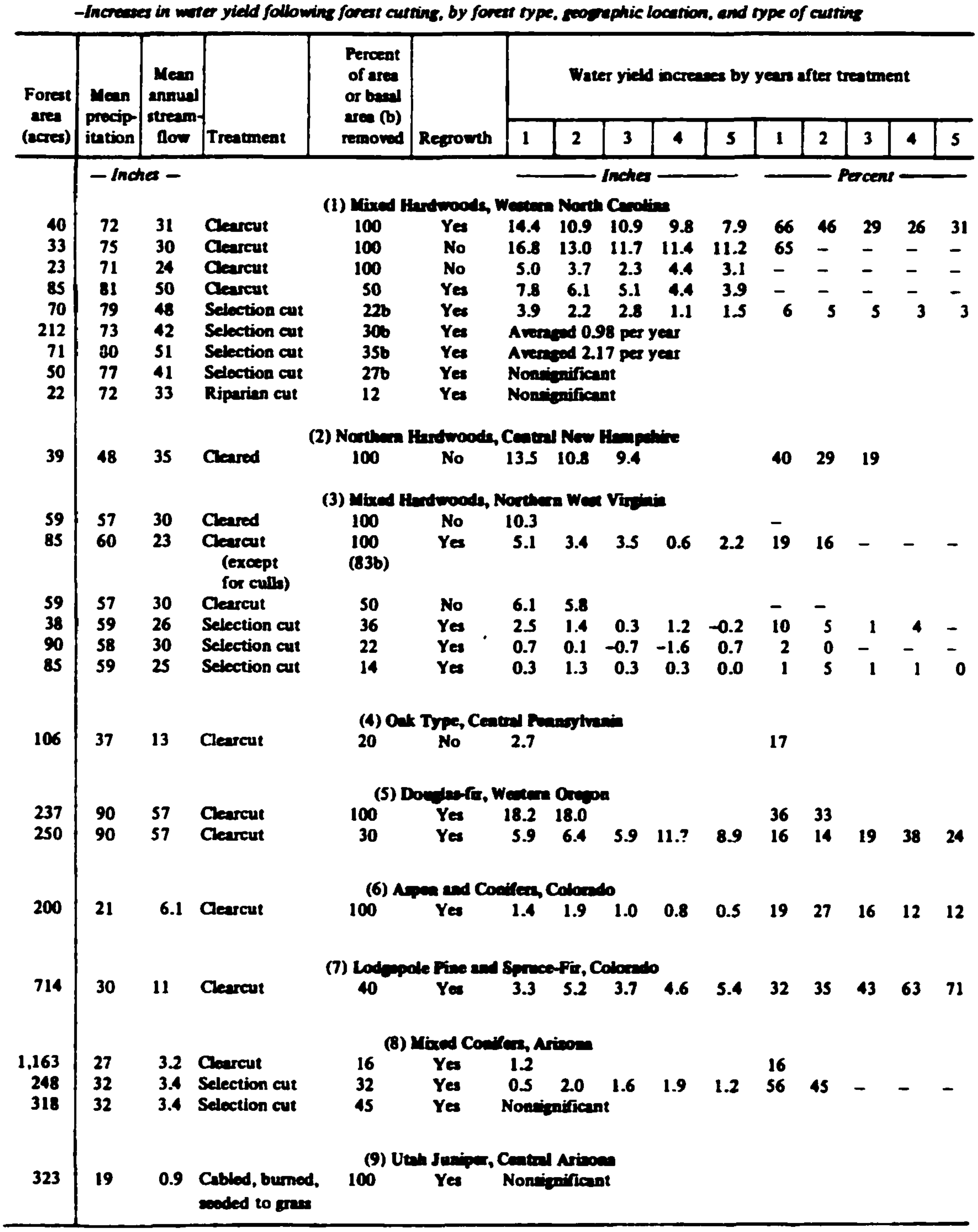
Streamflow is primarily affected by precipitation patterns; however the removal of vegetation by forest operations can also affect the streamflow (Jeffery 1968, Gibbons and Salo 1973, Hornbeck 1975, Anderson *et al.* 1976, Lynch *et al.* 1977). The reduction in evapotranspiration causes an increase in minimum streamflow as the precipitation runoff is increased. The hydrologic balance may be interrupted as soils remain wetter and more water is available for streamflow and ground water recharge (Gibbons and Salo 1973, Hornbeck 1975). The effects of forest removal with regard to water yield increase are considered under two components: immediate increase and durability of increase (Jeffery 1968).

Water yield increase after harvesting was generally proportional to the basin cutover and to the intensity of the cut, and was noted in northern forests of New Hampshire, the pacific northwest forests of Oregon, and coastal western Canada (Jeffery 1968, Anderson *et al.* 1976, Lynch *et al.* 1977). Jeffery (1968) suggested that the threshold level was a 20% cut of the basin as no increase in water yield was detected below 20%.

The durability of the increase relates to the decline of the increase of streamflow over a length of time. This rate is associated with the rapidity of revegetation and the initial intensity of the cut. Rapid revegetation causes rapid decline in streamflow increase, and slower revegetation is associated with slower decline in streamflow increase (Jeffery 1968, Anderson *et al.* 1976). Table 4, shows the increases in water yield following forest harvesting. Hornbeck (1975) showed that, in experimental cuttings on the Hubbard Brook Experimental Forest, streamflow increased as much as 41% but that the increase nearly disappeared after 4 years due to revegetation.

The effects of an increased streamflow can be both beneficial and detrimental to aquatic stream organisms. The increase in flow and velocity result in increased gravel grinding, gravel shift, and substrate transportation. This can cause problems for fish when their eggs and embryos become displaced, and for benthic algae and insects, which may become dislodged by the increased flow (Gibbons and Salo 1973, Lynch *et al.* 1977). Beneficial impacts of increased streamflow occur in summer and early autumn when additional streamflow is most needed (Hornbeck 1975). The increase in streamflow increases the available living space, thereby raising the carrying capacity of the stream. The increase in streamflow mitigates against the effects of increased solar radiation and consequent temperature increase (Gibbons and Salo 1973).

Table 4. Increase in water yield after forest operations (modified Anderson *et al.* 1976)



–Increases in water yield following forest cutting, by forest type, geographic location, and type of cutting

Forest area (acres)	Mean precip-itation	Mean annual stream-flow	Treatment	Percent of area or basal area (b) removed	Regrowth	Water yield increases by years after treatment									
						1	2	3	4	5	1	2	3	4	5
	— *Inches* —					*Inches*					*Percent*				
(1) Mixed Hardwoods, Western North Carolina															
40	72	31	Clearcut	100	Yes	14.4	10.9	10.9	9.8	7.9	66	46	29	26	31
33	75	30	Clearcut	100	No	16.8	13.0	11.7	11.4	11.2	65	–	–	–	–
23	71	24	Clearcut	100	No	5.0	3.7	2.3	4.4	3.1	–	–	–	–	–
85	81	50	Clearcut	50	Yes	7.8	6.1	5.1	4.4	3.9	–	–	–	–	–
70	79	48	Selection cut	22b	Yes	3.9	2.2	2.8	1.1	1.5	6	5	5	3	3
212	73	42	Selection cut	30b	Yes	Averaged 0.98 per year									
71	80	51	Selection cut	35b	Yes	Averaged 2.17 per year									
50	77	41	Selection cut	27b	Yes	Nonsignificant									
22	72	33	Riparian cut	12	Yes	Nonsignificant									
(2) Northern Hardwoods, Central New Hampshire															
39	48	35	Cleared	100	No	13.5	10.8	9.4			40	29	19		
(3) Mixed Hardwoods, Northern West Virginia															
59	57	30	Cleared	100	No	10.3					–				
85	60	23	Clearcut (except for culls)	100 (83b)	Yes	5.1	3.4	3.5	0.6	2.2	19	16	–	–	–
59	57	30	Clearcut	50	No	6.1	5.8				–	–			
38	59	26	Selection cut	36	Yes	2.5	1.4	0.3	1.2	–0.2	10	5	1	4	–
90	58	30	Selection cut	22	Yes	0.7	0.1	–0.7	–1.6	0.7	2	0	–	–	–
85	59	25	Selection cut	14	Yes	0.3	1.3	0.3	0.3	0.0	1	5	1	1	0
(4) Oak Type, Central Pennsylvania															
106	37	13	Clearcut	20	No	2.7					17				
(5) Douglas-fir, Western Oregon															
237	90	57	Clearcut	100	Yes	18.2	18.0				36	33			
250	90	57	Clearcut	30	Yes	5.9	6.4	5.9	11.7	8.9	16	14	19	38	24
(6) Aspen and Conifers, Colorado															
200	21	6.1	Clearcut	100	Yes	1.4	1.9	1.0	0.8	0.5	19	27	16	12	12
(7) Lodgepole Pine and Spruce-Fir, Colorado															
714	30	11	Clearcut	40	Yes	3.3	5.2	3.7	4.6	5.4	32	35	43	63	71
(8) Mixed Conifers, Arizona															
1,163	27	3.2	Clearcut	16	Yes	1.2					16				
248	32	3.4	Selection cut	32	Yes	0.5	2.0	1.6	1.9	1.2	56	45	–	–	–
318	32	3.4	Selection cut	45	Yes	Nonsignificant									
(9) Utah Juniper, Central Arizona															
323	19	0.9	Cabled, burned, seeded to grass	100	Yes	Nonsignificant									

2.2.4 Turbidity and Sedimentation

Sedimentation consists of erosion, sediment transport, and deposition (Anderson *et al.* 1976). Sedimentation in water systems is a natural event resulting from erosion. The degree and type of sedimentation is a factor of soils, geology, climate, and vegetation. Some forest practices may accelerate erosion and increase sediments in streams. Primary sediment production arises from logging roads, skid trails and the burning of slash (Gibbons and Salo 1973, Lynch *et al.* 1977, Steedman and France 2000). Surface erosion of roads is prominent in the seasons immediately following construction (Brown 1983). Brown (1983) also found in the pacific northwestern forests of United States, that felling trees was usually insufficient to produce increases in turbidity or suspended sediment concentration in streams as the forest floor can still trap sediment,. However, Brown and Krygier (1970) found that sediment production doubled after road construction but before logging and tripled after clear cutting and burning. Forests vary in their ability to remain stable after forest operations in regards to erosion problems. Differences arise as a result of different hydrological behavior and variations in climate, topography, geology and soils (Lynch *et al.* 1977).

Changes in the sedimentation concentration that exceed the tolerance level of aquatic stream organisms can change the population and reduce stream channel water carrying capacity. An increase in suspended sediment, (material light enough to be carried in the streamflow) can cause direct mortality of fish as a consequence of abrasion, thickening, and fusion of the gills.

Suspended sediments can increase bacterial infections in fish. Also, the decrease in light penetration limits the production of aquatic plants and can alter stream temperature change rates. Further more, turbid water reduces the visual feeding range of fish (Gibbons and Salo 1973, Lynch *et al.* 1977, Brown 1983).

Bedload sediment has the potential to cause the most damage to aquatic life; increases of bedload sediment reduce invertebrate diversity and populations, and reduce the living space and early survival of fish. The sediment 1) reduces water flow as intersticial spaces are filled with sediment, consequently 2) decreasing dissolved oxygen, and 3) physically preventing the emergence of fry (Gibbons and Salo 1973, Lynch *et al.* 1977, Brown 1983).

2.2.5 Organic Matter Input and Nutrient Input

Table 5 outlines sources of organic matter to running waters. Allochthonous material, the organic matter received by a stream from production that occurs outside of the stream channel, comprises a large portion of the stream's total organic matter. Plant litter and other coarse debris, fine particulates, and dissolved organic matter are the main components of non-living organic matter in streams. Heavily wooded stream banks provide abundant inputs of plant litter and other detritus while at the same time algal growth is reduced because of shade coverage. Non-living organic matter input is important for maintaining heterotrophic energy sources required by decomposers and detritivores. Changing the energy base through forest harvesting by removing non-living organic matter input may cause habitat quality to decline. Although the period during which logging affects allochthonous organic matter input is limited to a few decades, the quality of input change may last for 30 to 100+ years (Lynch *et al.* 1977, Allan 1995).

Table 5. Organic matter categories and source inputs into running water (Allan 1995)

Sources of Input	*Comments*
Coarse particulate organic matter (CPOM)	
Leaves and needles	Major input in woodland streams, typically pulsed seasonally
Macrophytes during die-back*	Locally important
Woody debris	May be major biomass component, very slowly utilized
Other plant parts (flowers, fruit, pollen)	Little information available
Other animal inputs (feces and carcases)	Little information available
Fine particulate organic matter (FPOM)	
Breakdown of CPOM	Major input where leaf fall or macrophytes provide CPOM
Feces of small consumers	Important transformation of CPOM
From DOM by microbial uptake	Organic microlayers on stones and other surfaces
From DOM by physical-chemical processes	Flocculation and adsorption, probably less important than microbial uptake route
Sloughing of algae*	Of local importance, may show temporal pulses
Sloughing of organic layers	Little infomation available
Forest floor litter and soil	Influenced by storms causing increased channel width and inundation of floodplain, affected by overland *versus* sub-surface flow
Stream bank and channel	Little known, likely related to storm events
Dissolved organic matter (DOM)	
Groundwater	Major input, relatively constant over time, often highly refractory
Sub-surface or interflow	Less known, perhaps important during storms
Surface flow	Less known, perhaps important during storms
Leachate from detritus of terrestrial origin	Major input, pulsed depending upon leaf fall
Throughfall	Small input, dependent on contact of precipitation with canopy
Extracellular release and leachate from algae*	Of local importance, may show seasonal and diel pulses
Extracellular release and leachate from macrophytes*	Of local importance, may show seasonal and diel pulses

2.2.6 Dissolved Nutrient and Mineral Input

Mineral and organic nutrients necessary for life and for regulating biological activity in forests come from geological weathering of parent material, atmospheric inputs, and biological inputs. Nutrient cycling is a complex process in forests involving pathways between living organisms and the atmosphere and/or the soil. As described by Kimmins (1997) the three major types of nutrient cycles are geochemical, biogeochemical, and biochemical. Geochemical nutrient cycling involves the exchange of nutrients between ecosystems and acts on a large spatial and temporal scale. Furthermore, most often nutrients exit and enter the ecosystem on different spatial pathways. Biogeochemical cycling is the exchange of nutrients within the ecosystem and operates on a smaller spatial and temporal scale. The nutrients remain in the pathways within the ecosystem. Biochemical cycling is the redistribution of chemicals within an individual organism.

Dissolved solids in streams in undisturbed forests are generally low and determined by several complex processes involved in the nutrient cycle of a forest system (Brown 1983, Allan 1995) (Figure 4). Forest ecosystems in which logging operations take place are subject to additional nutrient losses. Nutrient release is a function of soil, vegetation, and climate. Nutrients in the streams increase as a result of the exposure of site to the elements which accelerates: 1) organic matter decomposition, 2)leaching, 3) nitrification, and 4) blocks the uptake of available nutrients that normally would have occurred by the removed vegetation (Lynch *et al.* 1977, Brown 1983).

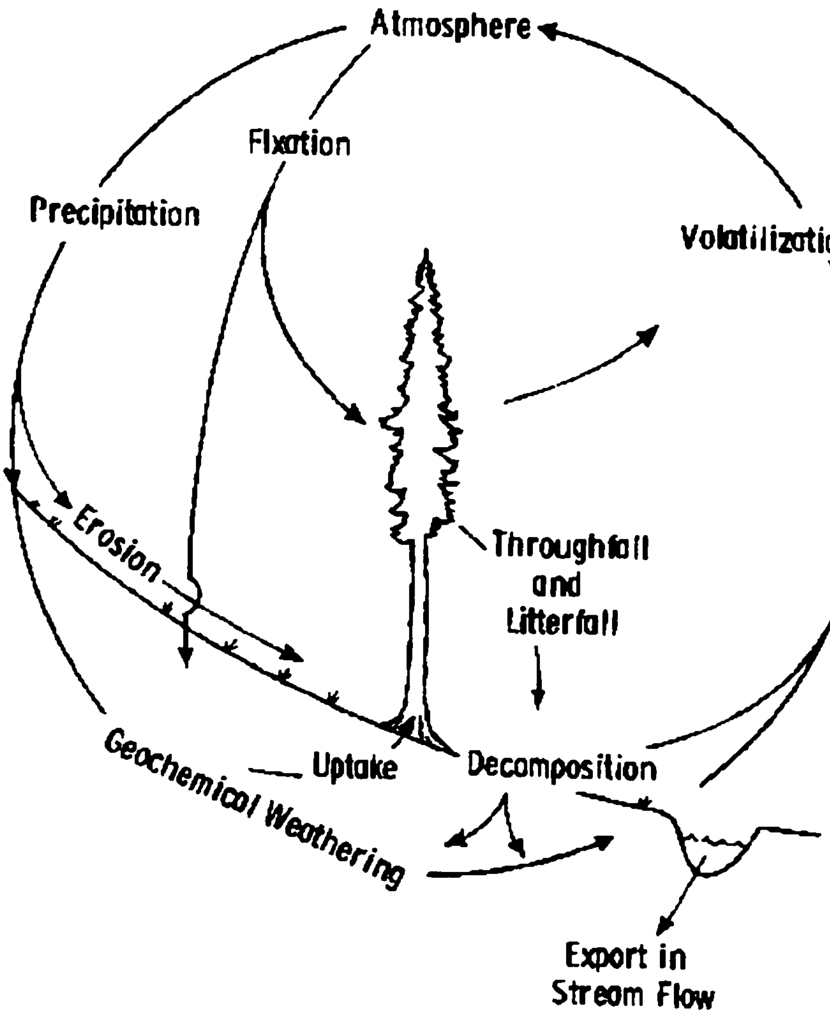


Figure 4. Nutrient Cycles in a Forest (Source: Brown 1983)

Dissolved nutrients often increase in streams after logging but do not have significant effect on water quality, aquatic ecosystems or fish production (Brown *et al.* 1973, Hombeck *et al.* 1986). The temporary changes in water quality are increased concentrations of dissolved organic carbon, cations (particularly potassium), nitrogen and phosphorus (Brown *et al.* 1973, Hombeck *et al.* 1986, Carignan *et al.* 2000). The magnitude of the nutrient increase controls the stream response. If nutrients increase significantly the stream may be able to support plant and animal life that previously did not exist (Lynch *et al.* 1977). Clearcutting may temporarily increase the nutrients in a stream in the clearcut area, but levels tend to rapidly decrease to those before the cut. This is probably because plant species (*Prunus* sp., *Rubus* sp., *Betula* sp.) establish in the cutovers (Kimmins 1997) prevent further leaching losses from the ecosystem.

2.2.7 Management of Harvesting Operations

Riparian Area

Riparian areas, (*e.g.*, the ecosystem(s) between the aquatic and terrestrial zones) can help to ameliorate the effects of forest clearing (Barton *et al.* 1985). Riparian zones have been found to absorb nutrients and sediments, balance the inflow and outflow of litter, regulate stream temperature, provide fish cover, retain bank stability, and provide allochthonous organic matter (Shure and Gottschalk 1985, Rostan *et al.* 1987, Wesche *et al.* 1987). The riparian zone often has distinct vegetation (different species and different mix of species) from the forest cover and is considered part of the Area of Concern (AOC) when the *Timber Management Guidelines for the Protection of Fish Habitat* are applied, as the AOCs for streams are currently measured starting at the high water mark. Forest riparian ecosystems are not only important for aquatic systems but are home to a high diversity of plant species (BC Government 2001); thus providing many opportunities to wildlife for nesting, feeding, hiding, roosting and migration corridors.

Numerous investigators have shown the importance of leaving undisturbed vegetation strips around streams and lakes during and after harvesting for environmental protection (Brazier and Brown 1973, Rishel *et al.* 1982, Brown 1983, Steinblums *et al.* 1984, Barton *et al.* 1985, Clinnick 1985, Wesche *et al.* 1987, Steedman 2000, Steedman and France 2000, and Steedman *et al.* 2000). These protective strips help to:

a) reduce sedimentation and erosion,
b) protect water quality by detaining sediment contaminated water from, roads and forest harvesting areas,
c) reduce sediment bound nutrient input,
d) promote infiltration of surface run off,
e) keep timber operations away from sensitive habitats,
f) prevent changes in natural temperature regimes,
g) maintain dissolved oxygen,
h) provide allochthonous organic matter input, and
i) provide bank stability.

When applied, the *Timber Management Guidelines for the Protection of Fish Habitat* attempts to mitigate against any negative impacts of logging on aquatic ecosystems (OMNR 1988). However factors such as terrain, vegetation type, soil, and climate can modify the success of any management scheme, (Barton *et al.* 1985).

The AOC width in the guidelines is slope dependent and based upon a model that predicts how inorganic sediment moves on slopes (Trimble and Sartz 1957).

SECTION III

3.0 OBJECTIVE

In southern Ontario, Stoneman and Jones (1996) recognized a relationship between stream temperature and ambient air temperature. From their document, "*A Simple Method to Determine the Thermal Stability of Southern Ontario Trout Streams*" (SMST) and Module 6, the *Stream Assessment Protocol For Southern Ontario* (SAPSO) was developed. These methods allow the user to obtain a reliable estimate of summer thermal stability of a stream site (*i.e.*, whether it is a cold, cool or warm water segment) based on maximum ambient air temperature and instream water temperature at 1600 hours. Table 6 shows the relationship between Stoneman and Jones (1996), *a Simple Method to Determine the Thermal Stability of Southern Ontario Trout Streams* (SMST) and Module 6, in the *Stream Assessment Protocol For Southern Ontario* (SAPSO).

The goal of this study was to calibrate the model for the Hearst District based on the information presented in Module 6 and to test the SAPSO model for the Hearst district. The desired outcome was to develop a nomogram by regressing maximum air temperature with water temperature. The nomogram would then be used to classify streams with unknown thermal regimes. The thermal classification of streams in the district was important for the Area biologist to determine to allow for application of the guidelines. The site characteristics were measured at the request of the Area biologist. This information may be used in future management planning.

Table 6. Relationship between models

Authority	Title	Source	Relationship
Stoneman and Jones (1996)	A Simple Method to Classify Stream Thermal Stability with Single Observations of Daily Maximum Water and Air Temperatures	Journal Article Stoneman, C.L. and M.L. Jones. 1996. A simple method to evaluate thermal stability of trout streams. N. Amer. J. Fish. Manage. 16:728-737.	Foundation for SAPSP Module 6 and SMST
Ontario Ministry of Natural Resources and Fisheries and Oceans	A Simple Method to Determine the Thermal Stability of Southern Ontario Trout Streams (SMST)	Action Plan of Fish Habitat Management Series - Ontario Code of Practice	Similar protocol to Module 6, SAPSO Protocol based on Stoneman and Jones (1996)
Great Lakes Salmonid Unit, Ministry of Natural Resources	Module 6, Thermal Stability, Stream Assessment Protocol For Southern Ontario (SAPSO)	Stream Assessment Protocol For Southern Ontario (SAPSO)	Similar protocol to SMST Protocol based on Stoneman and Jones (1996)

3.0.1 Basis for Module 6 (SAPSO)

Stoneman and Jones (1996) investigated the relationship between air and stream temperature in three contrasting thermal regimes (cold, cool and warm). Water temperature data was collected on six sites in Lake Ontario tributary streams during summer months over several years. Thermograph recorders (continuous water temperature collection) and temperature recorders (water temperature collection every 10 minutes) were used at the different sites. The air temperature data was obtained by weather stations in the area. The data analysis involved regression methods to determine a relationship between maximum air temperature and water temperature for the three thermal regimes at 900, 1400, 1500, and 1600 hours. Also, the residuals from the regression of maximum air temperature against water temperature were plotted against the previous day's maximum air temperature, the previous day's maximum water temperature, an average of maximum air temperature for the three previous days, and other information relating to precipitation and minimum air temperatures. Stoneman and Jones (1996) found that the relationship between daily change in air temperature and changes in stream temperatures did not differentiate well between the three thermal regime categories. However maximum daily air temperature plotted against water temperature at 1600h differentiated the stream thermal categories with the most separation evident for air temperatures above 25°C. Stoneman and Jones (1996) suggested that the thermal stability of a site can be assessed from a single stream temperature at 1600h provided that the maximum air temperature for that day and the previous 2-3 days had no major changes in weather (*e.g.*, drastic temperature changes).

Figure 5 shows a nomogram of maximum air temperature and water temperature at 1600h. The nomogram works by defining the most probable stream type for maximum air temperature and water temperature at 1600h.

The boundary lines represent the confidence intervals (95%) surrounding each of the three regression lines for the three thermal regimes. The nomogram boundary lines are the points at which a water temperature measurement for a given air temperature value is likely to come from either category. The further away from the boundaries the more likely the stream will be classified correctly.

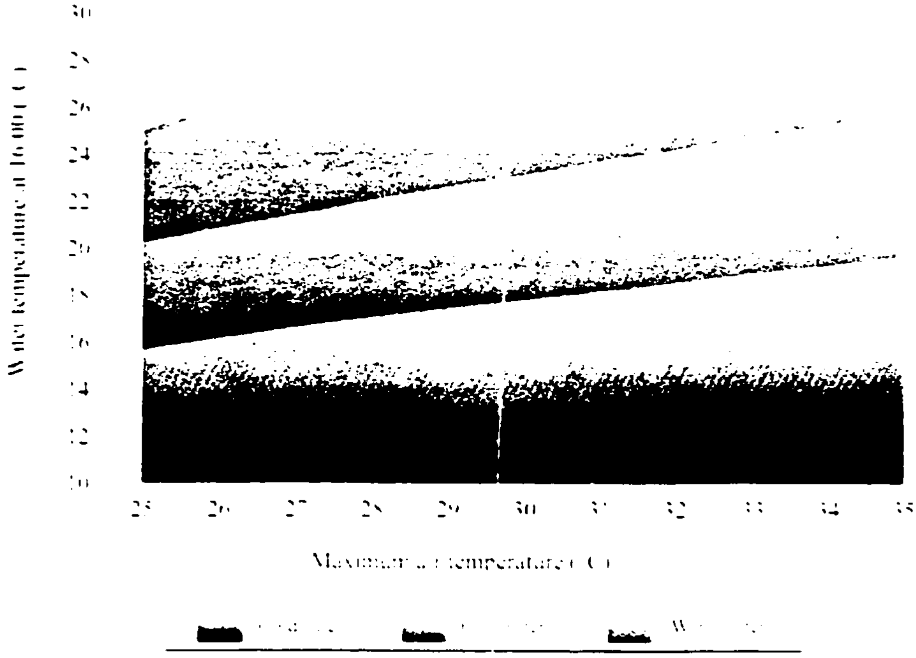


Figure 5. A nomogram of maximum air temperature and water temperature at 1600h (OMNR and DFO n.d.)

3.2 METHODS

3.2.1 Setting

The Hearst District (Figure 6) has a modified continental climate with cool summer temperatures and increased rainfall because of proximity to the Great Lakes and Hudson Bay. Glaciation formed the topography and surficial geology of the region. There is little topographic relief in the area. The soils are mainly clays (silt clays to clay loams) in the Northern Clay Belt region. In the James Bay Lowlands, there are poorly drained deep organic soils. The rest of the area has a mixture of clays, loams, sands, and organic soils with poor drainage (Hearst Forest Management 1997). Figure 7 shows the study locations in townships of the Hearst District.

3.2.2 Field Procedures

Module 6, Thermal Stability in the Stream Assessment Protocol (1999) provided the basis for the field procedures. The *Stream Assessment Protocol For Southern Ontario* (SAPSO) was prepared by The Great Lakes Salmonid Unit of the Ministry of Natural Resources. This protocol was designed to objectively assess the productive capacity of streams and as a means of quantitatively assessing stream habitat. The protocol is comprised of 12 different modules that provide information to aid management decisions and provide a means of rapidly assessing the physical habitat across a wide geographic area (Stanfield *et al.* 1999). Module 6, in the Protocol, was based on research by Stoneman and Jones (1996). This procedure is based on a

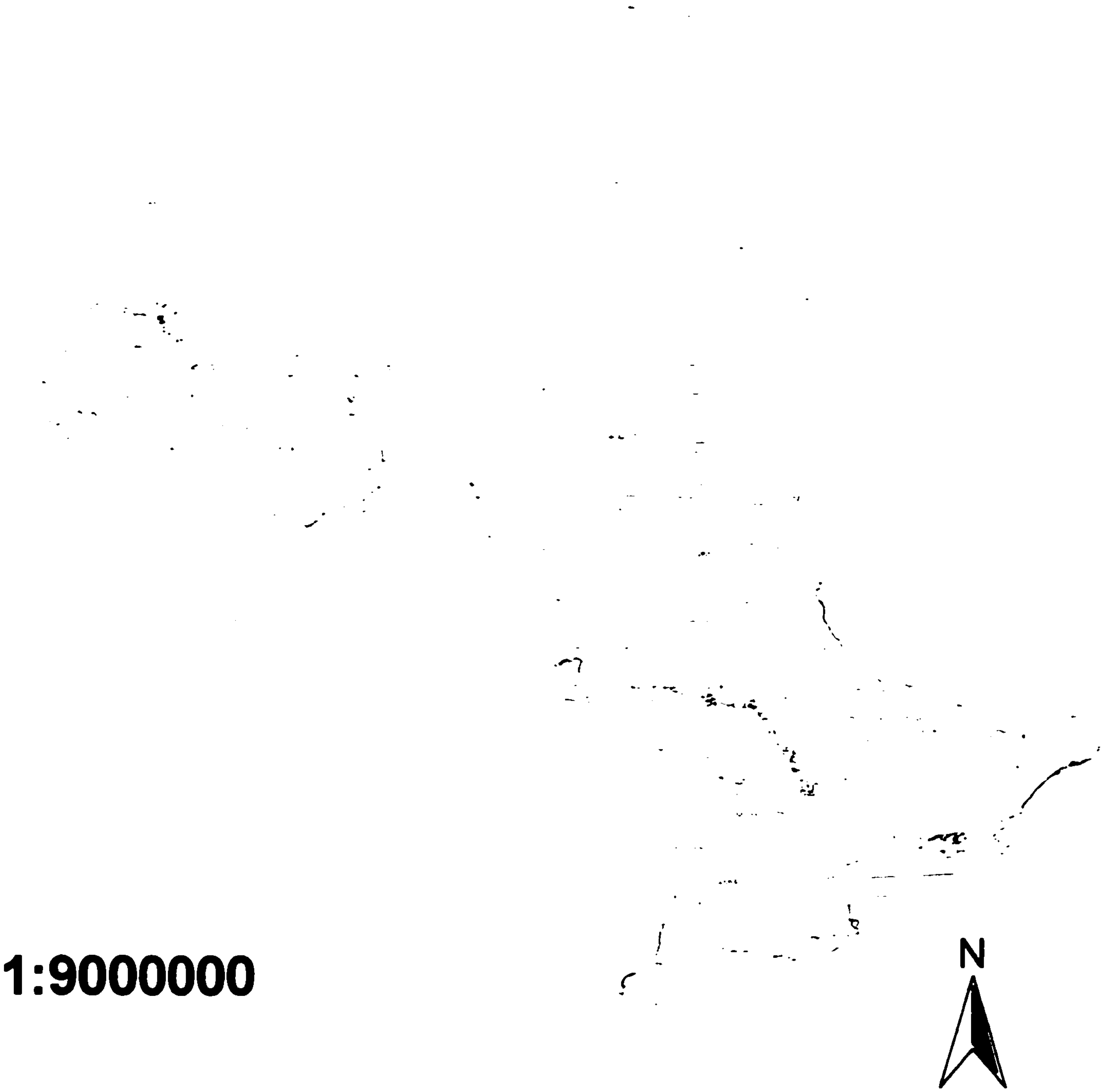


Figure 6. Map showing the Hearst District, OMNR

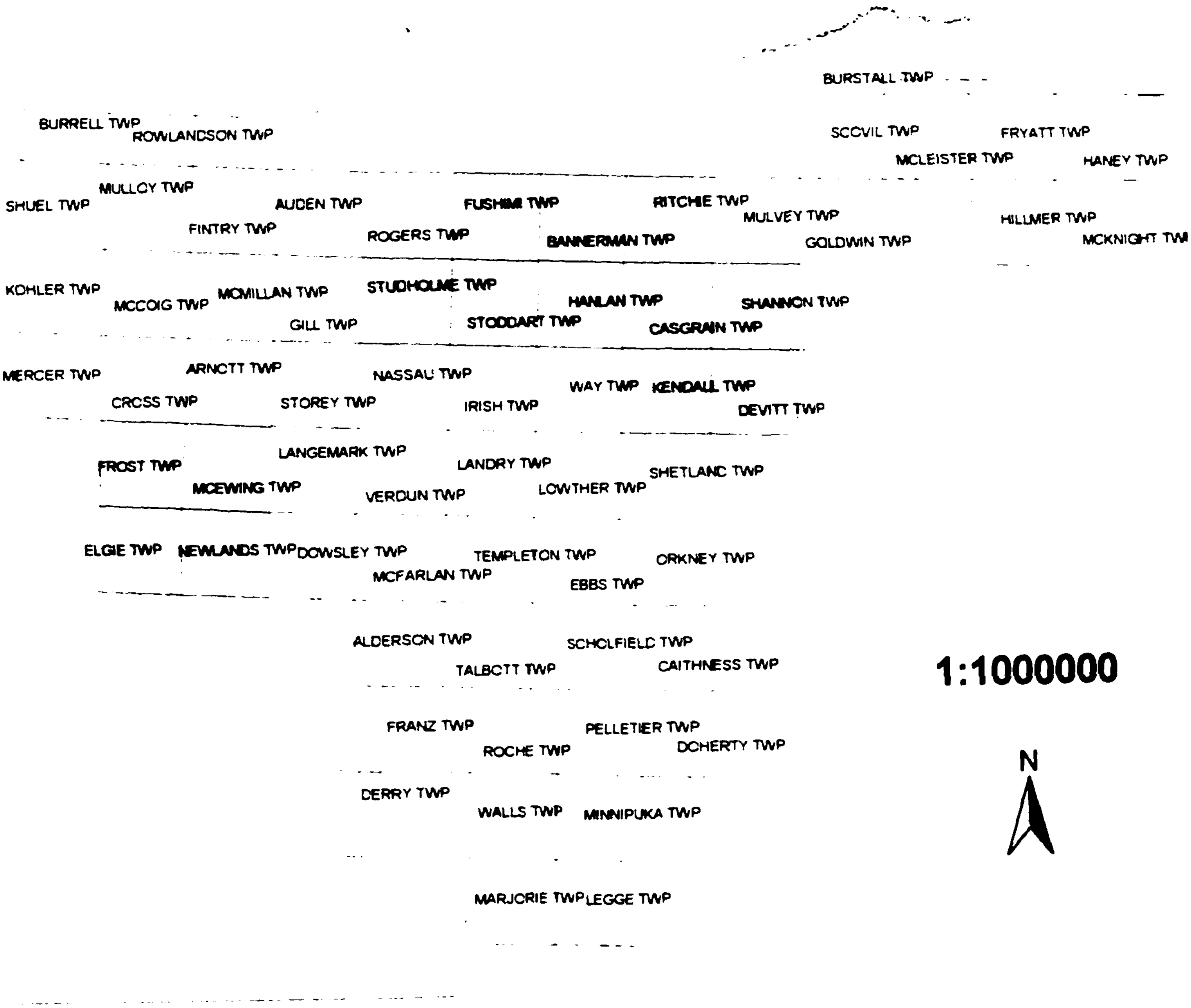


Figure 7. Hobo installation sites in the Hearst District.

single point observation to classify the stream's thermal regime. Stoneman and Jones (1996) found that on days with 24°C+ temperatures there was a linear relationship between the thermal stability of the stream and maximum water temperature.

Stream temperatures were collected for 51 stream segments in the Hearst District between July 14th and August 30th, 2000. Known stream segments for cool and cold water were selected by using previous MNR data to calibrate the module. Also, stream segments for which there were no data were selected for the upcoming Forest Management Plan. The Area Biologist initially chose all stream segments. Some of the streams were tested in more than one spot. The protocol suggested that temperature of the stream should be recorded at 1600h ± 15min on days when the temperature exceeded 24.5 °C when the previous 2 days were within ± 3 °C. The protocol indicated that 1600h might not be a suitable time for the model application outside of southern Ontario because streams may have not reached maximum temperatures; therefore temperatures were recorded hourly throughout the day.

Stream temperatures were measured with a Hobo (H 8) manufactured by Onset Computer Corp. (Figure 8 and 9). The Hobo (H 8) is a data logger that has an external sensor cable to determine stream temperature. The specifics are shown in Table 7.

Table 7. Hobo common specifications (Onset Computer Corp. 1997-1998)

Component	Specifics
Operating Range	-40°C - +120°C
Weight	28.35g
Size	6.1cm x 4.8cm x 2.0cm

The Hobo was sealed in a plastic food container and was secured in the stream segment in order to record the midstream temperature. The Hobo was placed in a well-mixed section of the main flow of the stream and placed in a representative area with regards to shade coverage and stream depth. The Hobo recorded the stream temperature according to the preprogrammed chip, designed to take a temperature reading once every hour, 24 hours a day for 365 days. The Hobo was not retrieved from the stream until the air temperature exceeded 24.5°C and the 2 days previous had been consistent within ±3°C. Detailed procedures are outlined in Appendix A.

Other stream characteristics measured included floodplain width, hydraulic head, water depth, bankfull width, type of stream material on the bottom, profile diagram, and notes on amount of shade. This information was recorded at the request of the Area Biologist and was not required as part of Module 6. The Universal Transverse Mercator (UTM) location was also recorded, along with the time and date. A sample data collection sheet is given in Appendix B.

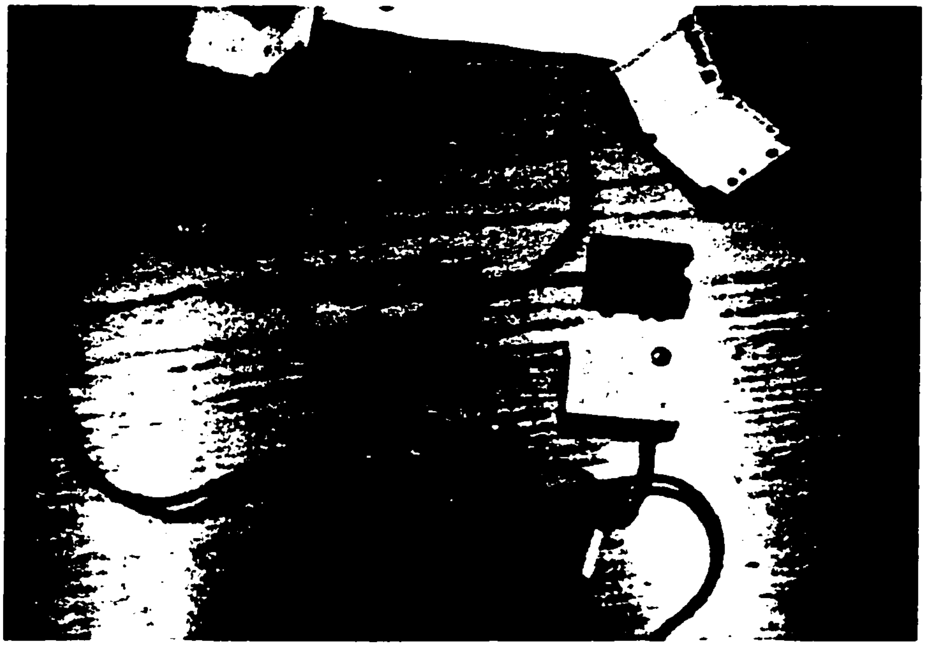


Figure 8. Display of the Hobo

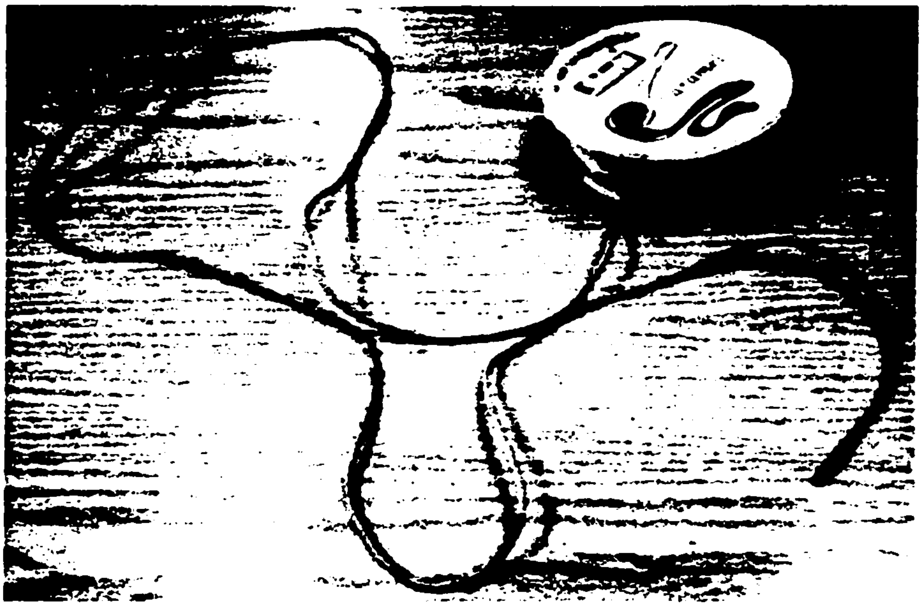


Figure 9. Example of Hobo inside waterproof container

3.2.3 Lab Procedures

BoxCar Pro software (Onset Computer Corp. 1997) was used to program and retrieve the data from the Hobo. The computer clock had to be set accurately as the Hobo used the computer clock to set its internal clock. To launch the Hobo, interval (time between measurements), duration (amount of time the logger will collect data), and temperature measurement unist (Celsius) were set. The Hobo was then secured in a waterproof container sealed with silicon.

3.2.3a During and After Field Procedures

The air temperature was monitored remotely at the Ministry office by using a maximum/minimum thermometer. Once the specified temperatures had been reached, the Hobos were collected. At the office the data from the information sheets for each logger was entered into the computer. Also the data was downloaded into the computer from the Hobo and sorted according to temperature and date. The BoxCar software provided several display options for the data. The Hobo recorded the temperature whether or not the Hobo is installed in the stream; therefore the installation and removal dates and times were important items to record. Several Hobos were damaged in the field either by animals or by water.

3.2.3b Data Analysis

The protocol for Module 6 suggested that stream temperature be recorded at 1600h or at the time when the stream temperature was at its hottest. In the Hearst Forest, stream temperature data was collected hourly; however after inspection the warmest temperature corresponded to1600h. Therefore data analyzed is stream temperatures at 1600h. Only 3 days during the study period met the criteria for the protocol of air temperature (>24.5°C along with the previous 2 days temperature = 24.5 ± 3 °C).

Linear regression analysis was performed using an ANOVA to test for differences among group means with regards to the water temperature at 1600h and maximum air temperature and to correlate the independent variable (air temperature) with the dependent variable (stream temperature).

3.3 RESULTS

July 26, 27 and August 12 were the only days to have met the protocol outlined in Module 6. Table 8 shows the ambient air temperatures for the study period. Figure 10, displays maximum air temperature versus water temperature at 1600h for the 3 days that met the protocol. Table 9 and Table 10 are the results of the regression analysis. Table 9 shows the extent to which the independent variable is correlated with the dependant variable and the F-value and the significance of F-value. For the coldwater streams 28.3% of the variation of stream temperature can be explained by air temperature, which is significant ($P<0.05$). The coolwater streams correlation is not significant ($P=1.09$) and only 26.0% of the variation of stream temperature can be explained by air temperature. Table 10 shows the variables in the regression equation. With no influence by air temperature the B intercept indicates the stream temperature. The B intercept is lower for cold than for cool. The B slope indicates the increase value for the influence of air temperature. The t value and associated significance value are also displayed in Table 10. The B value for coldwater is significantly different than zero , whereas the coolwater is not. Table 11 displays the regression equations for cool and cold water. A comparison was made for only two of the air temperatures on days when the protocol was met. A comparison of cool and cold for air temperature at 26°C showed that there was a significant difference, however at 29^0C there was not a significant difference (Table 12). This seems to indicate that the higher the air temperature the more difficult it is to distinguish between the thermal regimes. This is contrary to what module 6 indicates.

The physical data on stream floodplain width, stream width and depth showed no obvious trend (Figure 11), nor did stream bottom (Table 13, Table 14). This physical data was neither part of module 6 nor the calibration of the thermal model, and not part of this project report data analysis. Therefore the information is just summarized. The Area biologist had hoped that an obvious trend would be evident. This site characteristic data gathered however, provides pre-timber harvest background information on some stream segments. In the future this data could become useful if compared to post-timber harvest data in a monitoring program.

The desired outcome to calibrate (SAPSO) for the Hearst District was not achieved. Appendix C contains all the stream temperature data. Appendix D contains all the cool and cold stream physical data.

Information on floodplain width, stream depth and width were compared for the known cool and cold streams. As this was not part of the initial objectives, in the future more analysis of this data may provide useful information for the Area Biologist, as data analysis of this information in this report is limited.

Animals and water destroyed several of the data loggers. This perhaps could have been avoided if containers used were not food containers, and by more carefully monitoring of stream depth changes and precipitation events.

Table 8. Maximum ambient air temperature for the study period in Hearst

Date	Temperature °C Max/Min Thermometer	
July 14	22	
15	27	
16	27	
17	21	
18	16	
19	20	
20	18	
21	16	
22	20	
23	24	
24	27	
25	27	
26	29	
27	30	
28	25	
29	28	
30	32	
31	33	
Aug 01	29	
02	10	
03	18	
04	24	
05	26.5	
06	21	
07	16	
08	17 (at 13:00)	
09	24	
10	25	
11	27	
12	26	
13	21	
14	26	
15	25	
16	19	Hobo Temp
17	19	18.66
18	15	13.7
19	13.5	13.32
20	20	20.19
21	21	20.19
22	26	25.17
23	24	22.86
24	28	27.91
25	29	28.31
26	21	20.95
27	25	24.01
28	27	26.73
29	21	20.19

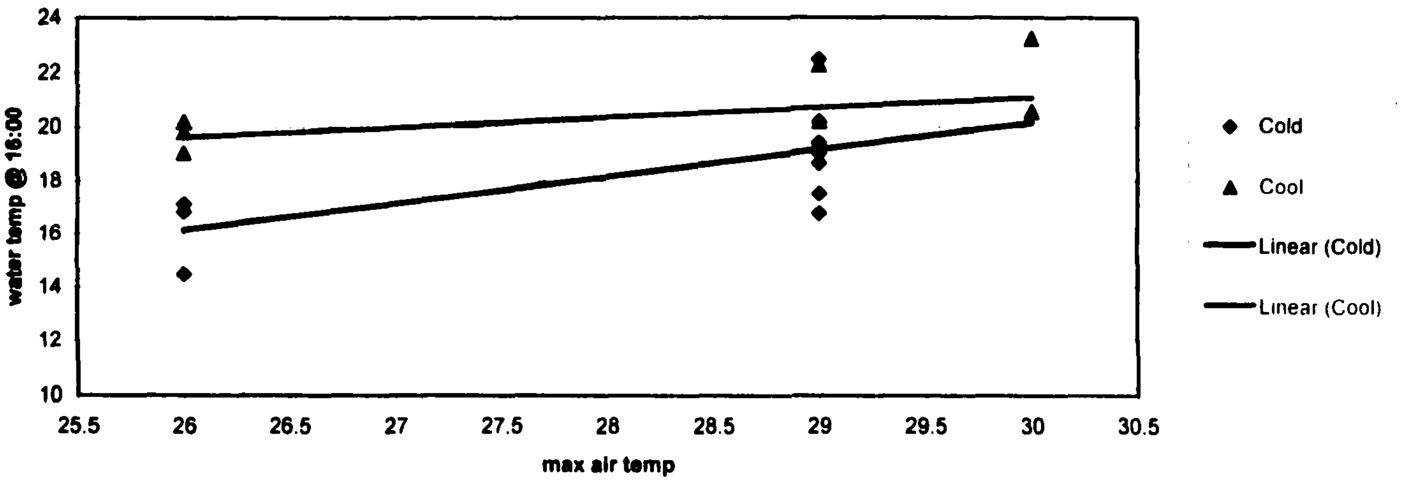


Figure 10. Maximum air temperature vs. water temperature @ 1600hr for days that met the protocol

Table 9. ANOVA results for thermal stream assessment

Thermal Type	R	R Square	Adjusted R Square	Std. Error of the Estimate	F	Sig
cold	0.532	0.283	0.252	1.9824	9.078	0.006
cool	0.51	0.26	0.178	1.1546	3.16	0.109

Table 10. Regression equation inputs and significance for thermal stream assessment

Thermal Type	B Intercept	B Slope	Std. Error	Beta	t	Sig
cold	-1.555	0.717	0.238	0.532	3.013	0.006
cool	10.129	0.365	0.205	0.51	1.778	0.109

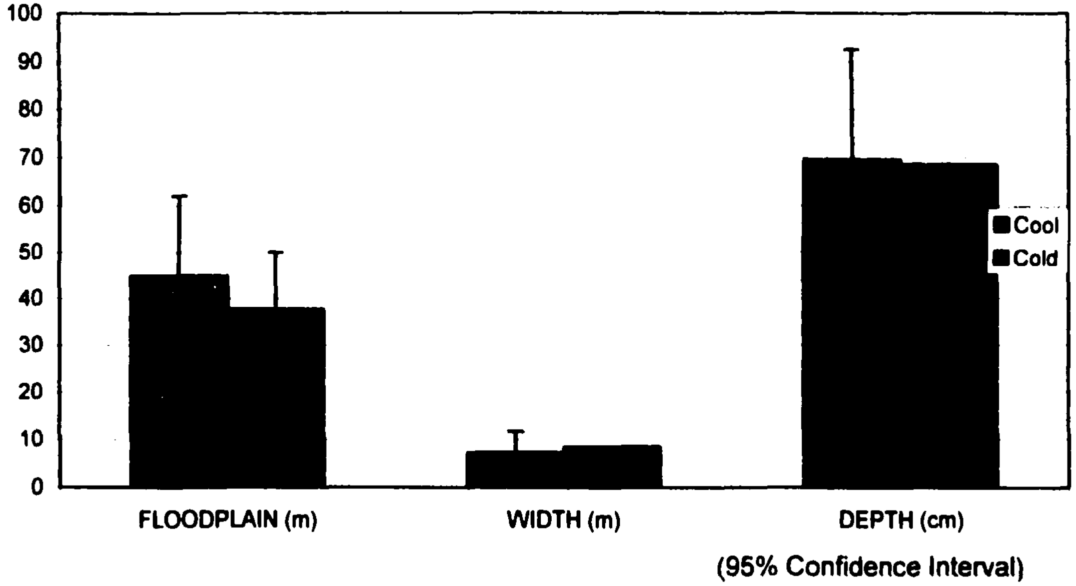


Figure 11. Comparison of floodplain, stream width and depth for cool and cold water stream means

Table 11. Regression equations for cool and cold water streams

Thermal Regime	Equation
Coolwater	y = .717(air temperature) + (-1.555)
Coldwater	y = .365(air temperature) + 10.129

Table 12. Comparison of cool and cold water on 2 days that met the protocol with air temperatures of 26°C and 29°C

Air Temperature	t	Sig
26	3.97	0.028
29	0.456	0.853

Table 13. Coldwater stream bottom summary

Stream Bottom (%)	Hobo 3-2	4-2	5-2	6-2	13-2	16-2	3-1	4-1	5-1	6-1	7-1	8-1	9-1	10-1	12-1	13-1	14-1	15-1	16-1
sand	50			38		50				50	2	70			100	100		40	70
gravel	50				25		100	99	100		2			100				59	30
muck		100	100	4						50			100				100		
cobbles				58	75						2							1	
silt						50													
bedrock								1			92								
bolder												30							

Table 14. Coolwater stream bottom summary

Stream Bottom (%)	Hobo 2-2	19-2	20-2	23-2	24-2	29-1	18-1	19-1	27-1
sand			20					50	
gravel	80			1				50	
muck		100			100		100		
cobbles	20			1					
silt						100			100
bedrock									
bolder			80						
clay				98					

3.4 DISCUSSION

3.4.1 RECOMMENDATIONS AND SAMPLING DESIGNS

3.4.1a Site Selection

The streams selected in this study were inappropriate. The rationale for choosing so many unknown streams was that the Area Biologist needed to know the thermal classification for streams in the upcoming Forest Management Plan. The biologist was under the assumption that the model could easily be calibrated and the unknown streams could be classified. Considering that there was not enough data retrieved from this study as a result of air temperatures and selected positions of loggers, any experiments in the future associated with air temperatures and heat stress studies should start earlier in the summer, and use known cool and cold water streams classified with certainty. The study should have used known sites and data collected for at least two summers. In Stoneman and Jones (1996) only six streams in total were assessed. Following that protocol only four streams (two for each thermal regime, cool and cold) should have been used to calibrate the model. In doing so these reference streams could have been used to compare data collected from other streams.

There are several reasons for why the model could not be calibrated. The main reason for the lack of success was attributed to the climate of the Hearst District. The heat stress that was needed for this procedure did not occur frequently enough to produce needed data points. The air temperatures rarely exceeded levels to allow for the contrasting thermal regimes to become evident.

A Simple Method to Determine the Thermal Stability of Southern Ontario Trout Streams cautions that this technique will not work if the air temperature rarely exceeds levels that allow contrasting thermal regimes to become evident. Stoneman and Jones (1996) state that the range of thermal conditions exhibited in a region depend on varying physiographic and land use features, along with the shading by riparian vegetation and stream size. They also state that this method does not necessarily determine the fish species at the site, but suggest a general conclusion about fish communities.

Other reasons for why this model did not work are based around the differences in surficial geology and ground water input differences between southern and northeastern Ontario. Also the initial classification for the stream may have caused problems as some of the stream classification in the Hearst District was based on anecdotal information and some streams that were classified as having a distinct thermal regime may be a mix of thermal regimes.

3.4.1b Sampling Designs in the Literature

Fisheries biologists in the past have found that basin-wide stream survey methodologies have been important tools to aid in fish population and habitat management. However the linkage of management impacts to fish habitat in cumulative watershed effects are viewed skeptically as there are problems of quantitatively assessing watershed cumulative effects (Chen 1992).

Habitat is the key concept when trying to manage fish populations. Survey efforts often collect limited data, and usually concentrate on short segments of a stream that are considered to be representative of the entire stream. Often statistical sampling methods are used to gather quantitative information on biological and geomorphologic aspects of stream characteristics. However, the amount of sampling is often limited by resources and time (Chen 1992, Simonson *et al* 1994). Newer survey methods classify individual channel units into primary levels of organization as each unit is classified as a particular habitat type and quantitative data is collected on its physical attributes, and at systematic intervals, fish abundance is determined, as fish numbers are linked to specific stream habitat (Chen 1992).

In the literature no sampling or survey procedures focused on thermal stream regime. However, there are a wide variety of methodologies used to inventory stream habitat variables but sampling design has not been well documented and sampling studies are limited. Hankin and Reeves (1988) and Simonson *et al.* (1994) present two different approaches to stream habitat sampling. Simonson's *et al.* (1994) sampling procedure deals only with stream habitat, whereas Hankin and Reeves (1988) combined both habitat and fish abundance.

Simonson *et al.* (1994) attempted to develop an efficient standardized framework for stream habitat evaluations that complement fish survey procedures. The sampling procedure was designed to be a framework that could be customized but maintain an accurate and precise system. Simonson *et al.* (1994) determined the efficient transect sample sizes and spacing needed to characterize the means of common habitat features over a broad range of streams.

Simonson *et al.* (1994) collected habitat data at 86 stations on 58 streams in Wisconsin over a 3-year period in the summer months. Each station ranged in length as length was based on 35–40 mean stream widths (MSW). First to fifth order streams were assessed. The habitat variables that were sampled were bankfull width, stream width, depth, maximum depth, velocity, substrate type, cover, shading, minimum bank height, maximum bank height, and back erosion. For each variable the minimum difference or change in the mean value that could be statistically detected was calculated.

Simonson *et al.* (1994) found that 20 transects spaced two MSWs apart yielded means that were accurate (95% of the mean values were within 5% of the true means). For streams less than 5m in width, 13 transects spaced three MSWs apart were sufficient. Random sampling was not used, as systematic sampling in field situations was a compromise between statistical accuracy, convenience, and ease. Simonson *et al.* (1994) also suggested that as their study only focused on means most often used in habitat modeling, their sampling protocol approach would also be used to identify optimal sampling for accurate estimation of variability in stream habitat characteristics and diversity. Hankin and Reeves (1988) presented a sampling design for estimating total areas of habitat types and total fish numbers in small streams. The design is based on based on habitat unit type and stream reach, and uses visual methods for estimating habitat areas and fish numbers to increase sample sizes. The effectiveness of the sampling design depended on the correlation between the visual estimates and the true habitat area and fish numbers. True habitat and fish numbers were determined using more accurate methods than visual estimations. Systematic sampling was used for the selection of units. The sampling design assumes that habitat units are stratified by type (riffle, pool, glide) and by location (lower, middle, upper reaches).

Hankin and Reeves (1988) stratified Cummins Creek in Oregon into three contiguous reaches (lower, middle, upper reaches) of similar length, each reach then was classified as riffle, pool, glide, or side channel. Visual estimates of the habitat areas were identified, and systematic samples of one out of every 10, or one out of every 20 units were accurately measured. Estimates for total habitat areas were calculated. Next a systematic sampling of one out of every five units, was done by divers counting of fish. The counts were calibrated for each habitat type. A more accurate method of estimation resulted from electrofishing selected units. Correlations were then made between habitat and fish species using both visual and actual measurements. Hankin and Reeves (1988) developed a series of equations to relate visual estimates and accurate measurements.

The sampling design by Hankin and Reeves (1988) was a practical method for estimating fish abundance and stream habitat. Also, they suggested that systematic sampling circumvents the need for preexisting maps of habitat unit locations and simplifies fieldwork. They believed that systematic sampling will outperform random sampling when there is a linear trend of fish numbers with habitat location, and will perform as well if fish numbers are unrelated to habitat.

Hankin and Reeves (1988) suggest that their sampling design may be less accurate than large-scale electrofishing methods, but on average the time and expenses are considerably less. However, this method relies on the experience of the diver to accurately determine species and numbers of fish.

Simonson's *et al* (1994) protocol appeared to evaluate habitat relatively rapid, and was easy to apply. This type of habitat survey can serve to monitor habitat quality and quantity and evaluate the streams' overall ecological integrity. In the Hearst District, this sampling protocol could be important with regards to the MNR's effectiveness monitoring programs. These monitoring programs are designed to assess forestry operations. The differences between expected results and actual results can then be used to adjust the planning process (OMNR n.d.). The Hankin and Reeves (1989) sampling design is more intensive, as it not only estimates habitat but fish abundance. This design appears to be more cost efficient than large-scale electrofishing but requires considerable more time and expertise than Simonson *et al.* (1994).

3.4.1c Other Methods to Determine Thermal Regime

The rationale behind this study was to be able to classify streams thermal regime to assist forest management guideline applications. Other methods of determining whether or not a stream is a cold waterbody might be used in the future. The presence of invertebrates as a biological indicator can establish the thermal regime. However, this would require expertise on identification, and require purchasing equipment and is very time consuming. Electrofishing, *e.g.*, by actually determining the species present in a stream, would help determine the streams thermal regime by identifying species associated with a particular regime, *i.e.* brook trout. The problem is that fish species that are absent in the survey at the site fail to indicate stream temperature and habitat suitability. Electrofishing can also be costly (McGovern 2000).

To meet the objective of determining the stream thermal regime necessary for implementation of guidelines, the sampling design of Hankin and Reeves (1989) would be ideal as it estimates habitat and fish abundance. This sampling design however is not feasible, and in the future it will not be necessary to determine thermal stability to implement the guidelines.

3.5 FUTURE DIRECTIONS AND CONCLUSION

Questions raised by Carignan and Steedman (2000) about the sustainability of healthy waters in forested landscapes revolve around the ideas that human activity may have threatened the ability of forested watersheds to produce clean water and support diverse productive aquatic biota, and new impacts may further exacerbate or counteract existing ones. With these types of questions surrounding human impact, the MNR has responded by undertaking an initiative to manage at the landscape scale.

The trend in the MNR is to move into a new paradigm of a more natural unit based management. Landscape-scale natural disturbance based management is at the forefront of new management schemes. With this, watershed management has an integral role in the new paradigm of thinking. However there is a distinct lack of ability to quantify impacts on aquatic habitat and biota at a watershed level (Carignan and Steedman 2000). According to Richards *et al.* (1996) the biotic composition of a stream is influenced by the physical habitat, which is operated on by a number of temporal and spatial scales, such as geology, climate, and land use. Richards *et al.* (1996) agrees that large-scale land use and catchments determine stream assemblages, but also suggests that fish distribution is related to land use at smaller scales. The idea to manage at watershed levels is not new, as Platts (1979) promotes the idea that site-specific stream data may be inadequate for management and that stream order analysis of the watersheds would prove to be better in trying to manage fish.

The OMNR has the very difficult task of trying to decipher at what appropriate scale to manage fish habitat and the myriad of ecosystem process and human impacts needed to produce sustainable resources for future generations. The proposed future Timber Management Guidelines for the Protection of Fish Habitat (OMNR 2001) move away from distinguishing between thermal regimes. The proposed guidelines (draft) suggest that all fish habitat regardless if the waterbody is cool, cold or warm deserves protection (OMNR 2001). This rationale stems from the Fisheries Act, in that the MNR is required to protect fish habitat. The Act does not specify differences for thermal regimes, only that fish habitat is to be protected. Keeping this in mind there will be no need to classify the streams to be in compliance with the Act. Also the proposed (draft) guidelines suggest that selective shoreline forestry is compatible with protection of fish habitat and as Ontario shifts towards emulating natural disturbance reserves or buffer strips will not be necessary for a management schemes (OMNR 2001).

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APPENDICES

APPENDIX A

FIELD METHODS

Equipment: GPS, compass, map, aerial photograph, axe, meter stick, Hobo, flagging tape, hip chain, hip waders, 50m tape, pencils, fishing line, electrical tape, plastic bags, string, floats, information forms, plastic container, silicon.

Procedures in the Office Prior to Field Operations

1. The Hobo was programmed to record temperatures once every hour, 24 hours a day. The Hobo connected to the computer using an interface cable, and the software BoxCar was used to program the Hobo.

2. The Hobo was encased in a small waterproof food container waterproofed with silicon.

3. The Area Biologist selected known and unknown stream segments to be assessed. However, due to access problems for some of the sites and the condition of the streams, some sites were changed.

4. Maps of the area were produced using ArcView to aid in the field, also air photos of the area were provided to assist in the field.

5. Several different crews worked on the installation of the Hobos therefore; training for the procedure occurred at different times throughout the project.

6. A Max/Min thermometer was set up initially to record air temperatures daily at the MNR Fire Center. Eventually a Hobo was set up to record temperature.

Field Procedures

1. After travel to a chosen stream the date, the time, the UTM location, the Hobo number, and the name of the stream (if known) were recorded on the information sheet and on the map.

2. A representative area of the stream with regards to shade, stream depth, and flow was selected for the installation site for the Hobo.

3. The plastic container containing the Hobo was attached to a branch along side the stream or a pole secured in the stream. When using a pole in some cases it was appropriate to peel off the bark to avoid animal

problems. The thermocouple was extended and secured in the mid depth of the stream using fishing line, rocks, electrical tape, or any other creative means (Figure 12). If the Hobo was secured on a pole within the stream, string was used to anchor the pole to the shore in the case that the pole became dislodged.

Figure 12. A typical data collection site.

4. While one person was installing the Hobo the other was using the 50m tape to measure the bankfull width and the floodplain. A meter stick was used to measure stream depth and hydraulic head. The hydraulic head is the height difference by measuring two water depths at the same

location in the stream. This was measured to the nearest 5mm, over a period of 3-5 seconds.

5. Facing upstream a profile of the stream was diagramed, this included notes on the surrounding vegetation and shade coverage etc.

6. The stream bottom was identified as a percentage of clay, silt, sand, gravel, cobbles, boulders, or organic.

7. The route to the Hobo was flagged, however the Hobo itself was not flagged to avoid animal attraction.

8. The Hobo was removed only after the air temperature reached over 24.5°C and the two previous days are consistent within ±3°C.

9. The Hobo was returned to the office and information was downloaded to the computer with Boxcar software. The Hobo was reprogrammed and sealed inside the container for reuse out in the field.

APPENDIX B

SAMPLE INFORMATION SHEET

Logger Information

Logger	**UTM Location**	**Projection**	**Input Date**	**Input Time**	**Removal Date**	**Removal Time**

Stream Information

Depth (cm)	**Width (m)**	**Headwater Velocity Difference (cm)**	**Floodplain (m)**	**Stream bottom**

Stream Profile

Stream Bottom

clay <0.002mm silt 0.05-0.002mm sand 0.05-2mm gravel <8cm cobble 8-25cm boulder >25cm bedrock muck

Notes

APPENDIX C

STREAM TEMPERATURE DATA - 1600HR

Date	DL3-1	DL4-1	DL5-1	DL6-1	DL7-1	DL8-1	DL9-1	DL10-1	DL11-1	DL12-1
7/17/00	19.42	19.04	17.9	17.14	17.9	18.66	20.95	20.19	25.95	18.28
7/18/00	17.9	18.28	17.14	17.52	16	18.28	18.66	20.57	20.19	18.28
7/19/00	16	16.38	15.62	15.62	14.47	16.38	17.52	19.42	20.57	15.62
7/20/00	16	16.38	15.62	15.62	14.85	16.38	16.76	19.81	19.42	16
7/21/00	15.62	15.62	14.85	14.47	13.7	15.23	16.38	17.9	19.81	14.85
7/22/00	16	16.38	15.62	15.62	14.47	16.76	16.76	19.42	17.9	16.38
7/23/00	17.9	18.28	17.14	17.9	15.62	17.9	33.59	21.71	19.42	17.9
7/24/00	18.66	19.04	17.52	17.9	16.38	17.9	16.76	22.09	21.71	18.28
7/25/00	19.04	19.42	17.9	18.28	17.52	18.28	16.76	21.71	22.09	19.04
7/26/00	20.19	20.19	18.66	20.19	17.52	18.66	16.76	22.48	21.71	19.04

Date	DL13-1	DL14-1	DL15-1	DL16-1	DL17-1	DL18-1	DL19-1	DL20-1	DL21-1	DL23-1
7/17/00	18.28	18.28	18.66	19.04				20.95		14.47
7/18/00	17.52	16.76	17.9	18.66	19.04	19.04		20.19		14.85
7/19/00	15.62	15.23	15.62	16.38	17.52	17.52	17.14	17.14		12.55
7/20/00	16	15.62	16	16.38	18.28	17.52	18.28	17.52		14.09
7/21/00	15.23	15.23	15.23	15.62	14.85	15.62	16	15.23		12.16
7/22/00	16	15.23	15.62	16	17.14	16	17.14	15.62		14.47
7/23/00	18.66	16	17.9	19.04	20.95	17.9	19.42	17.52		15.62
7/24/00	18.66	16.38	17.52	18.66	21.33	18.28	19.81	20.19		16.76
7/25/00	19.04	16.38	18.28	19.42	22.09	18.66	20.19	19.04	20.95	16.76
7/26/00	19.42	16.76	19.04	20.19	24.79	19.42	22.48	20.95	23.24	19.81

Date	DL24-1	DL26-1	DL27-1	DL28-1
7/17/00				
7/18/00	14.09	17.14	18.28	17.14
7/19/00	12.55	15.23	16.76	16.38
7/20/00	12.93	15.23	17.14	16.38
7/21/00	12.16	14.09	16	15.62
7/22/00	12.55	14.47	17.14	15.62
7/23/00	13.32	15.62	17.14	17.14
7/24/00	13.7	16.38	17.9	17.9
7/25/00	14.09	17.14	17.9	18.66
7/26/00	15.23	18.66	19.42	19.42

Date	DL 4-2	DL 6-2	DL 16-2	DL 8-2	DI 15-2	DL 26-2	DL 27-2	DL 17-2	DL 28-2	DL 21-2
07/31/00	19.04	20.57								
08/01/00	19.04	20.57		19.81						
08/02/00	13.32	13.7	15.23	15.23						
08/03/00	13.32	14.85	17.14	14.85	16					
08/04/00	14.09	17.14	19.04	16.76	19.04					
08/05/00	13.7	16.38	17.14	16	16.76					
08/06/00	13.32	14.85	15.62	15.23	12.93					
08/07/00	12.93	14.09	16	14.85	14.09					
08/08/00	12.93	14.09	15.62	14.09	15.23					
08/09/00	14.09	15.62	17.14	15.23	17.9			14.47	19.04	
08/10/00	14.09	16	17.9	15.23	17.9			14.09	17.52	
08/11/00	14.85	17.14	19.81	15.62	20.19		15.23	13.7	17.52	
08/12/00	14.47	16.38	17.14	14.85	16.38		14.85	13.7	17.9	
08/13/00	14.85	16	17.52	15.62	15.62		16	14.09	18.28	
08/14/00	14.47	15.62	19.04	16.38	18.28		14.47	13.32	17.9	12.16
08/15/00	16.38	17.9	20.19	17.14	18.28			14.09	20.19	14.09
08/16/00	15.23	17.14	18.28	17.14	17.52			13.32	20.19	12.16
08/17/00	12.55	14.47	15.62	13.7	11.77			12.16	15.62	9.82
08/18/00	12.55	14.09	15.62	14.09	12.93			12.16	16.76	11.38
08/19/00	12.16	14.09	16.38	14.09	14.09			10.99	14.47	9.82
08/20/00	11.77	14.47	18.28	14.47	15.62			10.6	14.09	8.23
08/21/00	12.16	14.47	16.76	13.32	12.93	15.23		10.99	16	10.21
08/22/00	13.7	15.62	20.19	16	17.14	15.62		12.16	19.42	11.38
08/23/00	14.47	17.52	21.33	16.38	16.38	16.76		12.55	20.95	12.16
08/24/00	14.85	18.28	23.24	17.14	17.9	17.14		12.93	20.95	11.77
08/25/00		17.9	24.01	17.9	17.9	18.28		13.7	22.86	12.93
08/26/00		17.52	19.04	16.38	17.9	19.04		13.32	23.24	13.32
08/27/00		16.76	16.76	14.85	17.14	17.52		12.16	21.33	

Date	DL 28-2	DL 21-2	DL 23-2	DL 24-2	DL 29-2	DL 9-2	DL 2-2	DL 19-2	DL 20-2
07/31/00					23.24				
08/01/00					24.4				
08/02/00					18.28				
08/03/00					16.76	18.66			
08/04/00					17.14	20.19			
08/05/00					17.52	19.81			
08/06/00					18.28	18.66			
08/07/00					17.9	17.52			
08/08/00					17.14	17.14			
08/09/00	19.04				18.66	18.28		19.04	18.66
08/10/00	17.52				18.28	18.28		19.42	19.04
08/11/00	17.52				17.9	19.04		20.95	19.81
08/12/00	17.9				19.81	19.04		20.19	19.81
08/13/00	18.28				19.42	19.42		19.04	19.42
08/14/00	17.9	12.16	14.09		18.28	19.04		20.95	19.42
08/15/00	20.19	14.09	16		20.19	20.57		20.57	20.19
08/16/00	20.19	12.16	14.09		18.28	19.04		19.04	19.04
08/17/00	15.62	9.82	11.38		16.38	17.52		17.14	17.14

08/18/00	16.76	11.38	12.16		16.76	17.14		16.76
08/19/00	14.47	9.82	10.99		14.47	16.76		
08/20/00	14.09	8.23	10.21		14.09	17.52		
08/21/00	16	10.21	11.77	16.38	15.62	17.52	15.23	
08/22/00	19.42	11.38	13.32	17.14	16.38	18.28	16.38	
08/23/00	20.95	12.16	14.47	18.66	17.9	19.42	17.52	
08/24/00	20.95	11.77	14.47	19.04	17.9	20.19	16.76	
08/25/00	22.86	12.93	15.62	19.81	18.66	20.95	17.9	
08/26/00	23.24	13.32	15.23	21.33	19.04	19.81		
08/27/00	21.33		12.93	19.81	17.14	18.66		

APPENDIX D

COLD AND COOL STREAM INFORMATION

Coldwater Data	3,2	4,2	5,2	6,2	13,2	16,2	3,1	4,1	5,1	6,1	7,1
Stream Bottom (%)											
sand	50			38		50				50	2
gravel	50				25		100	99	100		2
muck		100	100	4						50	
cobbles				58	75						2
silt						50					
bedrock								1			92
bolder											
width (m)	6	4	16	12	7.3	2.6	9.6	10.7	15.6	9.8	7.8
depth (cm)	25.5	110	120	95	40	20	69.5	64.2	86	36.5	76
headwater (cm)	1.1	0.1	0.1	0.1	0.1	0.2	1	1.3	0.5	1	1.2
floodplain (m)	32	60	75	55	11.3	10	25.6	20.7	31.6	21.8	9.8

Coldwater Data	8,1	9,1	10,1	12,1	13,1	14,1	15,1	16,1
Stream Bottom (%)								
sand	70			100	100		40	70
gravel			100				59	30
muck		100				100		
cobbles							1	
silt								
bedrock								
bolder	30							
width (m)	7	9.1	7.5	8.5	6.7	3.5	6.4	7.9
depth (cm)	88	108	42	94	38	114	43	32.5
headwater (cm)	0.4	0.2	2.5	1	1.5	0.1	4	0.3
floodplain (m)	19.9	12.8	30	17.5	28.7	67	72.9	96.6

Coolwater Data	2,2	19,2	20,2	23,2	24,2	29,1	18,1	19,1	27,1
Stream Bottom (%)									
sand			20					50	
gravel	80			1				50	
muck		100			100		100		
cobbles	20			1					
silt						100			100
bedrock									
bolder			80						
clay				98					
width (m)	5.3	7.2	7.8	1.3	25.7	5	2.5	1.8	7.6
depth (cm)	87	85	48	12	too deep	81	115	37.4	89
headwater (cm)	0.1	0.4	1.8	0.1	0.75	0.5	0.2	0.4	0.5
floodplain (m)	50	61	24	2.45	50	75	75	48	18