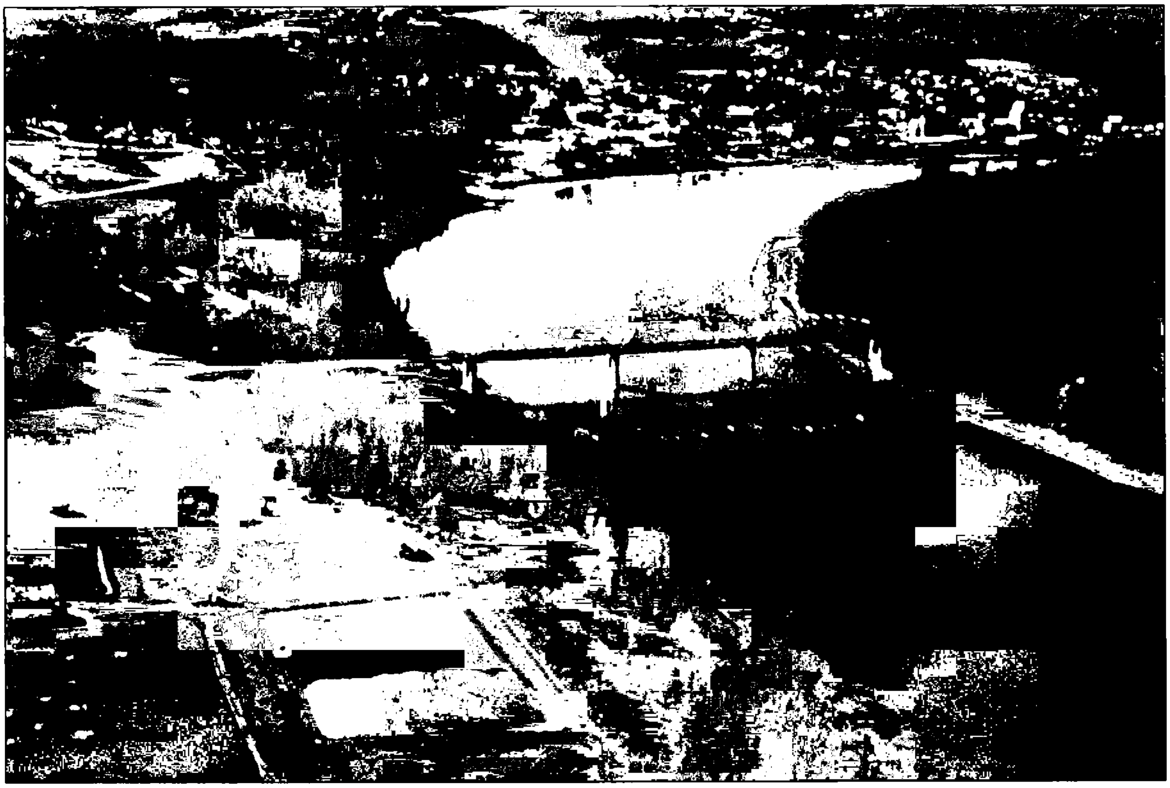
Assessment of Drinking Water Quality in the Northern River Basins Study Area – Synthesis Report

9

Synthes
Report



Canada Alberta Northwest Territories

Northern River Basins Study

NORTHERN RIVER BASINS STUDY
SYNTHESIS REPORT NO. 9

ASSESSMENT OF DRINKING WATER QUALITY IN THE NORTHERN RIVER BASIN STUDY AREA SYNTHESIS REPORT

by

Tanya F. Armstrong, Dennis S. Prince,
Stephen J. Stanley, and Daniel W. Smith

Environmental Engineering and Science Program
Department of Civil Engineering
University of Alberta

Published by the
Northern River Basins Study
Edmonton, Alberta
May, 1996

CANADIAN CATALOGUING IN PUBLICATION DATA

Main entry under title:

Assessment of drinking water quality in the
Northern River Basins Study area – synthesis report

(Northern River Basins Study synthesis report,
ISSN 1205-1616; no 9)
Includes bibliographical references.
ISBN 0-662-24699-3
Cat. no R71-49/4-4E

1. Drinking water – Alberta – Athabasca River Watershed
2. Drinking water – Peace River Watershed (B.C. and Alta.)
3. Drinking water – Slave River Watershed (Alta. and N.W.T.)
4. Water quality – Alberta – Athabasca River Watershed.
5. Water quality – Peace River Watershed (B.C. and Alta.)
6. Water quality – Slave River (Alta. and N.W.T.)

I. Armstrong, Tanya A.
II. Northern River Basins Study (Canada)
III. Series

TD226.A77 1996 363.6'1'0971231 C96-980246–3

If you would like:
- additional copies of this report, or
- other information regarding the Northern River Basins Study

please contact:

Alberta Environmental Protection
Information Centre
9920 - 108 Street
Edmonton, Alberta
T5K 2M4

Telephone (403) 422-2079
Fax (403) 427-4407

TABLE OF CONTENTS

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AEP	Alberta Environmental Protection
AlPac	Alberta Pacific Forest Industries Inc. pulp mill
AWWA	American Water Works Association
AO	Aesthetic objective
BOD	Biochemical oxygen demand
cfu	Colony forming units
CI	Confidence interval
CLSA	Closed loop stripping analysis
COD	Chemical oxygen demand
CT	Concentration Σ Time
CTMP	Chemi-thermomechanical pulp mill
FC	Fecal coliform
FPA	Flavour Profile Analysis
GC	Gas chromatography
GC/MS	Gas chromatography with mass selective detector
GCDWQ	Guidelines for Canadian Drinking Water Quality
HPC	Heterotrophic plate count
IMAC	Interim maximum acceptable concentration
IBMP	2-isobutyl-3-methoxy pyrazine
IPMP	2-isopropyl-3-methoxy pyrazine
MAC	Maximum acceptable concentration
MCL	Maximum contaminant level
MCLG	Maximum contaminant level goals
MIB	2-methylisoborneol
NPDWR	National primary drinking water regulations
NRBS	Northern River Basins Study
NTU	Nephelometric turbidity unit
OGC	Olfactory gas chromatography
PAH	Polycyclic aromatic hydrocarbons
PFRA	Prairie Farm Rehabilitation Administration
POU	Point-of-use
SDWA	Safe Drinking Water Act
TC	Total coliform
TCA	Trichloroanisole
TCU	True colour units
TCV	Trichloroveratrole
TDS	Total dissolved solids
THM	Trihalomethane
TOC	Total organic carbon
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organization
WPCF	Water Pollution Control Federation

1.0 INTRODUCTION

1.1 BACKGROUND AND SCOPE

"The Northern River Basins Study (NRBS) was a study that was aimed at examining the relationship between development and the Peace, Athabasca and Slave River Basins. The boundaries of the Northern River Basins Study enclose all areas that drain into these three rivers. This includes a large proportion of Northern Alberta, and parts of British Columbia, Saskatchewan, and the Northwest Territories. The basins and boundaries of the NRBS area are depicted in Figure 1.

The purpose of the study was to understand and characterize the cumulative effects of development on the water and aquatic environment of the study area. This was accomplished by coordinating with existing programs and by undertaking appropriate new technical studies. It was for this purpose that the study was divided into eight scientific components that were set up to answer a series of guiding questions that were central to the Northern River Basins Study. These components were: (1) Traditional Knowledge; (2) Other Uses; (3) Drinking Water; (4) Food Chain; (5) Hydrology/Hydraulics/Sediment; (6) Contaminants; (7) Nutrients; and (8) Synthesis and Modeling. Research for each group was directed by a series of guiding questions which were developed by the Study Board. The question directing the drinking water component was Study Board Question #8 which stated:

> "Recognizing that people drink water and eat fish from these river systems, what is the current concentration of contaminants in water and edible fish tissue and how are these levels changing through time and by location".

Based on this question the drinking water component was commissioned to assess the drinking water quality in the region, thereby identifying problems to be solved and providing recommendations for improving the drinking water quality if necessary. To do this, a number of linked studies were devised to assess the quality of drinking water in the NRBS area.

1.2 APPROACH

One of the first steps in the assessment of drinking water quality in the Northern River Basins Study area was to obtain as much existing information as possible. This information was then compiled, synthesized and summarized in order to provide direction and background for further studies of drinking water in the Northern River Basins. Figure 2 illustrates the approach taken by the Drinking Water Component in the assessment of drinking water quality in the Northern River Basins Study area. As shown in the figure, there were four main areas of research: (1) public health; (2) aesthetics; (3) drinking water supplies; and (4) drinking water treatment. Each of these four main areas are related to each other and are the major factors that must be considered in an assessment of drinking water quality. The approach taken in the assessment of each of these areas is discussed below.

Figure 1. Northern River Basins Study Boundaries

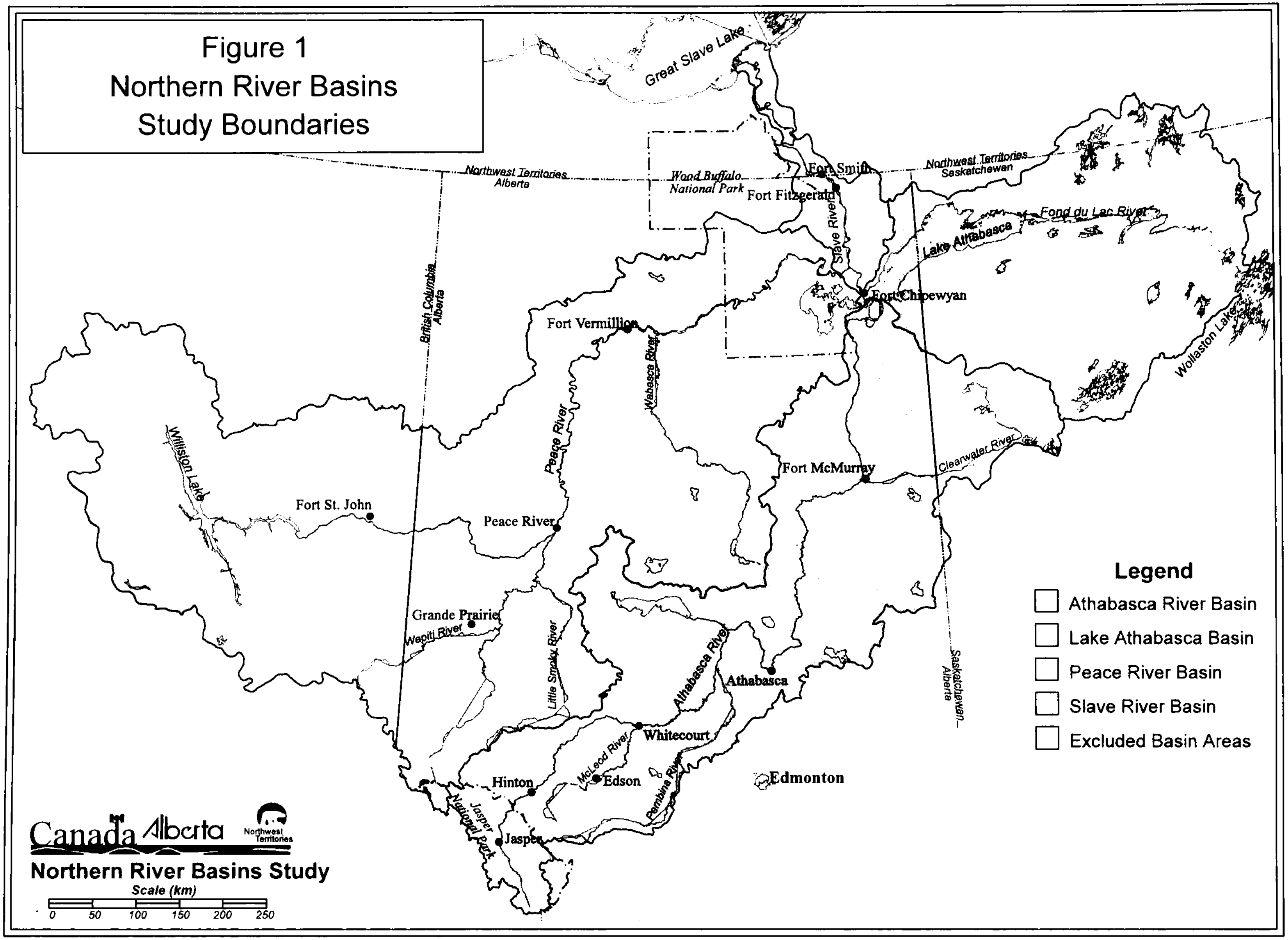
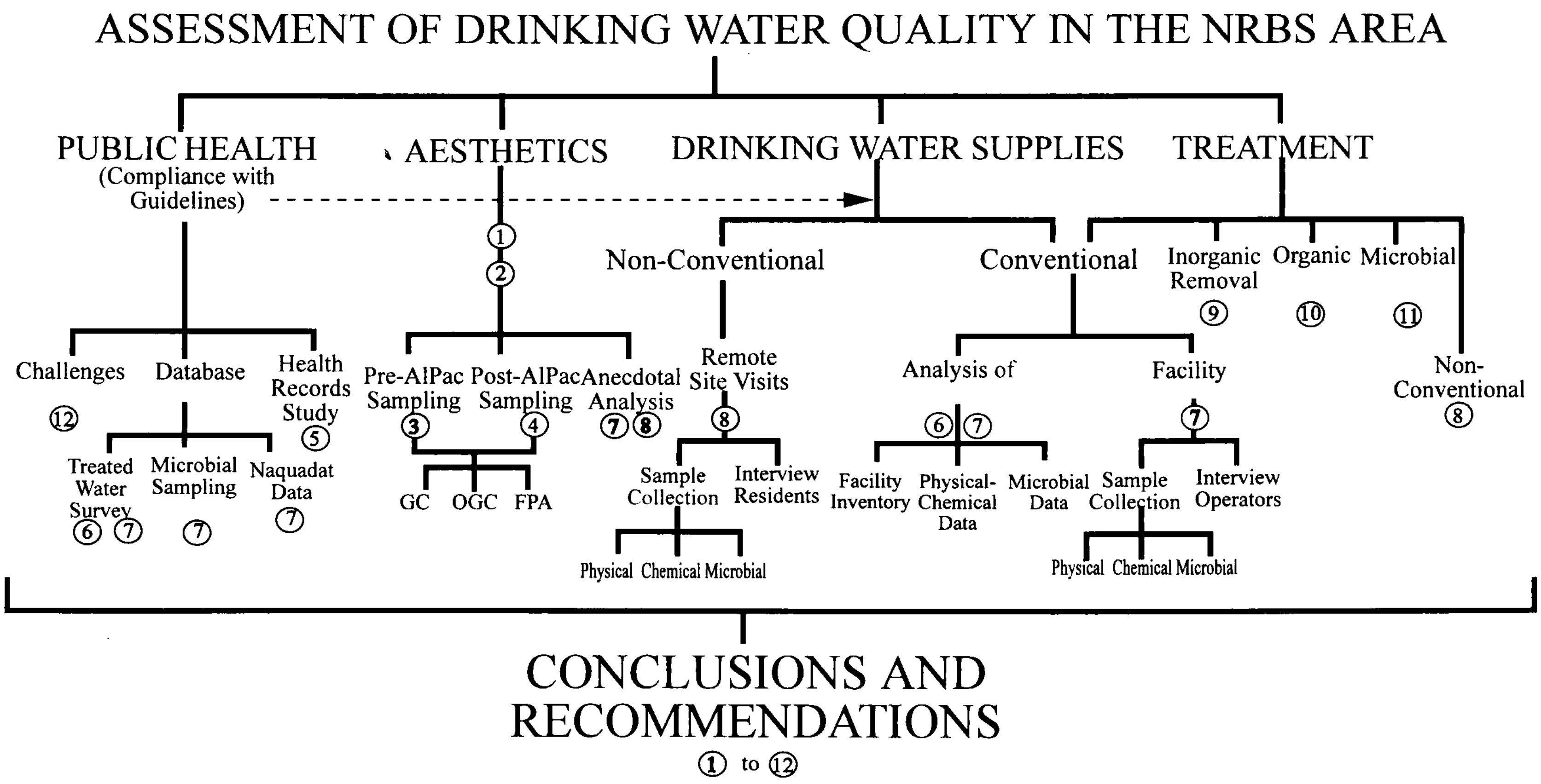


Figure 2. Approach Taken in Assessing Drinking Water Quality in the NRBS Area



Notes:

1. Circled numbers (i.e. ①, ② ... ⑫) correspond to the report identified with the same number in Table 1 on page 6.
2. Abbreviations: GC = Quantitative Gas Chromatography
   OGC = Olfactory Gas Chromatography
   FPA = Flavour Profile Analysis

1.2.1 Public Health

First, particular emphasis was placed on the examination of existing drinking water quality records from the NRBS area to determine compliance with the guidelines and to assess the potential public health consequences associated with not meeting guideline values. This was accomplished by downloading Alberta Environmental Protection (AEP) drinking water databases from the AEP mainframe to personal computer database format. Various software packages were then used to analyze the relevant data which was subsequently used to generate summary statistics and create charts and tables of the findings. The drinking water quality databases investigated included the: (1) Treated Water Survey; (2) Microbial Sampling Data; and (3) Naquadat Raw and Treated Water Data. The means and standard deviations were found for selected parameters in the databases and were compared to the limits established in the Guidelines for Canadian Drinking Water Quality (GCDWQ). Although the GCDWQ is a federal document, the jurisdiction of drinking water quality is with the provinces. Alberta is the only province in Canada that has adopted the GCDWQ as the regulatory standards. Based on these comparisons of the database values and the levels in the GCDWQ, an assessment of the drinking water quality in the NRBS area was made and potential public health concerns were raised. A discussion of the drinking water quality guidelines established for the protection of public health is included in Section 2.1. The results of the analysis of the NRBS drinking water quality data based on these guidelines are presented in Section 6.0.

There was also another method used in the assessment of the effect of drinking water quality on public health in the study area. Health records from the study area were examined and the incidences of selected waterborne diseases were compared with provincial averages. If the incidences in the study area were found to be significantly higher than the province as a whole, one source of this difference may be that the potable water quality was poorer in the study area than in the rest of the province. A discussion of this assessment of public health in the study area is presented in Section 2.2.

Finally, a summary of the challenges to water quality in the study area was compiled. These challenges are related to public health because high levels of contaminants from whatever source has an impact on finished water quality. Higher contaminant levels arising from a variety of natural and man-made influences may result in the requirement for additional treatment in order to ensure that the GCDWQ limits are met and public health is maintained. 00.Some of the natural and anthropogenic challenges to raw, treated and distributed water quality in the northern river basins are presented in Section 4.0.

1.2.2 Aesthetics

Second, the aesthetic quality of water in the NRBS area was investigated by the Drinking Water Component. This was necessary as the aesthetic quality of drinking water is an important aspect that significantly affects potable water consumption. The aesthetic quality of the water in the NRBS area was assessed both quantitatively and qualitatively. On the quantitative level, gas chromatography was performed on samples taken from or near the Athabasca River. Qualitatively, these same samples were also analyzed by members of a Flavour Panel and olfactory gas chromatography was also performed. Samples were taken in this study both before and after the Alberta Pacific pulp and paper mill came on stream. Other researchers also obtained qualitative taste and odour information through interviews with facility operators and residents of the study area. The results from the assessment of the aesthetic quality of drinking water in the NRBS area is presented in Section 5.0.

1.2.3 Drinking Water Supplies

The assessment of specific drinking water supplies in the NRBS area was the third main area of research conducted by the Drinking Water Component. Both conventional and non-conventional supplies of drinking water were assessed. Definitions pertaining to conventional and non-conventional drinking water supplies as well as the extent of utilization in the Northern River Basins is discussed in Section 3.0.

The dashed arrow in Figure 2 indicates that both conventional and non-conventional drinking water supplies in the study area were assessed in terms of compliance with applicable health related guidelines. For the evaluation of the quality of conventional drinking water supplies in the study area, several approaches were used. First, existing information was analyzed, including information from the databases described earlier, as well as information on the types of drinking water treatment facilities in the study area. The levels of physical, chemical and microbial parameters found in the databases were compared to GCDWQ limits. Conventional facilities were assessed individually as well as based on the size of the population served. That is, the performance of small facilities (such as towns, hamlets, watering points) was differentiated from the performance of larger facilities (such as cities). The second approach in the assessment of conventional drinking water supplies was based on information obtained from facility site visits. 38 of the 180 conventional drinking water facilities in the study area were visited and samples were taken of the raw, treated and distributed water. Each of these were assessed for selected physical, chemical and microbial parameters which were then compared to the GCDWQ. The treatment plant operators were interviewed during each site visit. A third assessment of conventional drinking water supplies involved further site visits in which a continuous monitoring turbidimeter was installed onto a treated water stream. The results from this continuous monitoring provided information on the treated water quality of the plant on a continuous basis. The results from the assessment of conventional drinking water supplies in the NRBS area are presented in Section 6.0.

As will be discussed in Section 3.0 not everyone in the study area receives drinking water from a conventional drinking water treatment facility. Therefore, work was carried out to assess the quality of some of the non-conventional sources of drinking water consumed in the Northern River Basins. Some non-conventional supplies were assessed based on available literature while other sources of non-conventional drinking water were sampled directly during field trips and assessed for various physical, chemical and microbial parameters. During this work, several NRBS area residents were interviewed regarding their non-conventional drinking water practices. The results from the assessment of non-conventional drinking water supplies in the study area are presented in Section 6.0.

1.2.4 Drinking Water Treatment

Finally, the fourth area of research by the Drinking Water Component was in regards to drinking water treatment. Since conventional drinking water implies some form of treatment, the assessment of conventional drinking water quality and the assessment of drinking water treatment are closely related. This close link is illustrated by the connection between the conventional drinking water supply and treatment methods in Figure 2. Therefore, much of the work carried out in the assessment of conventional drinking water supplies was, in fact, also an assessment of drinking water treatment in the Northern River Basins Study area. In addition to this evaluation of drinking water treatment, other studies were also carried out. In-depth literature reviews were completed which specifically investigated contaminant removal efficiencies of various treatment options. The contaminants assessed in this manner included microbial contaminants, inorganic chemicals and organic chemicals. Finally, a secondary study of non-conventional drinking water involved an assessment of portable drinking water treatment filters. The results of this analysis and other analyses of drinking water treatment in the Northern River Basins is discussed in Section 7.0.

1.3 PRODUCTS

All of the reports completed by the Drinking Water Component are listed in Table 1. The numbers assigned to each document in this table correspond to the circled numbers in Figure 2. For the most part, each of the reports listed present information on all four of the main areas of study. However, it is the focus of each of the reports that is identified in Figure 2. The report summary from each of these documents is included in Appendix A

Table 1. Reports Completed by the NRBS Drinking Water Component.

No.	Authors	Date	Title
1	Kenefick, S.L., and S.E. Hrudey	1994	Study of Water and Fish Tainting in Northern Alberta River Basins - A Review.
2	Kenefick, S.L., N.J. Low, and S.E. Hrudey	1994	Annotated Bibliography on Water and Fish Tainting in Northern Alberta River Basins.
3	Kenefick, S.L., B.G. Brownlee, E. Hrudey, L. Gammie, and S.E. Hrudey	1994	Water Odour Athabasca River February and March, 1993
4	Kenefick, S.L., B.G. Brownlee, E. Hrudey, G. MacInnis, and S.E. Hrudey	1994	Water Taste and Odour Study, Athabasca River 1994 (Post Al-Pac)
5	Emde, K.M.E., D.W. Smith, and S.J. Stanley	1994	Health Records Study for the Northern River Basins Project.
6	Prince, D.S., D.W. Smith, and S.J. Stanley	1994	Review and Synthesis of Existing Information on Consumptive Use of Drinking Water and Available Drinking Water Quality Data for the Northern River Basin Study.
7	Prince, D.S., D.W. Smith, and S.J. Stanley	1995	Data Report for the Independent Assessment of Drinking Water Quality in the Northern River Basins
8	Armstrong, T.F., S.J. Stanley, and D.W. Smith	1995	Assessment of Non-Conventional Drinking Water in the Northern River Basins Study Area.
9	Liem, E., D.W. Smith, and S.J. Stanley	1995	Inorganic Contaminants Removal
10	Oke, N.J., D.W. Smith, and S.J. Stanley	1995	Literature Review on the Removal of Organic Chemicals from Drinking Water
11	Zhou H., D.W. Smith and S.J. Stanley	1995	Removal of Microbial Contaminants from Water Treatment Processes for the Northern River Basins Communities.
12	Armstrong, T.F., D.S. Prince, S.J. Stanley, and D.W. Smith	1995	Synthesis Report on the Assessment of Drinking Water Quality in the Northern River Basins Study Area.
13	Aitken, B. and Golder Assoc. Ltd.	1995	Users Manual for NRBS-Spill Model

2.0 DRINKING WATER AND PUBLIC HEALTH

Water is a basic human need and it is essential to sustain life. The World Health Organization (WHO) has defined health as a fundamental human right for a state of complete physical, mental, social and spiritual well-being (WHO, 1978). he links between water and health are numerous and the interactions are complex (WHO, 1993). It has been stated that an adequate supply of safe drinking water is a prime requisite in the maintenance of good health (WHO, 1978; Health and Welfare Canada, 1973).

A person's health can be compromised by drinking water if the quality of the water is poor or if the quantity of water for consumption is inadequate. It is known that enteric diseases are generally related to poor water quality whereas diseases of the skin are related to limited water quantity and availability (Brocklehurst *et al.*, 1985). The average daily consumption of drinking water for a Canadian adult is about 1.5 L a day (Environmental Health Directorate, 1991). This consumption rate varies widely among individuals depending on attributes such as body weight, ambient temperature, diet, activity, culture, clothing and health status (McJunkin, 1982). If an average person is assumed to live for 75 years, that means that a person would consume approximately 43 000 L of water in his or her lifetime (Armstrong *et al.*, 1995). From this, it can be seen that water can be an important vehicle for contaminants to enter our body. Therefore, not only is water physiologically necessary for survival, but the physical, chemical and microbiological constituents of the water that are consumed can significantly impact a person's health.

The role of water in the chain of disease transmission has provided a basis for classifying water related diseases into one of four categories:

1. *Waterborne diseases* are transmitted by the ingestion of contaminated water whereby the infectious agent (chemical or microbial) is passively carried in the water supply.
2. *Water-washed diseases* are related to poor sanitation and hygienic practices that are often associated with an insufficient quantity of water. This unavailability of water contributes to eye and skin diseases as well as the transmission of diarrheal diseases.
3. *Water-based diseases* are those in which the pathogen is dependent on the water supply or upon aquatic organisms for part of its life cycle.
4. *Water-vectored diseases* are transmitted by disease causing insects that breed in water (Cairncross and Feachem, 1993).

In the assessment of drinking water quality in the Northern River Basins, the Drinking Water Component focused on waterborne disease constituents because waterborne diseases are illnesses in which a pathogen (a disease causing agent or microorganism) enters the body as a passive component of *drinking water.* "Waterborne diseases can be further categorized as those due to microbiological organisms and those due to inanimate toxic substances suspended or dissolved in the water (McJunkin, 1982)." Microbiological waterborne diseases are generally acute and episodic, whereas illnesses caused by chemical agents may be acute, but normally result from long term ingestion at low concentrations.

2.1 DRINKING WATER QUALITY GUIDELINES

As a result of the potential health consequences associated with the consumption of a poor quality drinking water, drinking water quality guidelines have been established. Normally, drinking water is assessed for various physical, chemical, microbiological, and radiological parameters. The levels of these parameters are then compared to the drinking water quality guidelines that have been established for the protection of public health. It is assumed that if the water supply in question meets all of the recommended levels set in these guidelines, that the quality is good, and that the water is safe to drink.

Considerable effort has been expended to determine water quality characteristics that are suitable for human consumption (Prince *et al.*, 1995a). Drinking water quality standards are based on the best available and most current research and information (Alberta Environmental Protection, 1988) that evaluates the human health risk that results from exposure to a particular contaminant in drinking water over a lifetime (WHO, 1993). Essentially, guidelines are set for an acceptable level of risk, with the general population in mind. The determination of an acceptable health risk is based on a judgment that weighs the costs to society of having a certain level of the contaminant in the water supply, with the benefit to public health for the removal of that contaminant to a given level. In general, conservative models and large safety factors have been incorporated to develop drinking water quality standards so that a high level of public health protection is ensured (Alberta Environmental Protection, 1988).

Both national and international drinking water quality guidelines are influential in safeguarding public health in Canada. In Canada, the federal document Guidelines for Canadian Drinking Water Quality (GCDWQ) is used as the basis for evaluating drinking water safety. Since the regulation of drinking water in Canada is under provincial jurisdiction, on the federal level, these guidelines only serve as recommendations for each province. However, in Alberta, the GCDWQ have been adopted by Alberta Environmental Protection (AEP) as regulatory standards; the only province to do so.

On the international level, the World Health Organization has established Guidelines for Drinking Water Quality which "are intended to be used as a basis for the development of national standards that if properly implemented, will ensure the safety of drinking water supplies through the elimination, or reduction to a minimum concentration, of constituents of water that are known to be hazardous to health (WHO, 1993)." In the United States, the *Safe Drinking Water Act* (SDWA) places the responsibility of drinking water regulation with the United States Environmental Protection Agency (USEPA). The SDWA requires that the USEPA publishes non-enforceable maximum contaminant level goals (MCLG) for known or suspected contaminants that may have an adverse effect on health (USEPA, 1994). Along with MCLG's, National Primary Drinking Water Regulation's (NPDWR) must also be published for each potential health related contaminant. The NPDWR's specify a maximum contaminant level (MCL) and/or a treatment option for the particular contaminant that must be met by drinking water treatment facilities (USEPA, 1994). These NPDWR's are regulated at the federal level, so that all drinking water facilities in the United States must meet the established MCL's or have the required treatment technique in place. The USEPA standards are occasionally more strict than both the Canadian and World Health Organization guidelines. Since the NRBS Study area is within Canada and Alberta, an exhaustive discussion of the elements in the WHO and USEPA guidelines is beyond the scope of this report. However, further detail about the Canadian guidelines is necessary.

As mentioned, in Canada, the regulation of community drinking water supplies is under provincial jurisdiction. In Alberta, the applicable document stipulating regulations for drinking water supplies is Standards and Guidelines for Municipal Water Supply, Wastewater, and Storm Drainage Facilities (AEP, 1988). Section 4.4 of these *Standards and Guidelines* outline the minimum requirements that must be fulfilled by drinking water supply facilities in Alberta:

> "The availability and quality of drinking water can have a significant impact on both the public health and the overall quality of life within a community. A major objective of Alberta Environment is to ensure that drinking water supplies and treatment systems provide a high level of public health protection while being able to meet the water supply needs of the community. In developing a drinking water supply system the following three requirements must be satisfied:
>
> 1. The water delivered to consumers shall meet the health related quality standards as outlined in the Health and Welfare Canada Guidelines for Canadian Drinking Water Quality. For those standards based on aesthetic considerations, less stringent requirements may be adopted by Alberta Environment;
> 2. The water treatment system shall provide a basic level of protection against all possible sources and types of raw and treated water contamination; and,
> 3. Sufficient water must be available to meet the needs of the consumers, which may include fire protection (AEP, 1988)."

The Guidelines for Canadian Drinking Water Quality have established limits on the levels of various physical, chemical, microbial, and radiological parameters (Federal-Provincial Subcommittee on Drinking Water, 1993). Within these guidelines, a parameter is assigned a guideline value if the assessment of data on the contaminant of concern indicates a need to set a numerical guideline on the constituent. The parameter is then assigned a Maximum Acceptable Concentration (MAC), an Interim Maximum Acceptable Concentration (IMAC) and/or an Aesthetic Objective (AO). "Maximum Acceptable Concentrations have been established for certain substances that are known or suspected to cause adverse effects on health (Federal-Provincial Subcommittee on Drinking Water, 1993)." MAC's are derived to protect health based on the assumption of lifelong consumption of the substance at the established guideline concentration. Interim Maximum Acceptable Concentrations (IMAC) are set for substances that are assumed to have an adverse effect on health but for which there is insufficient toxicological data to set a MAC with reasonable certainty. Larger safety factors have been employed to compensate for the uncertainties for these substances. Aesthetic Objectives are applied to parameters that affect the acceptability of the water by consumers and so that a good quality of water can still be supplied. If the concentration is well above an aesthetic objective, there is a possibility of a health hazard. Appendix B contains a concise summary of the physical, chemical, microbiological and radiological parameters regulated in the 1993 Guidelines for Canadian Drinking Water Quality. Further discussion on some of the parameters regulated in the GCDWQ appear in the relevant sections that follow.

2.1.1 **Physical Parameters**

Physical parameters are the general properties of a composite water sample. That is, all of the elements in water contribute to the physical characteristics of the water sample. Some of the more common physical parameters that affect the aesthetic quality of drinking water are temperature, pH, total dissolved solids, taste, odour and colour. Taste and odour in drinking water may originate from biological processes, chemical contaminants, and as a by-product of treatment (WHO, 1993). Water temperature influences the perception of taste and odour. Generally, cooler water is preferred by consumers (WHO, 1993). The colour in water can be from many sources. Naturally occurring humic and fulvic acids are coloured organic matter that add colour to the water. The presence of iron and other metals also influences the colour of the water. And of course, industrial effluents sometimes contribute to the colour in a water supply (WHO, 1993). Total dissolved solids (TDS) are a measure of the concentration of dissolved inorganic chemicals in the water. The pH of a water sample is another physical parameter that is measured and provides insight into some of the internal processes that may be going on in the water. The pH is a measure of the hydrogen ion concentration in the water and is measured on a scale from 0 (acidic) to 14 (alkaline). All of these parameters have been assigned AO values in the GCDWQ.

Turbidity is one physical parameter of particular importance in the assessment of drinking water quality that has been assigned a MAC. Turbidity is a direct indicator of clarity and is caused by suspended particulates in the water such as clay, silt, finely divided organic and inorganic matter, and microorganisms (Letterman, 1994a). "Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample (American Public Health Association et al., 1992)." The reason that turbidity has been assigned a MAC is because "the presence of turbidity can significantly affect both the microbiological quality of the drinking water and the ability to detect bacteria, viruses and protozoa. Waterborne bacteria, viruses and protozoa can be embedded in, or adhered to, particles in the raw water, or they can become trapped within floc formed during water treatment. Thus, turbid finished water can contain undesirable microorganisms that may not be detectable or that may be grossly underestimated by current detection methods (Federal-Provincial Subcommittee on Drinking Water, 1993)." Furthermore, the disinfection process can be hindered by turbidity-causing material in the water because enmeshed microorganisms are protected from chemical disinfectants and are even provided with a nutrient source by the presence of these particles (WHO, 1993; Letterman, 1994b). The MAC for turbidity is 1 NTU 95 % of the time, although a turbidity of 5 NTU is acceptable if it can be shown that disinfection has not been compromised (Federal-Provincial Subcommittee on Drinking Water, 1993). On the international level, "no health-based guideline value for turbidity has been proposed" by the WHO (1993), but the USEPA regulation for turbidity in the NPDWR Surface Water Treatment Rule is 0.5 NTU. Based on this, Canadian guideline value may be reduced in the future.

2.1.2 Microbiological parameters

The microbiological quality of drinking water is of particular importance to public health. As stated by the World Health Organization, "infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and widespread health risk associated with drinking water (WHO, 1993)." The table in Appendix C lists some of the pathogenic microorganisms that may be found in Northern River Basins Study area water- bodies. The table includes information on the pathogenicity, infective dose, and range of symptoms for various bacterial, viral, fungal, and protozoan organisms. It should be noted that this table is not exhaustive. The etiological agent for many suspected waterborne illnesses are still reported as

"Unknown Etiological Agent" (Emde *et al.*, 1994). This could be because the cause was not investigated, or because the agent was not detected, isolated or identified.

Nonetheless, by inspection of the list in Appendix C, it is evident that the numbers and types of microorganisms that may be found in a water supply is extensive. Although techniques are available to identify and enumerate most of the common types of pathogens found in water, due to the large numbers and types that can be found, this is not always practicable when monitoring drinking water supplies (McJunkin, 1982). Therefore, when assessing the microbiological quality of potable water, indicator organisms are used as indirect measure of pathogens in the water.

At least three simple requirements should be satisfied in order for an agent to be considered an indicator organism. First, indicator organisms should be present in sewage and polluted water where pathogens are present. Second, the population of indicator organisms should be correlated with the degree of pollution. Third, indicator organisms must be easily and quickly identified and enumerated in simple lab procedures (McJunkin, 1982). If these criteria are met, then the organism is a good indicator of the presence of microbial pathogens in a water supply. The coliform group of microorganisms are common indicator organisms used in the assessment of the microbiological quality of potable water.

Total Coliform (TC) organisms are gram-negative, rod shaped bacteria that ferment lactose at 35°C to 37°C with the production of acid, gas and aldehyde within 24 to 48 hours and are capable of growth in the presence of bile salts or other agents with similar growth inhibiting properties (McJunkin, 1982). Coliform bacteria are members of the *Enterobacteriaceae* that are usually found in the intestinal tract of warm-blooded animals. Although this group is limited in its ability to indicate fecal pollution, (because there are non-fecal bacteria that fit the coliform definition as well) monitoring for Total Coliforms is still important to assess the microbial quality of the water (WHO, 1993).

Thermotolerant Fecal Coliforms (FC) are a subset of the Total Coliform organisms that can ferment lactose at 44 to 45°C including the *Escherichia* genus and to a lesser extent species of *Klebsiella*, *Enterobacter*, and *Citrobacter*. It has been found that thermotolerant coliforms other than *E.coli* may also originate from industrial effluents, decaying plant matter and soil. Therefore, the common description of this group of bacteria as "Fecal Coliforms" is not an accurate one and instead they should be called Thermotolerant Coliforms (WHO, 1993).

The Guidelines for Canadian Drinking Water Quality state that the general bacterial population and coliform bacteria should be monitored routinely. The maximum acceptable concentration for Total Coliforms (TC) is zero colony forming units (cfu) per 100 mL. However, due to the variation in the detection method of these organisms, compliance is considered when the following criteria is met:

1. "No sample should contain more than 10 total coliform organisms per 100 mL, none of which should be fecal coliforms;
2. No consecutive sample from the same site should show the presence of total coliform organisms; and

3. For community drinking water supplies:
    a) not more than one sample from a set of samples taken from the community on a given day should show the presence of coliform organisms; and
    b) not more than 10 % of the samples based on a minimum of 10 samples should show the presence of coliform organisms" (Federal-Provincial Subcommittee on Drinking Water, 1993)

If any of these criteria are exceeded, corrective actions should be carried out which includes measures such as re-sampling, increasing disinfectant dosage, flushing water mains, utilizing an alternative source of water and advising consumers to boil their water.

The GCDWQ also require that the general bacterial population is assessed even though this general bacterial enumeration does not usually have a direct health significance (McFeters, 1990). The reason it must be monitored then is because excessive bacterial concentrations can hinder the recovery of coliforms, therefore preventing the detection of a potential health threat (Federal-Provincial Subcommittee on Drinking Water, 1993; McCabe and Winton, 1990; and McFeters, 1990). There are two acceptable methods for enumerating the general bacterial population in the GCDWQ. One is to count the background colonies on the Total Coliform plate. If the number of non-coliform background colonies is greater than 200 cfu/100mL, then the water should be re-sampled. The second acceptable measurement of the general bacterial population is a Heterotrophic Plate Count (HPC). The HPC count is a measure of aerobic and facultative aerobic bacteria found in water that are capable of growth on simple organic compounds (primarily carbohydrates, amino acids and peptides) found in the culture medium, and under incubation times and temperature conditions specified (McFeters, 1990).

It has been argued that the limited coliform monitoring requirement in the GCDWQ is insufficient in terms of protecting public health. This is because there is a large spectrum of organisms that can survive conventional treatment processes including spore formers, acid-fast bacilli, pigmented organisms, disinfectant-resistant bacterial strains, various yeasts, fungi, and actinomycetes (American Water Works Association, 1990). Therefore, sometimes, the regular coliform enumeration is supplemented by further microbiological assays. Currently, viruses and protozoa are under review for possible addition to the Guidelines for Canadian Drinking Water Quality (Federal-Provincial Subcommittee on Drinking Water, 1993).

2.1.3 Chemical Parameters

The long term chronic ingestion of low levels of chemical contaminants in drinking water has been associated with adverse health effects in some cases. The American Water Works Association (AWWA, 1990) outlines a variety of adverse health effects possible depending on the exposure level of a particular chemical:

> "Toxic: Causing a deleterious response in a biological system, seriously injuring function, or producing death. These effects may result from acute conditions (short high-dose exposure), chronic (long-term, low-dose) exposure or sub chronic (intermediate-term and dose) exposure.

Neurotoxic: Exerting a destructive or poisonous effect on nerve tissue.
Carcinogenic: Causing or inducing uncontrolled growth of aberrant cells into malignant tumors.
Mutagenic: Causing heritable alteration of the genetic material within living cells.
Teratogenic: Causing non-hereditary congenital malformations (birth defects) in offspring."

Although the health effects of some waterborne chemicals have been established with certainty, there are many health effects that have not been established. This is because much of the work on the chemical contaminants in water is based on toxicological data that is derived from animal experiments. The extrapolation of data obtained from animal experiments to human effects definitely has its limitations. Although some epidemiological data is available on human exposure to a variety of chemicals, much of the health effects information for many chemicals is inadequate and inconclusive.

The chemical parameters that are regulated in the Guidelines for Canadian Drinking Water Quality are either inorganic or organic in nature. Metals and other non-carbon containing elements are considered inorganic. Organic chemicals, on the other hand, contain carbon in their structure. Pesticides and organic disinfection by-products are examples of chemicals that would fit into this classification. Appendix B lists the MAC, IMAC and AO limits set for various organic and inorganic chemical contaminants. It is beyond the scope of this paper to discuss all of the chemical agents regulated in the GCDWQ on an individual basis. Therefore, interested readers are referred to AWWA's book Water Quality and Treatment: A Handbook of Community Supplies that contains health effects information on many of the inorganic and organic chemicals regulated in the GCDWQ.

2.1.4 Radiological Parameters

Radioactivity is energy that is released from radioactive atoms. There are different forms of radioactive energy and each of these forms reacts differently within the human body (AWWA, 1990). The USEPA has estimated that drinking water only contributes about 0.1% to 3% of a persons annual dose of radiation which is very small in relation to other exposures. Nonetheless, the GCDWQ has established limits for certain radiological parameters although these are currently under review.

2.1.5 Sampling and Monitoring

The frequency of bacterial sampling as set out in the Guidelines for Canadian Drinking Water Quality is not regulated, but it has been suggested that for systems that serve less than 5000 people, a minimum of 4 samples per month are taken (Federal-Provincial Subcommittee on Drinking Water, 1993). This would account for the majority of the community drinking water supplies in the Northern River Basins Study area. Conventional drinking water treatment plants that serve larger populations are recommended to sample more often. Sampling for parameters that are assigned an aesthetic objective is to be decided by the appropriate control agency. Chemical and radiological substances in the GCDWQ that have maximum acceptable concentrations should be sampled semi-annually. This frequency may be increased if the water is suspected to be polluted or decreased if substances are consistently absent. All sampling and analyses performed should be done following the protocols set out in Standard Methods for the Examination of Water and Wastewater (American Public Health Association *et al*, 1992).

In summary, all of the guidelines and standards presented in Appendix B and throughout section 2.1, cannot be considered as representing a clean demarcation between safe and unsafe drinking water (AEP, 1988). While it is important that every effort is made to protect water supplies from contamination and to produce the best quality drinking water possible, an occasional exceedance of a drinking water quality standard may not necessarily be a cause for public health concern (AEP, 1988). However, if a standard is exceeded, the reason for failing to meet the guideline should be determined immediately and appropriate remedial actions should be initiated to ensure the health of the general public is protected (Federal-Provincial Sub-Committee on Drinking Water, 1993; AEP, 1988).

2.2 PUBLIC HEALTH IN THE NORTHERN RIVER BASINS

According to the WHO (1978) definition of health, an assessment of health in a particular area should address physical, mental, social and spiritual factors. A study such as this would be a very complex and difficult one, and was beyond the scope of the Drinking Water Component. The NRBS Human Health Monitoring Committee was involved in an overall assessment of health in the study area based on the analysis of health records (Huberman, 1995). The results from this study are presently being compiled.

There are many Indian Reservations in the NRBS area and therefore, a significant proportion of the population is of native descent (Armstrong *et al.*, 1995). It is well established that the native population in Canada experiences more ill-health than the rest of the Canadian population (Fraser-Lee and Hessel, 1994; Robinson and Heinke, 1990; Weller and Manga, 1987). Life expectancy for native Canadians is ten years less than the national average, and the infant mortality rate is more than double the rate for Canada as a whole (Fraser-Lee and Hessel, 1994). Epstein (1982) has likened the health of the Native population to that of "developing societies within developed countries" and Postl *et al.*, (1987) observed that the health of the Canadian Aboriginal is "perhaps the largest public health problem our county faces (Fraser-Lee and Hessel, 1994)." Robinson and Heinke (1990) found that in native communities in the Northwest Territories, some of these health problems could be related to the drinking water supply.

The Traditional Knowledge Component of the NRBS addressed native people's perceived health in an interview survey administered by the component. Based on the responses of 221 Aboriginal elders or second generation elders, it was found that "overall, respondents tended to be positive about their health with an average rating of 2.8 on a scale of one (excellent) to five (poor) (Traditional Knowledge Component, 1995)." Illnesses cited as increasing in the community included cancer (59 %), diabetes (25 %) and heart problems (17 %) (Traditional Knowledge Component, 1995). So, although the majority of the First Nation's people interviewed in this survey rated their own health positively, many of them also indicated a rise in several diseases in their communities.

Much of the work completed by the Drinking Water Component was indirectly related to an assessment of public health in the area. This is because drinking water quality guidelines are established with the intention of protecting public health. These guidelines were used in the study of both conventional and non-conventional drinking water supplies. The guidelines were used for comparison with both: (1) the physical, chemical, and microbial parameters obtained from tests done on field-collected water samples; and, (2) the physical, chemical, and microbial parameters in several water quality databases of water samples from the study area. In this way, risks to public health could be established based on any of the guideline values that were exceeded in a particular water supply. In addition to the continuous reference to the Guidelines for Canadian Drinking Water Quality that ultimately reflect drinking water's effect on public health, a further study of health records was completed by the Drinking Water Component. This particular study was an assessment of waterborne illnesses in the study area; the results of which are presented in the following section.

2.2.1 Assessment of Waterborne Disease Rates in the Study Area

One method of determining the risk of obtaining a microbial waterborne disease from a particular drinking water supply can be assessed by analyzing health records. The results from such an analysis is twofold. First, an indirect indication of the microbiological quality of the drinking water in the study area will be gained. This has been found to be an effective method of assessment because the response to microbial contaminants in drinking water is often sudden and acute, compared to long-term chronic responses to many chemical contaminants (Emde *et al.*, 1994). Furthermore, studies have shown that compared to potential risks associated with chemical exposures in drinking water, the actual or documented health risks associated with microbes is high. In fact, for many of them, "the risk of infection over a lifetime is a certainty (probability = 1) (Emde *et al.*, 1994)." Second, insight into the general level of public health in the study area, using waterborne disease rates as the indicator, is attained

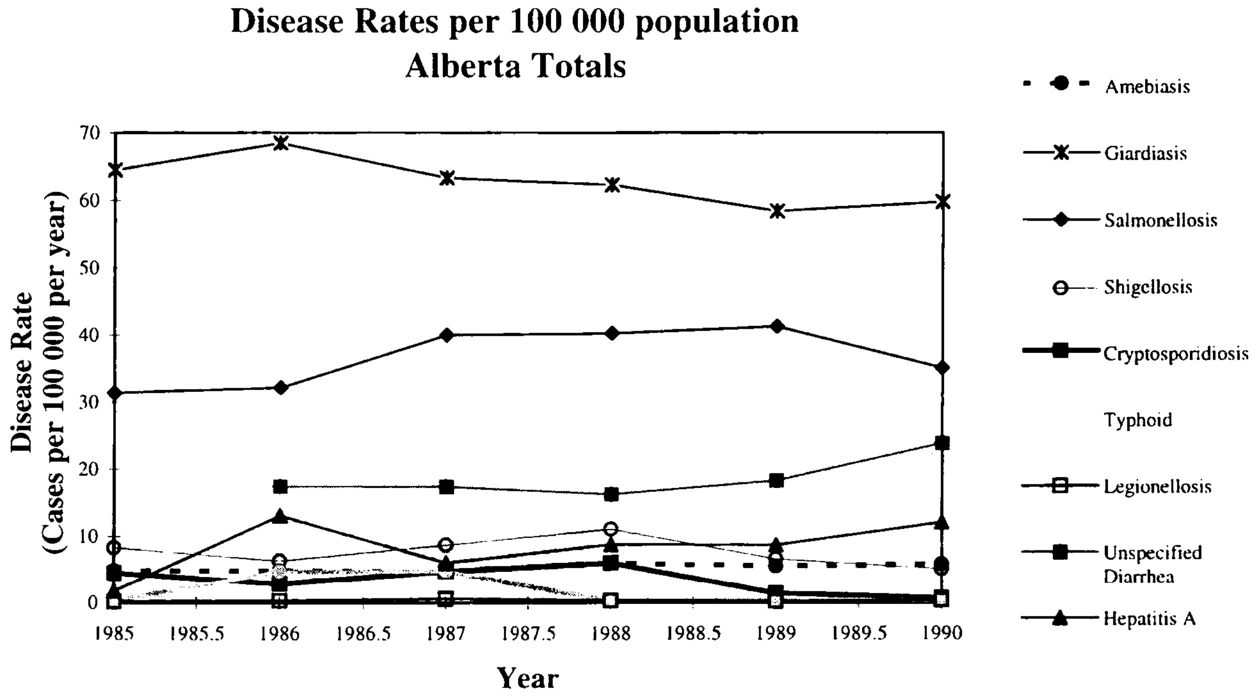
For the Northern River Basin Study it was beyond the scope of the drinking water component to do an epidemiological study of water borne disease in the study area. However, as a preliminary assessment of the occurrence of water borne disease in the study area, Alberta Health Communicable disease statistics and health unit records were analyzed (Emde *et al.*, 1994). The purpose of this investigation was to determine in a qualitative way if any significant differences in water borne disease rates occur in the Northern River Basin Study area. Due to limitations in easily attainable data and limitations in the data itself care must be exercised in the interpretation of the results.

Northern River Basins Study health records were analyzed by the Drinking Water Component for the case rates of selected waterborne diseases including: (1) amebiasis; (2) giardiasis; (3) salmonellosis; (4) shigellosis; (5) cryptosporidiosis; (6) typhoid; (7) legionellosis; (8) hepatitis A; and,

(9) unspecified diarrhea. As mentioned, incidences of these diseases were obtained from Alberta Health Communicable disease statistics and from health unit records. Records were only available for the Alberta portion of the Northern River Basin Study area. The rate of each disease was calculated per 100 000 population per year, for each of the health units in the NRBS area which includes: (1) Alberta West Central; (2) Sturgeon; (3) Athabasca; (4) Fort McMurray; (5) South Peace; (6) Peace River; and, (8) High Level - Fort Vermilion.

The disease rates for each of the selected waterborne diseases for all of Alberta are presented in Figure 3. This figure illustrates that giardiasis has the highest rate in Alberta of all of the chosen waterborne diseases for the years analyzed. Salmonellosis and unspecified diarrhea are also highly reported for all of Alberta. Besides this, there does not seem to be any provincial trends occurring simultaneously with any of the diseases.

Figure 3. Reported Cases of Waterborne Illnesses in Alberta from 1985 to 1990.



In the data analyzed in the study of waterborne disease health records by the Emde *et al.*, (1994), it was found that information on cryptosporidiosis, typhoid, legionellosis, and unspecified diarrhea was either not reported or not available for each of the health unit regions in the NRBS area. Therefore, only data for giardiasis, salmonellosis, shigellosis and hepatitis A incidences was available for each individual health unit area. The disease incidences per 100 000 population per year are presented for these waterborne diseases in Table 2 and the average value for each disease in each health unit is plotted for the 1985 to 1990 period in Figure 4. The results for each of the waterborne diseases presented in Table 2 and Figure 4 are discussed separately below.

Table 2. Notifiable Disease Statistics for Select Waterborne Diseases (Incidence/100 000 per year)

(a) GIARDIASIS

	Alberta Total	Jasper	Alberta West Central	Sturgeon	Athabasca	Fort McMurray	South Peace	Peace River	High Level - Ft. Vermilion
1985	64.5	205.4	20.7	89.7	170.4	141.6	117.3	117.3	307.3
1986	68.5	231.1	36.2	50.1	95.0	133.5	148.8	102.3	119.0
1987	63.3	102.7	46.6	46.0	85.2	152.5	120.8	85.6	99.1
1988	62.3	77.0	31.1	67.8	104.8	79.0	75.3	83.1	218.1
1989	58.4	128.4	72.5	64.6	98.3	103.5	49.0	53.8	89.2
1990	59.8	154.0	82.8	68.9	39.3	62.2	69.7	56.2	69.4
Average	62.8	149.8	48.3	64.5	98.8	112.1	96.8	83.1	150.4
Std Dev	3.6	59.5	24.4	15.6	42.2	36.4	37.9	25.0	92.9

(b) SALMONELLOSIS

	Alberta Total	Jasper	Alberta West Central	Sturgeon	Athabasca	Fort McMurray	South Peace	Peace River	High Level - Ft. Vermilion
1985	31.4	NR	23.3	14.2	39.3	24.5	29.8	29.8	19.8
1986	32.2	25.7	12.8	33.9	36.0	19.1	36.8	12.2	9.9
1987	40.0	NR	15.5	17.5	45.9	46.3	50.8	51.3	NR
1988	40.3	NR	33.6	40.5	59.0	27.2	42.0	34.2	29.7
1989	41.3	NR	33.5	39.4	55.7	30.0	36.8	44.0	49.6
1990	35.1	77.0	20.7	23.0	19.7	38.1	8.3	9.8	19.8
Average	36.7	51.4	23.2	28.1	42.6	30.9	34.1	30.2	25.8
Std Dev	4.4	36.3	8.8	11.4	14.4	9.8	14.4	16.7	15.1

(c) SHIGELLOSIS

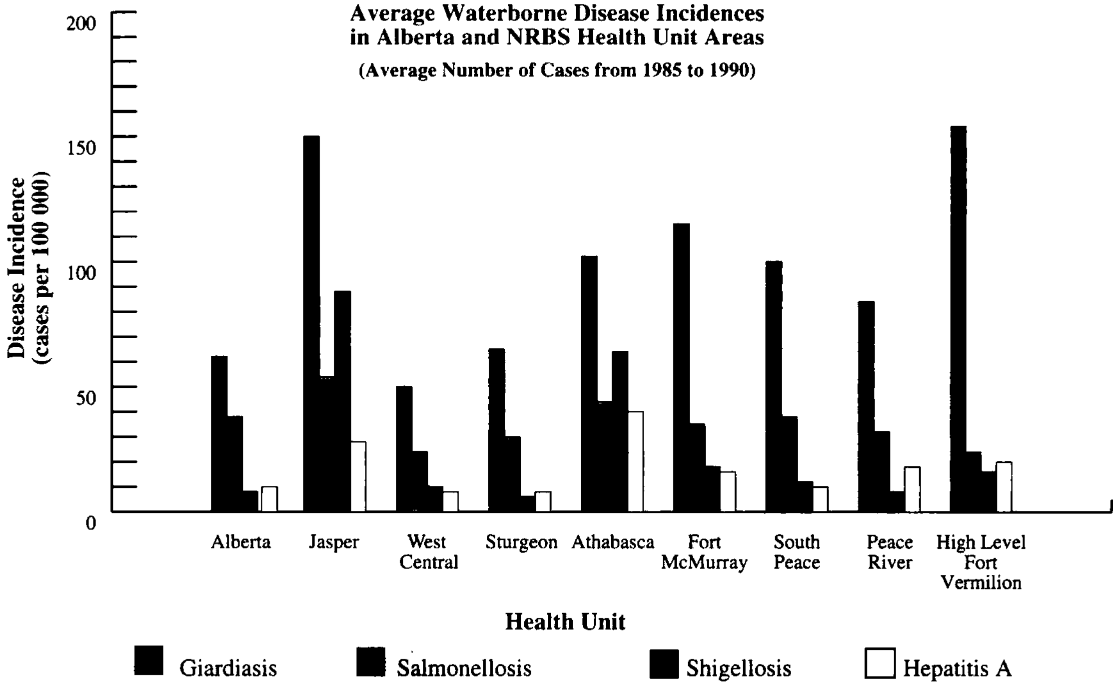
	Alberta Total	Jasper	Alberta West Central	Sturgeon	Athabasca	Fort McMurray	South Peace	Peace River	High Level - Ft. Vermilion
1985	8.3	205.4	NR	9.8	144.1	NR	10.5	10.5	-
1986	6.3	NR	NR	2.2	19.7	13.6	1.8	7.3	19.8
1987	8.7	NR	NR	6.6	16.4	5.4	17.5	NR	NR
1988	11.1	NR	10.4	3.3	NR	16.4	14.0	NR	NR
1989	6.6	25.7	13.1	3.3	NR	NR	NR	2.4	NR
1990	5.1	26.7	2.6	4.4	NR	2.7	NR		9.9
Average	7.7	85.9	8.7	4.9	60.1	9.5	11.0	6.7	14.9
Std Dev	2.1	103.5	5.5	2.8	72.8	6.5	6.7	4.1	7.0

(d) HEPATITIS A

	Alberta Total	Jasper	Alberta West Central	Sturgeon	Athabasca	Fort McMurray	South Peace	Peace River	High Level - Ft. Vermilion
1985	1.8	NR	NR	NR	NA	NR	NA	NA	NA
1986	13.1	NR	15.5	8.8	108.1	2.7	21.0	14.7	NR
1987	6.0	25.7	2.6	5.5	6.6	NR	5.3	NR	19.8
1988	8.8	NR	7.8	3.3	26.2	10.9	3.5	NR	NR
1989	8.7	25.7	5.2	3.3	26.2	5.4	12.3	NR	NR
1990	12.1	25.7	10.4	14.2	29.5	5.4	5.0	NR	NR
Average	8.4	25.7	8.3	7.0	39.3	6.1	9.4	14.7	19.8
Std Dev	4.1	0.0	5.0	4.6	39.5	3.4	7.3	–	–

Notes: NA = Information not available in databases examined; and NR = No Cases reported for given period

Figure 4. Average Waterborne Disease Incidences in Alberta and the NRBS Health Unit Areas for the period from 1985 to 1990.



First, the average rate of giardiasis in all of Alberta for the period of 1985 to 1990 was 62.8 cases per 100 000 population per year. The rate was higher than this for all of the NRBS health units except for Alberta West Central which was 48.3 cases per 100 000 people per year. The Jasper and High Level health unit areas have the highest incidence of giardiasis in the study area with a rate of 150 cases per 100 000 people per year. However, it should be noted that the high value for Jasper may not be truly representative given the number of tourists included in the disease reports, but not in the population estimates (Emde *et al.*, 1994). Likewise, care should be taken in the assessment of the High Level Fort Vermilion health unit area because of the high standard deviation that occurred as a result of apparent outbreaks in 1985 and 1988. Nonetheless, giardiasis appears to be higher in the NRBS area than the provincial average.

Second, the provincial average of salmonellosis cases in Alberta from 1985 to 1990 is 36.7 cases per 100 000 people per year. Once again, Jasper has a higher rate than the provincial average, likely for the same reason discussed above. Despite this, the average of all of the NRBS area health units for the study period is slightly less than the provincial average. Therefore, it is concluded that the difference in waterborne disease incidence for salmonellosis is not significant when comparing the NRBS area to all of Alberta.

Third, in the period from 1985 to 1990, the incidence of shigellosis in Alberta averaged 7.7 cases per 100 000 people per year. A much higher case rate of shigellosis was observed in the Jasper and Athabasca health unit over the same time period. However, there were several health units in which no cases were reported for given years. The 'zero' reporting by the health units in those years were neither included for derivation of the statistics in Table 2, nor for plotting the results in Figure 4. Therefore, the averages obtained cannot be analyzed with certainty. Furthermore, very high shigellosis rates observed in 1985 in both the Jasper and Athabasca health unit areas skew the average results high. Regardless, slight differences within each health unit over the years and differences between the health units are noticeable.

Finally, the Hepatitis A incidence in Alberta from 1985 to 1990 was 8.4 cases per 100 000 people per year. Higher average rates of Hepatitis A were observed in the Jasper, Athabasca, South Peace, Peace River and High Level-Fort Vermilion health units over the same time period. Once again, the standard deviations in the derivation of this 6 year average were high and there were several years for which cases were not reported or not available in the particular health units. These 'zero' values were not included in the calculated averages.

There were several limitations with this assessment of waterborne disease health records. One such limitation was the incompleteness of the databases. Another major limiting factor in this assessment was that the actual incidence of waterborne disease does not necessarily reflect the reported incidence. Emde *et al.*, (1994) state that this is due to a number of factors that may include:

- "The individual(s) may have exposure from greater than one environmental source (food, water, other) and may not associate water consumption, inhalation, or contact with the symptoms experienced;
- The individual(s) may have self-limiting symptoms and not seek medical attention;
- The individual(s) may have other health conditions that mask or overshadow the waterborne exposure;
- Medical facilities, especially in remote areas, may not always allow for timely investigation or treatment, especially if the condition is self-limiting;
- The individual(s) may not be sampled by medical personnel, thus the causative agent(s) may not be established;
- The medical condition may not be considered within the definition of notifiable diseases, as specified by the Public Health Act, and consequently not be reported;
- The epidemiological investigation may not detect the causative agent from the water source, especially if the agent was a transient member of the water flora, rather than a resident member;
- Laboratory detection may fail to detect the actual causative agent, fail to detect injured organisms or, not be sufficiently sensitive for low populations of the suspected microorganism."

As a result the disease incidences reported in health records are probably small compared to the total number which occur (Emde *et al.*, 1994). Another limiting factor was that the health records examined were obtained from Alberta Health and Alberta Health Units in the NRBS area. As discussed above, there are many Indian Reserves in the study area. Health care on the reserves is under federal jurisdiction with Health Canada (Bingham, 1994). Since federal health records were not investigated in this assessment, this segment of the population was not included in the estimates above. Nor were records obtained for areas of the NRBS area outside of Alberta.

Based on this assessment of health records, it was concluded that some waterborne disease rates tend to be somewhat higher in the NRBS area than the provincial average. However, there are several limitations in an assessment such as this one which limits the certainty of the results. Nevertheless, the data does show the rates of water borne disease are similar to other areas in Alberta and North America. Given this, the risk of acquiring water borne disea-se is of concern, as it is in the rest of North America.

3.0 SOURCES OF DRINKING WATER IN THE NORTHERN RIVER BASINS

It has been stated that a typical Canadian adult consumes approximately 1.5 L of drinking water per day (Environmental Health Directorate, 1991). The source of this 1.5 L can come from either a conventional supply of potable water or from a non-conventional drinking water supply. Both conventional and non-conventional supplies are consumed in the Northern River Basins. It is not known exactly how many people consume one or the other type of water, but several estimates are discussed in the following sections.

3.1 CONVENTIONAL DRINKING WATER SUPPLIES

A conventional drinking water supply is defined in this study as a community drinking water supply that is obtained from a drinking water treatment facility. Although there are numerous variations and types of processes used at such a facility, conventional treatment of surface water supplies typically consists of coagulation, flocculation, sedimentation, filtration, disinfection and distribution steps. However, depending on the source water quality, some of these steps may not be included or others may be added.

There are 214 drinking water facilities located in the Northern River Basins Study area (Prince *et al.*, 1995a). Appendix D contains a summary of all of the conventional drinking water treatment facilities in the study area. Included in this summary is the name of the facility, the population served, the raw water source, the treated water storage and the type of treatment processes utilized. Treatment processes used at conventional drinking water treatment facilities in the Northern River Basins range from no treatment (for some groundwater sources) up to and including: storage, screening, coagulation, flocculation, clarification, sedimentation, filtration, pH adjustment, iron removal, fluoridation, and several methods of disinfection (Prince *et al.*, 1995a). Distribution is the final step for water supply systems. In the NRBS area, the distribution of the potable water supply can be by an underground piped distribution system or by trucked delivery to the home. Water distribution trucks are common in rural remote areas because it is not often feasible to have underground piped infrastructure extending to remote areas. Therefore, the water trucks deliver potable water to basement or underground cisterns, or other water holding devices, such as 45 gallon barrels.

The locations of the conventional drinking water treatment facilities in the study area are depicted in Figure 5. The raw water source (groundwater or surface water) is also shown, as well as whether the facility serves a population more or less than 500. A breakdown of the population served by surface water or groundwater facilities is illustrated in Figure 6. From this breakdown it is shown that the majority of the people in the study area consume treated water from a surface water facility. The two cities in the area and the majority of the towns rely on treated surface water supplies. Some of the smaller villages, hamlets and other establishments rely on conventional groundwater facilities as their potable water source.

Using the population profile in Figure 6, the total number of people reported as receiving drinking water from a conventional drinking water treatment facility was 170 737 (Prince *et al.*, 1995a). As of September, 1994, the total population living within the Alberta boundaries of the Northern River Basins Study area was 227 864 (Ellehoj, 1994). Therefore, 57 127 people, or approximately 25 % of the residents of this area, are reported as not receiving their drinking water from a conventional drinking water treatment facility. Consequently, in order to obtain safe potable water, people living in areas where conventionally treated water is unavailable must find an alternate source of drinking water and provide some form of treatment if necessary. Therefore, it is important to assess the utilization and quality of alternative drinking water sources in the study area as well as the effectiveness of the non-conventional methods used to treat the water.

3.2 NON-CONVENTIONAL DRINKING WATER SUPPLIES

A non-conventional drinking water supply is defined in this study as any water supply that has not been obtained directly from a conventional drinking water facility either through a piped distribution system or from a community water distribution truck. The 25 % population figure just presented as the percent of population that relies on a non-conventional supply of drinking water was determined by the Drinking Water Component based on the total population of the study area minus the "conventionally served" population. Other estimates of the extent of conventional versus non-conventional drinking water consumption are discussed below.

The map of the study area in Figure 7 illustrates the number and distribution of the people that do not receive their drinking water directly (either piped or trucked delivery) from a conventional water treatment facility. The top number in each area is the total population in that area (based on Census 1991 data at the sub-division level) and the bottom number is the conventionally "served population" that receives their drinking water from a conventional drinking water treatment plant (Ellehoj, 1995). The served population numbers are those that were reported by each of the water treatment facilities in the given area as to the population that they supplied drinking water to (Ellehoj, 1995). Since many of the northern river basins areas are sparsely populated, the delineated areas presented in Figure 7 were selected so that confidentiality was maintained. According to this map, there are 14 202 people living in the northwest corner of the province, yet only 5 498 (39%) of these people receive their drinking water for a conventional treatment facility (served population). The other 61% or 8104 people

Figure 5. Licensed Drinking Water Facilities in the Alberta Portion of the NRBS Study Area

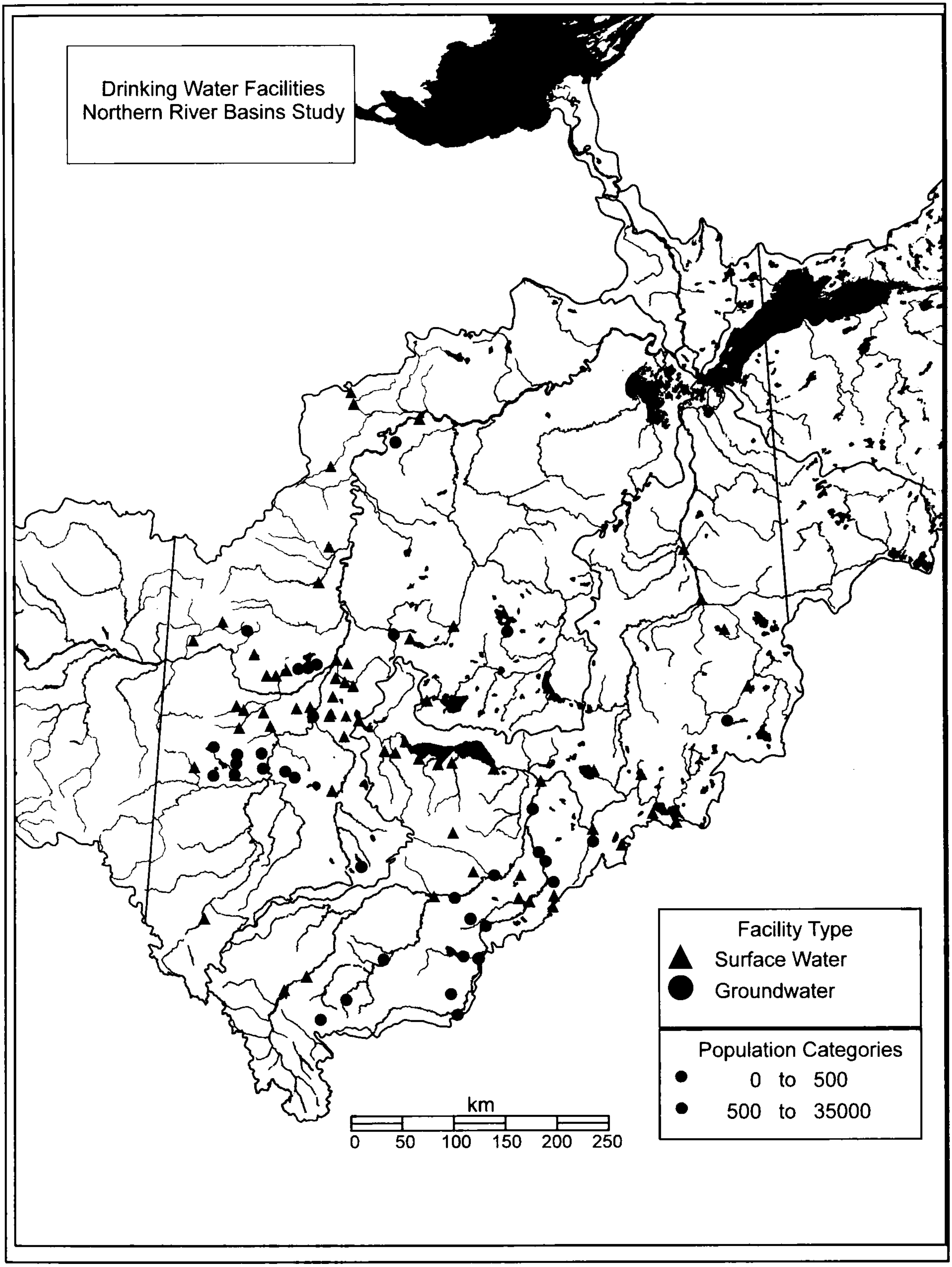


Figure 6. Population Served by Conventional Drinking Water Treatment Facilities in the NRBS Area

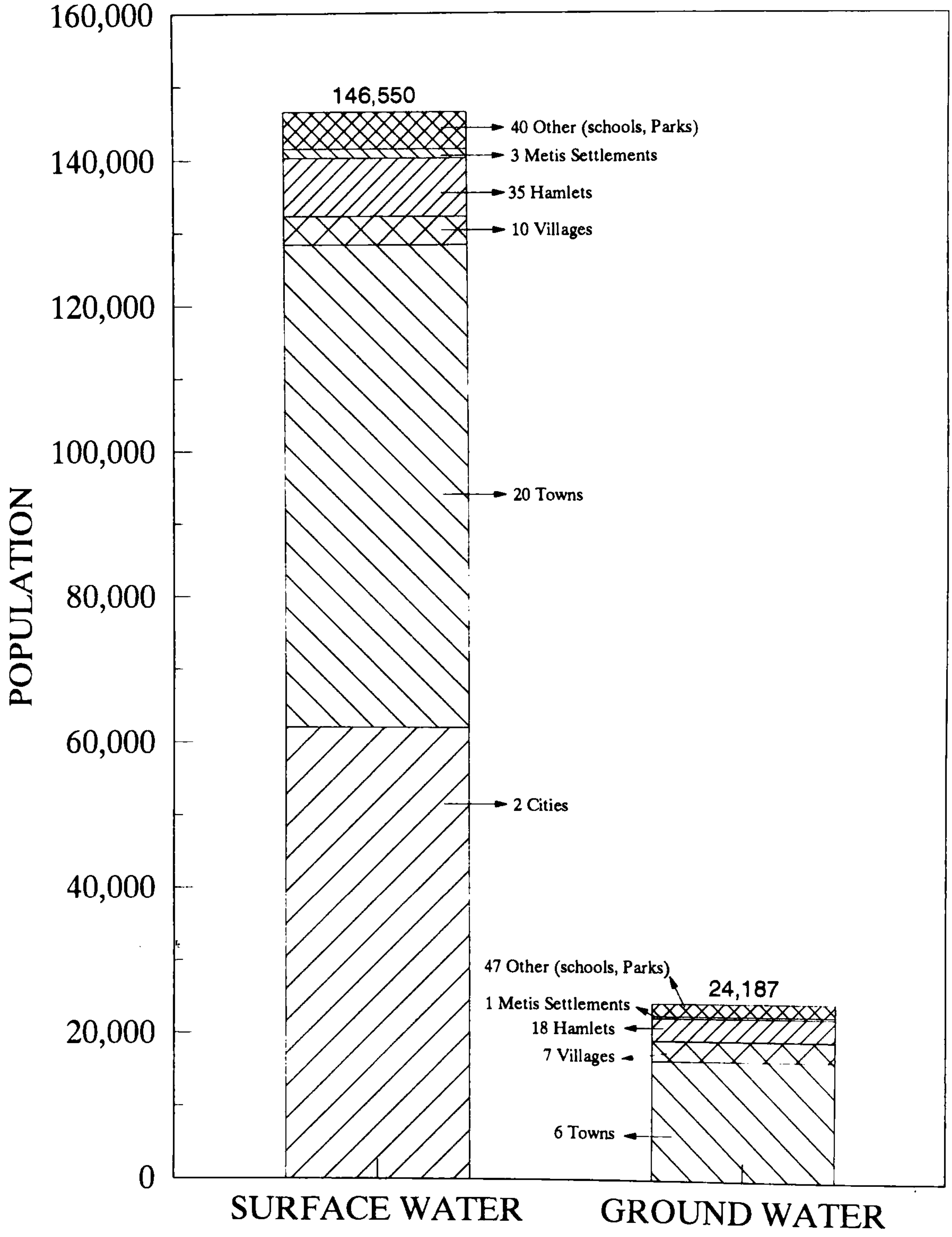
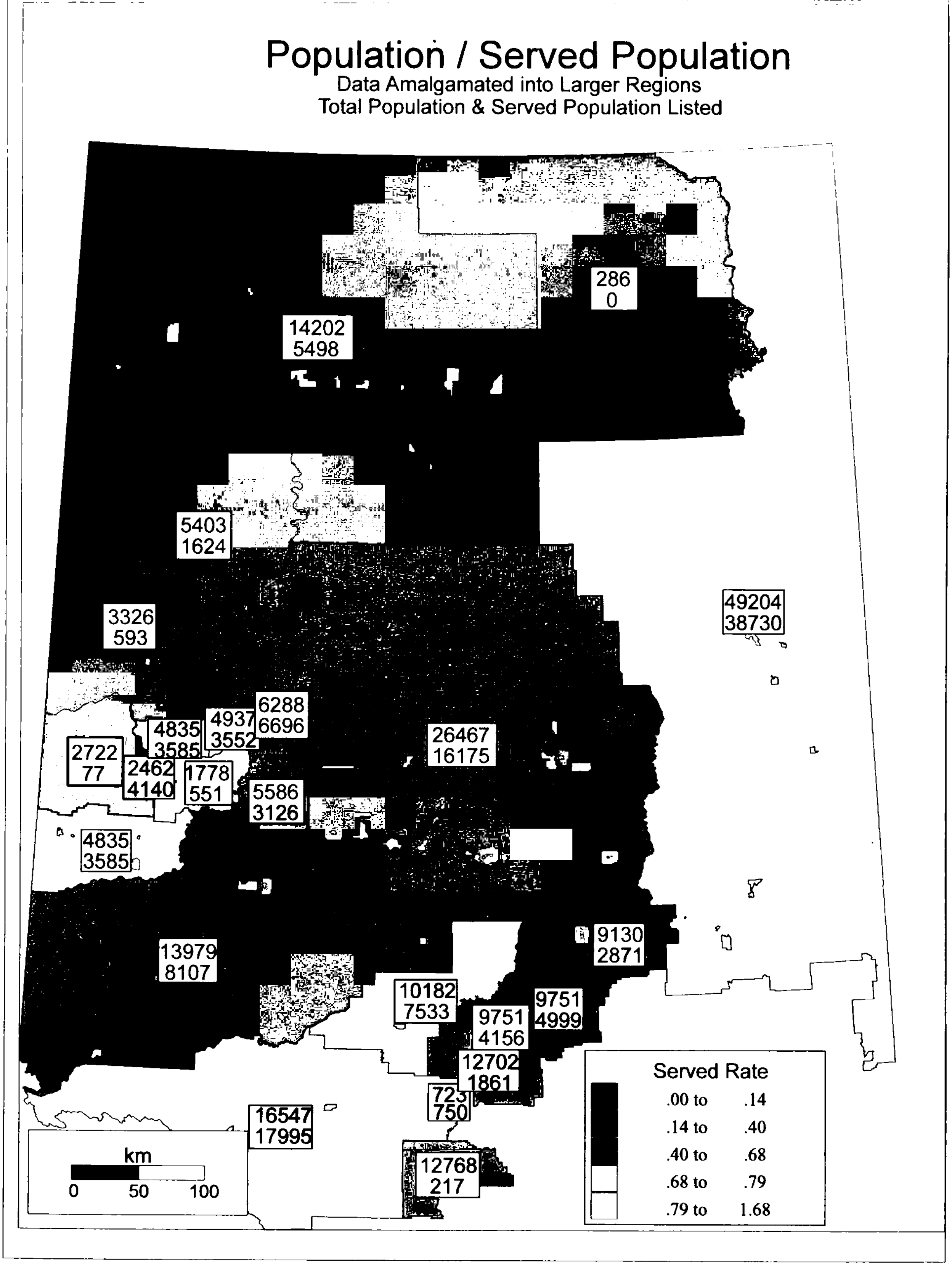


Figure 7. Distribution of Population Consuming Conventionally Treated Drinking Water.



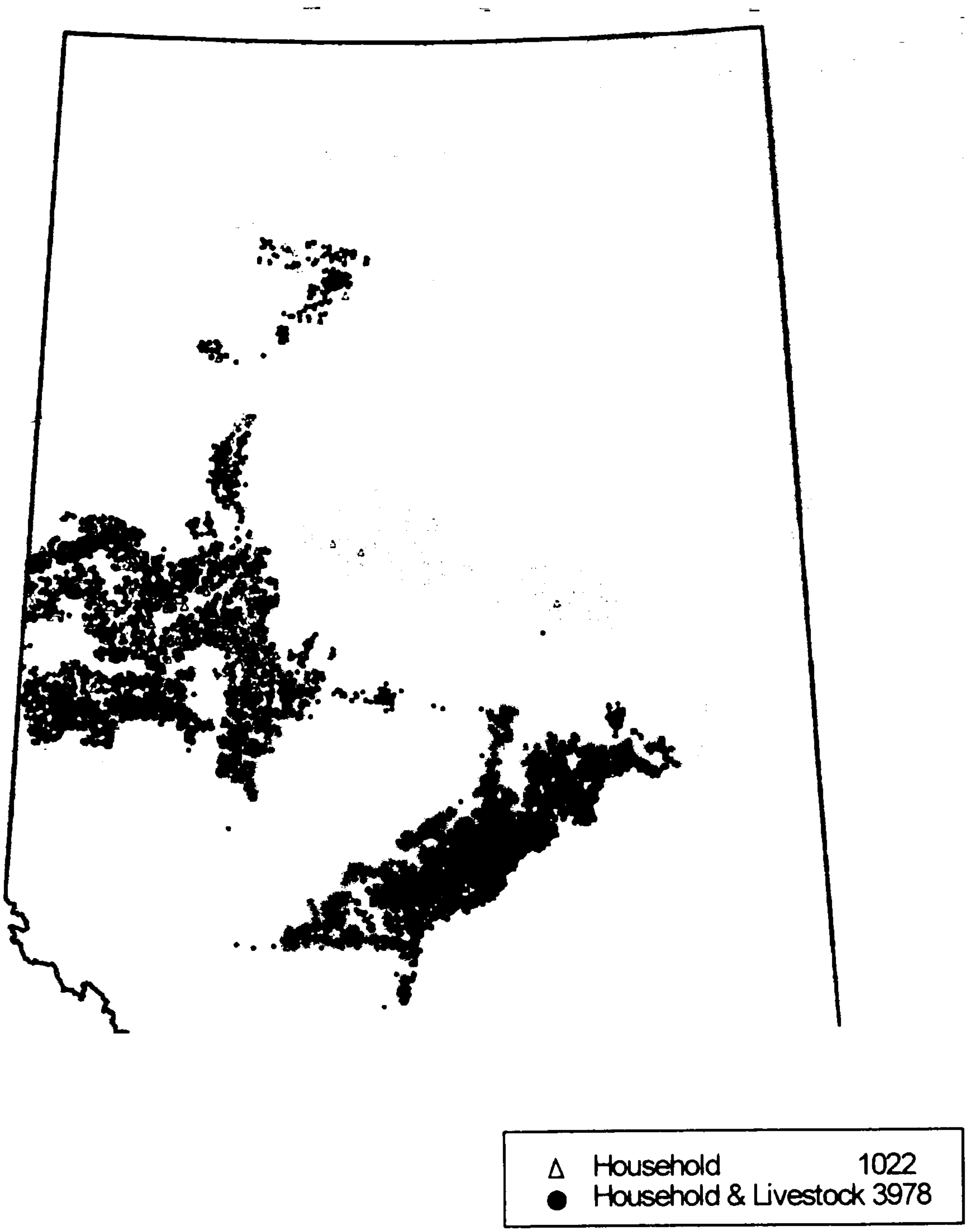
(unserved population) must obtain their drinking water from an alternate source. The general trend that can be observed from this map is that there are many people living in the northwest corner of Alberta and other pockets throughout the NRBS area that do not have easy access to water from a conventional drinking water treatment facility. Therefore, it is assumed that these people utilize a non-conventional source of drinking water.

The numbers in Figure 7 can also be used to generate another estimate of the extent of non-conventional drinking water consumption. This was done by adding all of the top numbers in the map together to get the total population in the study area and subtracting the total of all of the bottom numbers in the map which are the served population. From this, it was found that of the 227 864 people living in the study area, only 136 391 received their drinking water from a conventional drinking water treatment facility. Therefore, based on these figures, 91 473 people (40.1%) rely on a non-conventional source of drinking water.

It is also possible to map the dugouts and wells in the area to see if there was a relationship between the pockets of low conventionally "served" population with areas where there were several dugouts and wells. The information used to generate the maps in Figure 8 and Figure 9 was obtained from Prairie Farm Rehabilitation Administration (PFRA). It should be noted that the dugouts and wells in these figures are only those in which PFRA has been involved. Therefore, it is possible that there are other wells and dugouts in the NRBS area that were built without the assistance of PFRA and hence, would not be included on this map. Also, the wells and dugouts presented were those for which the category of domestic use was assigned. There were other dugouts and wells for which the use was not identified so it is possible that there these dugouts may also be used for drinking water purposes. In any case, the trend for both types of water supply systems is to be concentrated in areas of high agricultural activity; particularly in the fertile Peace River area and also in the middle reaches of the Athabasca River Basin. It is also interesting to note that the distribution of groundwater wells and dugouts appears to be similar in the Athabasca River Basin, but there are far fewer groundwater wells than dugouts in the Peace River Basin. Because, the PFRA database did not contain any information about the household size, only broad generalizations could be made about the population served by these wells and dugouts. Nonetheless, the results suggest that there are many Northern River Basins Study residents not included in the population figures as a conventionally served individual, who likely consume water from household wells and dugouts.

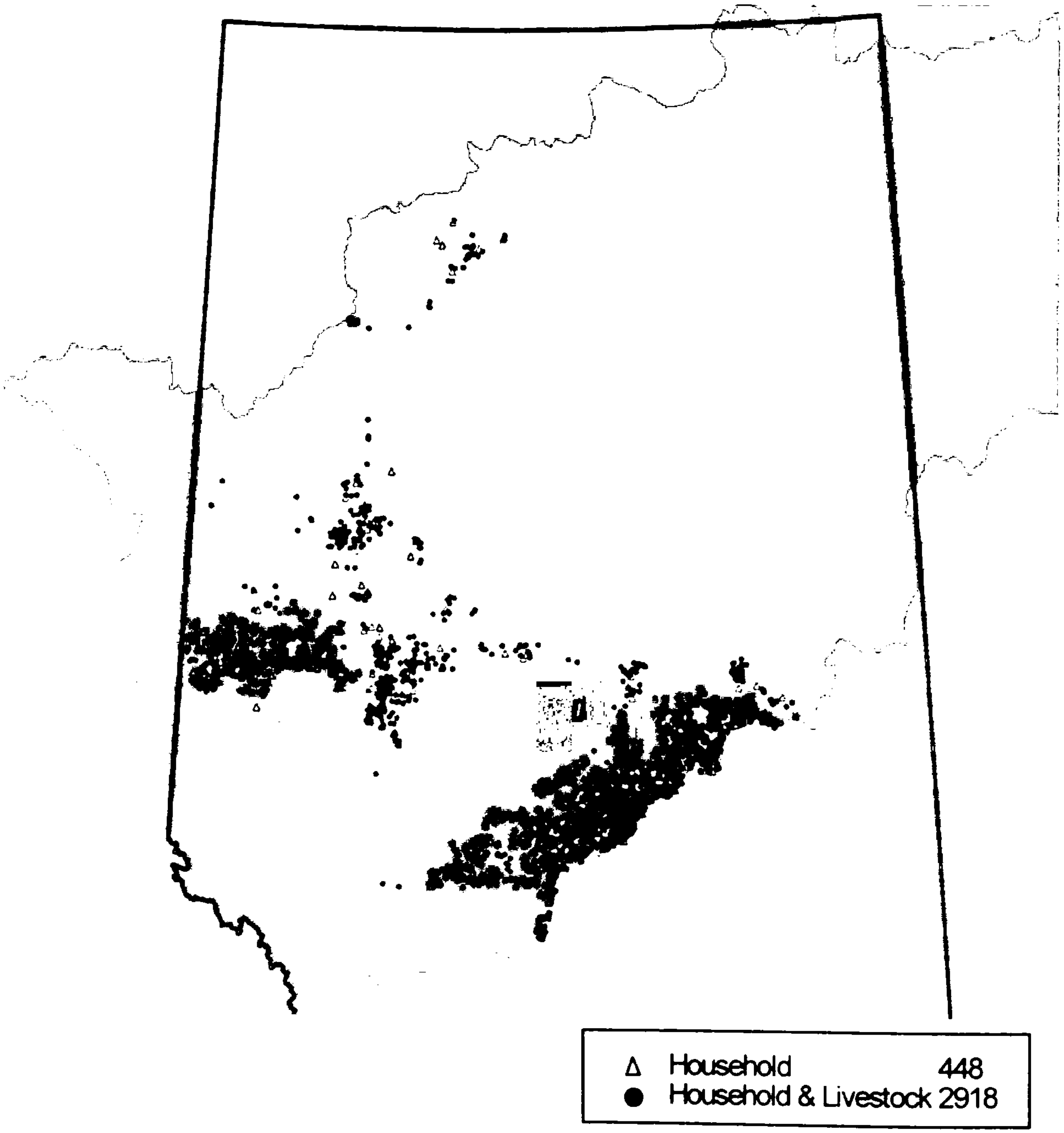
There were other projects involved in determining the types of water consumed in the Northern River Basins during the course of the NRBS study. For example, the Other Uses Component, of the Northern River Basins Study conducted a random sample telephone survey of 718 study area residents. One of the findings from this survey was that 55.3% ± 0.4% of the people interviewed reported that municipal water was their source of drinking water (Reicher and Thompson, 1995). Therefore, the remaining 44.7% of the people surveyed reported consuming a non-conventional source of drinking water. The extent of conventional/non-conventional potable water consumption throughout the study area based on the results from the Other Uses Component research is presented in Table 3. From this Other Uses Component study it was also determined that overall, one-third (33.7%) of households that relied on non-conventional water sources reported using some form of water treatment, especially those that use surface water sources (Reicher and Thompson, 1995). The types of treatment reported included filtration, chlorination,

Figure 8. Dugouts used for Domestic Water Supply in the NRBS Area.



Data is based on PFRA assisted Dugouts

Figure 9. Groundwater Wells used for Domestic Water Supply in the NRBS Area.



Data is based on PFRA assisted wells

distillation, boiling, minerals, copper sulphate and reglone (Reicher and Thompson, 1995). Some of these non-conventional treatment methods are discussed in Section 7.0.

Table 3. Sources of Drinking Water in the Northern River Basins

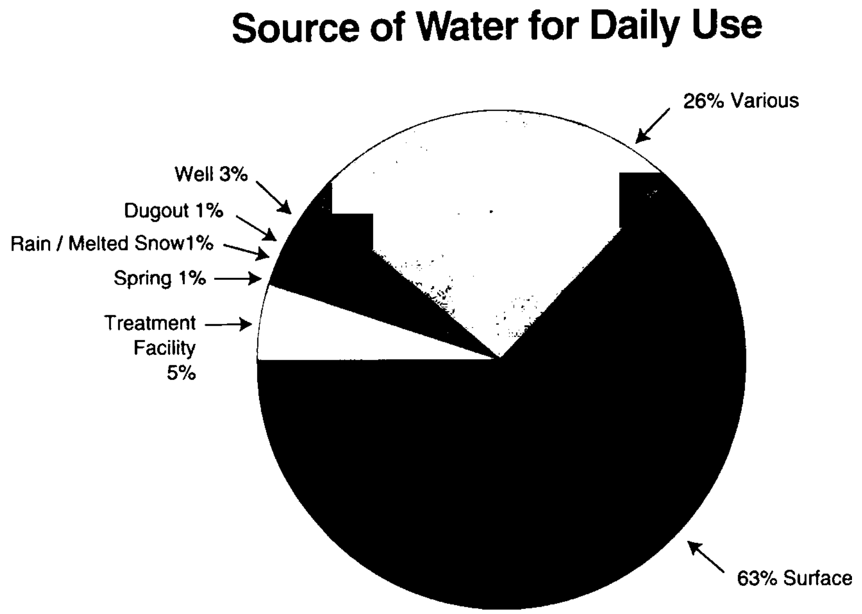
Region	Municipal Water	Bottled Water	Well/ Spring	Lake Water	River Water	Dugouts
Upper Athabasca	72.0 %	2.0 %	18.0 %	0.0 %	8.0 %	0.0 %
Middle Athabasca	18.6 %	0.0 %	79.7 %	0.0 %	1.7 %	0.0 %
Lower Athabasca	98.1 %	1.9 %	0.0 %	0.0 %	0.0 %	0.0 %
Upper Peace	42.6 %	1.9 %	25.9 %	0.0 %	1.9 %	27.8 %
Middle Peace	48.9 %	2.8 %	23.4 %	0.0 %	2.1 %	12.8 %
Lower Peace	66.7 %	3.9 %	9.8 %	2.0 %	5.9 %	11.8 %
Slave River/Delta	92.3 %	1.9 %	0.0 %	3.8 %	0.0 %	1.9 %
Smoky/Wapiti	51.1 %	6.7 %	31.1 %	4.4 %	3.3 %	3.3 %
Lesser Slave	79.2 %	1.9 %	3.8 %	3.8 %	3.8 %	7.5 %
Pembina/Macleod	39.4 %	5.3 %	53.2 %	0.0 %	2.1 %	0.0 %
Wabasca	76.9 %	7.7 %	3.8 %	5.8 %	5.8 %	0.0 %
La Biche/ Other	36.2 %	4.3 %	46.8 %	12.8 %	0.0 %	0.0 %
Total (95 % CI)	55.3 % ± 0.4 %	4.4 % ± 0.2 %	31.0 % ± 0.4 %	2.0 % ± 0.1 %	2.8 % ± 0.2 %	4.4 % ± 0.2 %

(Source: Reicher and Thompson, 1995)

The Other Uses Component also came up with another estimate of the extent of conventional versus non-conventional drinking water consumption in the study area. Their second estimate was based on the responses of municipal and local governments who were questioned about the number of people in their district consuming conventionally treated drinking water. All reported responses were tabulated, and from this assessment it was extrapolated (using weighted averages) that 68.5 % of the population in the study area consume drinking water from a conventional facility (Thompson, 1995).

Another estimate of conventional versus non-conventional drinking water consumption was obtained by the Traditional Knowledge Component of the Northern River Basins Study. In this study, information was collected through in-person interviews of 221 people from nine different native communities in the Northern River Basins. There was a qualifying criterion in the selection of the sample in that the respondents of the questionnaire had to have lived a traditional lifestyle at some point in their lives. Based on the questioning of these residents it was found by the Traditional Knowledge Component (1995) that only 5% of the respondents obtain their daily water from a water treatment facility. The non-conventional sources cited by respondents included: surface water (63%), wells (3%), rain or melted snow (1%), and dugouts (1%) (Traditional Knowledge Component, 1995). These results are illustrated in Figure 10.

Figure 10. NRBS Traditional Knowledge Component Findings Regarding Conventional and Non-Conventional Drinking Water Consumption.



Adapted from *Summary Results From the Document "How Our Knowledge Lives"* (Traditional Knowledge Component, 1995)

In summary, there were several estimates of the extent of utilization of conventional and non-conventional drinking water supplies. The pertinent results obtained in this regard by the Drinking Water Component, the Traditional Knowledge Component and the Other Uses Component are summarized in Table 4

The results in Table 4 should be interpreted with caution because there are limitations with each of the estimates presented. The first estimate by the Drinking Water Component that 25% of the people in the study area consume non-conventional sources of drinking water is based on the total population of the study area and the number of people reported in Alberta Environmental Protection's Facility Survey. For the most part the served population figures presented in AEP's Facility Inventory are based on the population design capacity of the facility, and therefore may be skewed high because the actual number of consumers is not necessarily the same as designed capacity

The second estimate by the Drinking Water Component (in Table 4) that 40.1 % of the population consumes non-conventional drinking water supplies is based on the numbers in Figure 7. Although the numbers for the served population in this map were obtained from the drinking water treatment plants themselves, there is some uncertainty about how the numbers for this served population were calculated by the treatment facilities.

Table 4. Summary of the Estimates of Conventional and Non-Conventional Drinking Water Consumption in the NRBS Area

Researchers	Estimate Based On:	Conventional	Non-Conventional
Drinking Water Component	Total Population = 227 864 (Census Data)[1] Served Population = 170 737 (Facility Inventory)[2] [Based on 146 550 (Treated Surface Supplies) + 24 187 (Treated Groundwater Supplies)]	74.9 %	25.1 %
Drinking Water Component	Total Population = 227 864 (Census Data)[1] Served Population = 136 391(Figure 7 data)	59.9 %	40.1 %
Drinking Water Component	Number of Dugouts in area ≈5000 Number of Groundwater Wells ≈3366	_	5000 dugouts 3366 wells
Other Uses Component	Telephone survey of 718 NRBS residents.	55.3 %	44.7 %
Other Uses Component	Survey of local governments and municipalities	68.5%	31.5 %
Traditional Knowledge Component	221 Traditional Knowledge interviews of first and second generation elders who were currently living off the land or did live off the land at some point in their life.	5 %	95 %

[1] Census Data Total Population estimate was construed by adding each of the top numbers in Figure 7 to get a total population of the study area. These population figures were obtained from 1991 Census data and were fit into the areas in Figure 7 to maintain confidentiality.

[2] The Facility Inventory Data is presented in Appendix D of this report. Population served by surface and groundwater sources were taken from Figure 6.

The main limitation with the first set of results presented by the Other Uses group in Table 4 (55.3 % served population) was that the interviewees were limited to those households that owned telephones. Many people that live in remote areas, and rely on alternative sources of drinking water, may not have telephones. Furthermore, there is some question as to whether those who responded that they consumed well water were actually consuming water from a community treatment facility that used groundwater as their source. If this was the case, then they should be included in the "conventional" users category. In the second estimate (68.5 % served population), this result was obtained based on the responses of representatives from local governments. For all surveys sent out, the response rate was 31 % (Thompson, 1995). The source of the information supplied by the government representatives is not known by the authors of this report.

The 5 % of the population reported in Table 4 by the Traditional Knowledge Component as consuming treatment plant water must be interpreted mindful that the sample population interviewed consisted of people that currently live off the land or have lived off the land at some point in their life. Furthermore, the 221 people interviewed in this survey were first or second generation Aboriginal elders and the average age of all of the respondents was 58 years old (Traditional Knowledge, 1995). Therefore, although these results are very indicative of a select population within the NRBS area, they cannot be considered to be representative of all people living in the Northern River Basins. However, based on these results, it can be concluded that First Nation's People, especially the elder population that live off the land, may be particularly pre-disposed to consuming non-conventional drinking water. Hypotheses for this action may be for traditional, cultural, spiritual, aesthetic, health, or accessibility reasons, but without further study, it is impossible to determine the exact reasons why.

In summary, both conventional and non-conventional drinking water is consumed in the Northern River Basins Study area. Conventional drinking water supplies are obtained from one of the 214 drinking water treatment facilities. Non-conventional drinking water supplies can be obtained from any one of a number of water sources including: (1) self-hauled treated water; (2) lake or river surface water; (3) groundwater wells or springs; (4) *environmental* water (such as rain, snow, ice, muskeg, birch tree); (5) dugouts, and; (6) point-of-use treated water. The extent of utilization of conventional versus non-conventional drinking water is not known exactly, but it is expected to be between 55 % and 75 % of the residents of the study area who consume conventionally treated drinking water. Therefore, the other 25 % to 45 % of the people rely on a non-conventional drinking water supply.

4.0 CHALLENGES TO DRINKING WATER QUALITY IN THE NORTHERN RIVER BASINS

The quality of drinking water is primarily dependent on three factors: (1) the quality of the raw water source; (2) the efficiency and type of treatment processes utilized; and (3) the distribution system characteristics. Challenges to any of raw water, treated water or distributed water can affect the overall quality of the drinking water supply. Each of these three factors will be addressed with respect to physical challenges, inorganic and organic chemical challenges, and microbial challenges:

- Physical parameters are general properties of the composite water sample such as temperature, pH, taste, odour, colour and turbidity. Therefore, physical assessments of water supplies include all constituents of the sample in the measurement.
- Inorganic contaminants are a class of chemicals that generally do not contain carbon. Heavy metals, nitrates, sulphates, phosphates and other salts are included in this category.
- Organic chemicals are made up of one or more carbon atoms along with other elements (Gabler, 1988). Although the majority of organics in the water originate from the natural decay of animal and vegetable matter, and

includes humic substances, microorganisms and various hydrocarbons, there are many man-made organic chemicals that have been targeted as having adverse health effects.

- Microbial challenges to water include the presence of any of a number of bacterial, viral, protozoan, or other small aquatic lifeforms in the raw water source. Microbiological agents are of particular concern because many of them can cause waterborne illnesses if ingested in a drinking water supply.

4.1 RAW WATER CHALLENGES

In general, drinking water originates from raw surface water sources or from groundwater sources. Although modern technological advancements allow even the most extremely polluted waters to be treated to acceptable standards, a better raw water quality requires less expensive and less sophisticated treatment processes, and is therefore desirable. Challenges to the quality of the raw water supplies in the NRBS area can be a result of a number of natural or anthropogenic activities in the watershed. Some of these challenges to raw water quality are highlighted below. The major sources of contaminants considered include: natural sources; agricultural activities; municipal discharges; and industrial activities.

4.1.1 Natural Factors

4.1.1.1 Physical Challenges. Some physical parameters in raw source waters are a challenge to drinking water quality because their presence in the raw water affects treatment effectiveness, or in other cases, the aesthetic acceptability of water. For example, the turbidity, which is a measure of the suspended matter in the water column, can be naturally high and may fluctuate by orders of magnitude after a storm (Environmental Health Directorate, 1993). There are also seasonal fluctuations in raw water turbidity. High turbidities are a challenge to drinking water quality because turbidity has been associated with the presence of microorganisms. As a result of this, turbidity guidelines have been established and the higher the raw water turbidity, the greater the reduction during treatment is required to meet the GCDWQ guideline of 1 NTU 95% of the time.

Colour and odour are other physical parameters that may occur as a result of naturally occurring substances in the water. Prime suspects of naturally occurring tastes and odours range from humic and fulvic substances to aquatic organisms and microbial degradation products. Inorganic substances are also associated with colour, such as in iron-rich waters.

Water temperature is an aesthetic objective in the GCDWQ. However, naturally occurring cold water found during winter conditions in the NRBS area is a challenge to finished water quality because treatment efficiency of some unit processes is decreased for cold water. For example, the disinfection contact time of chlorine is greater for colder waters. Furthermore, several researchers have found that microorganisms survive longer in cold water (Gordon 1972; Davenport *et al*, 1976; Putz *et al*, 1984) because cold water retards respiration and predation (Emde *et al.*, 1994). Cold water, in essence then, is a challenge to water quality in the Northern River Basins

4.1.1.2 Inorganic Chemical Challenges. The geology of the underlying bedrock influences concentrations of many major inorganic ions such as calcium and magnesium, which are the prime determinants of hardness (Environmental Health Directorate, 1993). Furthermore, many metallic elements that are naturally part of the earth's crust can sometimes be found in water supplies. Groundwater sources are typically harder and have higher dissolved solids content than surface waters in the same area. The total dissolved solids content in groundwater is a result of the much greater rock and soil interactions with the water, whereas, the dissolved solids in surface water is a result of atmospheric precipitation, evaporation-transpiration and rock interaction processes (Liem *et al.*, 1995).

The oxidation of organics can often result in the formation of inorganic materials. Sulphate is one example of an inorganic that can leach from sedimentary rocks or else be formed from the oxidation of organics. In turn, bacterial reduction of sulphate and organic sulphur under anaerobic conditions results in the formation of sulphide which has a characteristic rotten egg odour. Another example of an inorganic substance being formed naturally from decomposition or metabolic processes is cyanide. The decomposition or metabolism of certain types of plants or microorganisms (blue-green algae) results in the formation of cyanide (Liem *et al*, 1995).

4.1.1.3 Organic Chemical Challenges. Naturally occurring organics constitute a very large class of organic compounds. Included in this category are the humic and fulvic substances, and the degradation products of proteins and other biological compounds (Environmental Health Directorate, 1993; AWWA, 1990). Since the determination of these compounds individually would be extremely difficult and not very illuminating, total organic carbon (TOC) is used as an approximate measure of the concentration of these substances (Environmental Health Directorate, 1993). With the exception of pathogenic microorganisms that would be considered as part of the natural organic matter, and toxins that may be produced by certain organisms, most of the other naturally occurring organics do not necessarily pose a serious threat to health. However, they may interfere with treatment processes, act as haloform precursors and cause taste and odour problems (Environmental Health Directorate, 1993).

4.1.1.4 Microbial Challenges. There are a variety of microorganisms that could be found naturally in northern Alberta water bodies. Granted, the levels and strains of microorganisms present are somewhat dependent on the nature and quantity of discharge to the water supply in question (Emde *et al.*, 1994). A list of potential microbial organisms that may be found in NRBS water supplies is in Appendix C. Although some of these organisms originate from municipal or other types of discharges, many of these organisms reach the water body through natural processes.

One natural process that may be responsible for transporting microorganisms into a water supply is from recirculation of organisms entrapped in bottom sediments. This can occur [either from mechanical stirring] or from seasonal water turnover events (Geldreich, 1990).

A storm event is another natural process that can also influence the concentration of microorganisms in raw water supplies. Each storm event brings an elevation in suspended solids, organic demand material and organisms into the water body from erosion type processes in the surrounding drainage basin (Geldreich, 1990). Furthermore, during storms, small amounts of bacterial organisms are contributed by the rainwater itself. The source of bacteria in rainwater is from windswept dust particles that can be carried hundreds of miles in the upper atmosphere until absorbed by the falling rain (Geldreich, 1990).

Probably, the most significant natural reservoir of microorganisms in Northern River Basins waterbodies is wild or domestic animals. Contributions by wildlife in remote areas, such as in many locations in Northern Alberta, tend to be significant (Geldreich, 1972; Emde *et al.*, 1994; Zhou *et al.*, 1995). A good example of a microorganism that can be found in pristine watersheds is the protozoan, *Giardia lamblia*. This is the agent responsible for the wilderness illness that many people call "Beaver Fever". Although, initially beavers were the prime suspect as the reservoir of this organism, other wild and domestic animals also carry *Giardia*.

Based on the extensive list of microorganism found in Appendix C, and based on all of the natural processes just described that can contribute microorganisms to a watershed, it cannot be assumed that pristine protected watersheds away from human influences are free from pathogenic organisms. Therefore, appropriate actions must be taken to ensure safe drinking water is supplied even from *pristine* watersheds.

4.1.2 Agricultural Activities

In the Northern River Basins Study area, considerable agricultural activities are taking place in both the Athabasca River basin and the Peace River basin. Agricultural practices result in the contribution of non-point sources of physical, chemical and microbial pollution into a water system. Because of the large area involved in farming activities, and the diffuse nature of the contaminants, agricultural non-point source pollution is a definite challenge to water quality in the NRBS area.

4.1.2.1 Physical Challenges.

The tilling, or cultivation, of agricultural lands can result in increased erosion into nearby water systems. Uncontrolled grazing or overgrazing by livestock also promotes erosion by eliminating the vegetative layer that deters erosion. The eroded runoff that ensues adversely affects water quality by increasing the colour, turbidity and sediment load in the waterbody (AWWA, 1990). Also, surface runoff also carries with it other inorganic, organic and microbial constituents that may be present in the eroding layer.

4.1.2.2 Inorganic Chemical Challenges. Inorganic chemical contaminants can come from different types of farming. The use of fertilizers in cash crop farming to enhance crop growth adds significant amounts of nutrients to the soil. Hatfield (1993) attributed nitrate-nitrogen levels found in both surface and groundwater supplies to the application of nitrogen containing fertilizers to crops. Other inorganic nutrients are also contributed from fertilizers. Livestock farming also results in the possible contribution of inorganic nutrients. For instance, every gram of cattle manure contains 3.75 mg of nitrogen and 1.15 mg of phosphorus (Hatfield, 1993). As a result, surface runoff from livestock operations can potentially carry large loads of inorganic materials into nearby watersheds from non-point sources such as these.

4.1.2.3 Organic Chemical Challenges.

Agricultural land use results in the input of a wide range of organic pollutants into a water system. Agricultural chemicals such as pesticides and herbicides are toxic to most life forms and can therefore be significant contaminants of groundwater and surface waters (AWWA, 1990; Metcalf and Eddy, 1991). Organic chemicals used in agriculture may make their way into downstream drinking water supplies in several ways. First, surface runoffs containing these pesticides can runoff into downstream water supplies. Second, pesticides and herbicides can percolate through the soil into the underlying groundwater. And third, aerial spraying can lead to direct input of chemicals into water bodies (Manahan, 1991). Generally, watershed protection is preferred over watershed remediation from these chemical organic pollutants. Animal wastes are rich in organic material and non-anthropogenic organic sources such as animal waste can also be contributed to waterbodies as a result of agricultural practices.

4.1.2.4 Microbial Challenges.

The presence of livestock in the NRBS area has a direct effect on the bacterial contamination of the watershed. Feedlots have been shown to contribute significant amounts of fecal coliform bacteria to surface water supplies (AWWA, 1990). It is likely that a wide variety and large numbers of other types of microorganisms are also contributed to water from livestock farming practices. The use of manure as a fertilizer for crops is also a potential source of microorganisms entering NRBS waterbodies as non-point source pollutants.

4.1.3 Municipal Discharges

Human settlements generate human wastes. There are both point source and non-point source municipal pollutants. Sanitary wastewater (sewage) discharges are typically considered point source effluents whereas, leachate from landfills or surface runoff from municipal townsites would be categorized as non-point source discharges. There are both intermittent and continuous sanitary wastewater discharges in the NRBS area. Smaller communities usually have (intermittent) lagoon systems that are discharged once or twice a year, normally in the autumn and/or spring (SENTAR, 1995). The continuous discharging facilities were typically found in the larger towns and villages in the study area. There are a total of 124 intermittent discharging facilities, and 16 continuous discharging sewage treatment plants in the NRBS area (SENTAR, 1995). A discussion of some of the physical, chemical, and microbial challenges to water quality as a result of both point source sewage discharges and other non-point source municipal discharges is presented below.

4.1.3.1 Physical Challenges. The total solids content of wastewater is its most important physical characteristic (Metcalf and Eddy, 1991). As a result of the total solids content, if untreated wastewater is discharged into the aquatic environment (such as with continuous discharging lagoons) the suspended solids can deposit on the streambed and anaerobic conditions can occur (Metcalf and Eddy, 1991). There are also several aesthetic challenges associated with sanitary wastewater discharges. Oil and grease within the sewage can cause unsightly floating matter and films (SENTAR, 1995). Also, the odours in domestic wastewater are distinctive and unpleasant.

4.1.3.2 Inorganic Chemical Challenges. Nitrogen and phosphorus have been identified as two of the most important elements controlling the growth of algae and aquatic plants in surface waters (Water Pollution Control Federation (WPCF), 1983). The total nitrogen concentration in untreated domestic wastewater ranges from 20 mg/L to 85 mg/L and the total phosphorus concentration ranges from 4 mg/L to 15 mg/L (Metcalf and Eddy, 1991). Therefore, even after treatment, the addition of wastewater may cause eutrophication, oxygen depletion in the receiving water, as well as odour problems (WPCF, 1983). Related to this is the surplus of ammonia in municipal sewage. Other inorganic constituents such as chlorides, calcium, sodium, and sulfate are also found in municipal wastewater (Metcalf and Eddy, 1991) from laundering and other domestic activities. Although metals are also present in sanitary wastewater, they are typically removed with the sewage solids during treatment (SENTAR, 1995). The decomposition of domestic wastes results in the formation of hydrogen sulfide and methane (Metcalf and Eddy, 1991). The hydrogen sulfide that is formed has a characteristic rotten egg odour. Finally, inorganic constituents are also contributed to receiving waterbodies from other municipal activities such as runoff from streets and other community areas. Inorganic contaminants that make their way into streams via municipal runoff include metals and salt and other de-icing compounds (AWWA, 1990).

4.1.3.3 Organic Chemical Challenges. Domestic wastewater is laden with organic matter. Metcalf and Eddy (1991) discuss the organics in wastewater as being either *biodegradable organics* or *refractory organics.* Biodegradable organics consist of fats, carbohydrates and proteins and are measured in terms of biochemical oxygen demand (BOD) and chemical oxygen demand (COD) (Metcalf and Eddy, 1991). As a result of the high BOD and COD of sewage, if untreated wastewater is discharged into the aquatic environment, dissolved oxygen levels will become depleted and septic conditions can develop. Refractory organics include detergents, surfactants, phenols and agricultural pesticides (Metcalf and Eddy, 1991; Manahan, 1991). This class of organics are more resistant to conventional treatment. It is interesting to note that the high level of biodegradable organics may result in the production of refractory organics if the wastewater is chlorinated. In other words, trihalomethane concentrations in chlorinated wastewater streams may be high. It is possible that landfill leachate will also contain a level of organic pollutants depending on the type, amount and extent of garbage disposed at the site (AWWA, 1990). Landfill leachate percolation is a particular problem for underlying groundwater supplies if there are any toxic organic (or inorganic) chemical materials being disposed of in the landfill. Once again, it would be remiss to exclude a discussion of the potential organic contaminants that can enter water supplies through surface runoff. Various hydrocarbons such as from automobile fuels may run off into waterbodies.

4.1.3.4 **Microbial Challenges.** Information regarding the microbial characteristics of the sanitary discharges in the NRBS area is very limited and only included total and fecal coliform counts at the most (SENTAR, 1995). It should be emphasized that the total microbial loading from wastewater treatment facilities is significantly greater and much more diverse than would be indicated by these two microbial enumerations. Table 5 lists the types and numbers of microorganisms typically found in untreated domestic wastewater as reported by Metcalf and Eddy (1991).

Table 5. Types and Numbers of Microbes Typically Found in Untreated Domestic Wastewater

Organism	**Concentration** (number per mL)
Total coliform	10^5 to 10^8
Fecal coliform	10^4 to 10^5
Fecal streptococci	10^3 to 10^4
Enterococci	10^2 to 10^3
Shigella	present
Salmonella	10^0 to 10^2
Pseudomonas aeroginosa	10^1 to 10^2
Clostridium perfringens	10^1 to 10^3
Mycobacterium tuberculosis	present
Protozoan cysts	10^{-1} to 10^3
Giardia cysts	10^{-1} to 10^2
Cryptosporidium cysts	10^{-1} to 10^1
Enteric virus	10^1 to 10^2

(Adapted from Metcalf and Eddy, 1991)

From this lis it is apparent that untreated domestic wastewater discharged into a receiving water adds significant microbial challenges to it. Therefore, it is important that sanitary wastewater is properly treated to reduce the microbial levels as much as possible.

4.1.4 Industrial Activities

The industry sector in the Northern River Basins are related to the regions natural resources including forests, coal, tar sands, oil, gas and gravel (SENTAR, 1995). Population centers are often closely tied to the industries that support them. Therefore, discharges of industrial wastewater are often in close proximity to sanitary wastewater discharges (SENTAR, 1995). There is evidence of this relationship in some of the major towns in the NRBS area. For example, Fort McMurray is located near the oil sands developments, and Slave Lake, Whitecourt, Athabasca, Peace River and Grande Prairie are situated near pulp and paper mills (SENTAR, 1995). As a result of proximity, there is an increased potential for cumulative impacts. The physical, chemical and microbial challenges to raw water quality in the Northern River Basins Study area that result from mining, forestry harvesting and pulp and paper mill operations are discussed below.

4.1.4.1 Mining

There are a variety of mining operations going on in the NRBS area, but many of these do not discharge wastewater directly into surface waters. There are four active coal mines located in the western Athabasca River basin (Stanley, 1987). These coal mines do not discharge process wastewaters directly to the surface waters. However, surface runoff from coal mining sites may contain high concentrations of nitrates from explosives (SENTAR, 1995). There are 13 gravel and sand washing enterprises in the NRBS area, but they do not generally discharge effluent (SENTAR, 1995). And there are 37 gas plants in the Northern River Basins with licensed discharges, although none of them directly discharge process wastewater (SENTAR, 1995). There is a possibility that some of the surface runoff from the plants would have elevated sulphates at plants with sulphur blocks (SENTAR, 1995). There are also numerous oil wells in the NRBS area. Although, direct discharges are uncommon from well-designed wells, SENTAR (1995) reported that surface water quality in the Peace River basin may be affected by a flowing abandoned oil well that was found to be discharging into the Peace River during the 1988/89 synoptic survey.

There are a few oil sands operations in the Northern River Basins. Several of them are reported as having no industrial discharge (SENTAR, 1995). There are two oil sand refineries located near Fort McMurray: Syncrude Canada Ltd. and Suncor Inc. Syncrude Canada Ltd. completely recycles the industrial effluents from their operations, so they do not discharge into the Athabasca River. However, mine depressurization and runoff water enters the Athabasca River via Poplar Creek (SENTAR, 1995). Suncor Inc., on the contrary, has a continuous discharge to the Athabasca River and is the only non-pulp mill industrial effluent that discharges a *significant* volume to the Northern River Basins. Therefore, the following discussion on the physical, chemical and microbial challenges to raw water quality will focus on the Suncor Inc. effluent.

4.1.4.1.1 **Physical Challenges.** There are two main physical challenges associated with the discharge of SUNCOR effluent into the Athabasca River. One is the high volume of discharge which averaged 35 000 m^3/day (SENTAR, 1995) that may alter the natural hydrology of the Athabasca River and contribute sediments to the river bed. The second challenge is the odour contributed by the SUNCOR effluent.

4.1.4.1.2 **Inorganic Chemical Challenges.** The Suncor Inc. effluent contributes inorganic chemicals to the Athabasca River. In terms of nutrient loading the only nutrient that is monitored by Suncor Inc. is ammonia nitrogen (SENTAR, 1995). The ammonia nitrogen levels in the treated effluent ranged from 0.02 mg/L to 0.5 mg/L in the period from 1991 to 1993 (SENTAR, 1995) and the total phosphorus levels ranged from 0.168 mg/L to 0.2 mg/L. The average sulphide load in Suncor Inc.'s industrial effluent was 0.06 kg/d; arsenic was 0.01 kg/d, ammonia (as N) was 2.4 kg/d. In terms of the metals, the concentration of metals in the Suncor Inc. effluent is generally low, although the Alberta guidelines for copper, iron, manganese, mercury, selenium and zinc have been exceeded on one or more occasions in the Suncor Inc. effluent (SENTAR, 1995). However, the guidelines apply to ambient water quality and not effluent quality so that once the effluent sufficiently mixed in the stream, the guideline concentration may have been achieved.

4.1.4.1.3 Organic Chemical Challenges. The Suncor Inc. refinery effluent discharges approximately 0.11 kg/day of phenols and 46.1 kg/day of oil and gas (SENTAR, 1995). This phenol discharge is a challenge because phenol can cause taste and odour problems which are enhanced if the water is chlorinated (SENTAR, 1995). The total organic carbon content of the industrial effluent was 8.4 mg/L (SENTAR, 1995), which is less than the TOC found in many natural waterbodies.

4.1.4.1.4 Microbial Challenges. The Drinking Water Component is unaware of any microbiological challenges that are imposed on the Athabasca River as a result of Suncor Inc. discharging its effluent.

4.1.4.2 Forestry Harvesting

Logging is the dominant land use activity in the watershed (SENTAR, 1995). The trees in the NRBS area are logged for pulp and paper applications, as well as for further processing at sawmills, and other types of wood processing. Challenges to raw water quality from the effluent discharges from pulp and paper mills in the study area will be discussed in the subsequent section. Most of the sawmills and other wood processing plants in the area do not discharge effluent to the rivers and if they do, it is only a small quantity of effluent (SENTAR, 1995). Therefore, the assessment of the physical, chemical and microbial challenges to raw water from forestry harvesting practices will be limited to the effects from the harvest itself.

4.1.4.2.1 Physical Challenges. The hydrology of a watershed is affected by forestry harvesting practices. Hydrological responses vary depending on the characteristics of the watershed and forested areas, as well as the amount logged and the layout of the cut. Generally, changes to the water yield and the timing of the runoff are expected (Prepas, 1994). Furthermore, an increased frequency and magnitude of peak flows are also associated with forestry harvesting (Prepas, 1994). Increased sediment loads are associated with the construction and maintenance of roads that come with forestry harvesting (Prepas, 1994). Increased erosion may be a result of unstable streambanks, reduced infiltration into compacted soil and fewer barriers to the eroding material itself. The higher sediment loads in the waterbody likely contributes to increased turbidity, as well as negatively impacting the aquatic environment. The aquatic environment is affected by the reduction of benthic habitats for primary producers (Hansmann and Phinney, 1973) and potential suffocation of developing eggs and fish larvae (Newcombe and MacDonald, 1991) (Prepas, 1994). This is a concern, because a healthy 'waterbody' ecosystem is necessary in the maintenance of a good quality water supply.

4.1.4.2.2 Inorganic Chemical Challenges. A major concern for northern boreal forests is the potential total phosphorus and nitrogen loading to receiving waterbodies following a timber harvest (Prepas, 1994). Increased nutrient yields in stream flows are associated with increased runoff following forestry harvesting, but these results can not necessarily be applied to the NRBS area because these studies were conducted in areas with a different climate, physiography, soils, and forest characteristics than in Northern Alberta (Prepas, 1994). Nonetheless, as a result of the increased runoff discussed above, an increase in the inorganic nutrients carried into the water supply from the natural and anthropogenic activities in the watershed is expected.

4.1.4.2.3 Organic Chemical Challenges. There are both short term and long term challenges to raw waterbodies in terms of the organic chemical constituents affected by forestry harvesting practices. Over the short term, there will be an increase in the organic debris, such as leaves and bark, from logging slash (Prepas, 1994). This increases the dissolved oxygen demand of the water which challenges the ecosystem, particularly in the winter. Furthermore, depending on the system, the increased organics may influence the taste and odour of a nearby drinking water supply, as well as increase possible disinfection by-product precursors in the raw water supply. Over, the long term, there may be a decreased amount of organics contributed to the waterbody from the riparian canopy (Culp and Davies, 1983; Prepas, 1994).

4.1.4.2.4 Microbial Challenges. It has been stated that when the phosphorus concentration increase in a receiving water, the phytoplankton biomass will likely follow suit (Prepas, 1994). Furthermore, it is also possible that increased phosphorus loads to the water will stimulate cyanobacteria growth, particularly if the inorganic nitrogen level is low (Smith, 1983; Prepas, 1994). Therefore, the higher nutrient loading following a forest harvest may translate into changes in the species composition within the waterbody (Prepas, 1994).

4.1.4.3 Pulp Mills. As indicated in Table 6, there are ten pulp and paper mills in the Northern River Basins Study area.

Table 6. Pulp and Paper Mills in the NRBS Area

Company	Location	Type of Mill	Effluent Recipient
ATHABASCA RIVER BASIN			
Weldwood of Canada Ltd.	Hinton	Bleached kraft pulp	Athabasca River
Millar Western Pulp Ltd.	Whitecourt	Bleached CTMP	Athabasca River
Alberta Newsprint Company Ltd.	Whitecourt	CTMP Newsprint	Athabasca River
Slave Lake Pulp Corporation	Slave Lake	Bleached CTMP	Pembina River
Alberta Pacific Forest Industries Inc.	Athabasca	Bleached kraft pulp	Athabasca River
PEACE RIVER BASIN			
Fletcher Challenge Canada Ltd.	Mackenzie	Bleached kraft pulp	Peace River
Finlay Forest Industries Ltd.	Mackenzie	Newsprint	Peace River
Fletcher Challenge Canada Ltd.	Taylor	Bleached CTMP	Peace River
Weyerhaeuser Canada Ltd.	Grande Prairie	Bleached kraft pulp	Wapiti River
Diashowa-Marubeni International Ltd.	Peace River	Bleached kraft pulp	Peace River

Notes: CTMP = Chemithermomechanical pulp mill
(Adapted from Alberta Environmental Protection, 1993; McCubbin and Folke, 1993)

Although the individual processes at each of the mills are distinct, there are two main types of mills listed in this table; bleached kraft mills and mechanical mills. Bleached kraft mills produce bright coloured pulp by using chlorine compounds in their process to bleach the pulp product.

Chemithermomechanical pulp (CTMP) mills and the newsprint mills are both mechanical pulp mills. CTMP mills bleach the mechanical pulps without using chlorine containing products; typically hydrogen peroxide based processes (McCubbin and Folke, 1993). The two newsprint mills manufacture mechanical pulp without using any chemicals at all, except for small amounts of chlorine-free bleaching agents (McCubbin and Folke, 1993). The effluents produced from a given pulp mill depends greatly on the process used and on the treatment applied to the effluent prior to discharge. In the NRBS area, half of the mills are bleached kraft mills and half are mechanical pulping mills. Therefore, in the discussion of the physical, chemical and microbial challenges that follows, reference to both types of mills are made.

4.1.4.3.1 Physical Challenges. Since mechanical pulping processes do not have chemical recovery systems, the BOD and TSS effluent loads are greater than from kraft process plants (Lindsay, 1993). These effluent solids have been known to carry bioaccumulative organic compounds and also may settle out of solution in the receiving stream and form a sludge that is disruptive to the ecosystem (McCubbin and Folke, 1993). However, recent BOD and total suspended solids levels from pulp mills are not as much of a concern as they were in the past, as a result of lower discharge rates and more sophisticated knowledge about environmental impacts (McCubbin and Folke, 1993).

This high colour discharged from pulp mills is considered to be a major aesthetic problem, particularly for kraft pulp mills. The colour of pulp mill effluents has been attributed to the presence of dissolved organic solids (Lindsay, 1993). Highly coloured waters also have non-aesthetic concerns because coloured waters increase the stability of some metallic ions by chelation (Panchapakasan, 1991; McCubbin and Folke, 1993) so that they would not be removed as easily.

Aesthetic concerns have also been raised in terms of taste and odour contributions to receiving waters and ultimately drinking waters. Several researchers reported that bleached kraft mill effluent impairs the taste and odour of drinking water at effluent concentrations ranging from 0.1 to 0.4% (Kenefick and Hrudey, 1994). The compounds in pulp mill effluents that have been attributed to producing odours are sulphite waste liquors, and more recently the potent musty smell of 2,4,6-trichloroanisole that results from the biomethylation of trichlorophenol (Nystrom *et al.*, 1992; Kenefick and Hrudey, 1994). Furthermore, there are also several constituents of pulp mill wastes that have been implicated as possible fish tainting compounds. This too is also an aesthetic concern, particularly to those that consume fish.

Another physical challenge of pulp mill effluents is that they are potential thermal pollutants because pulping processes are carried out at high temperatures and the raw effluent produced also has a high heat content (Lindsay, 1993). Although the warm water are beneficial for biological treatment, it can have a detrimental effect on the aquatic life in the receiving waters (Lindsay, 1993).

Finally, effluent toxicity can also be considered a 'physical' measurement. This is because the entire effluent is tested for toxic effects for a given bioassay. That is, the toxicity of the combined constituents of the effluent, including the inorganic chemicals, organic chemicals, microorganisms that comprise the physical characteristics, is measured. Toxicity tests typically involve observing the effects that occur from submerging aquatic organisms in a whole effluent. There are short term acute toxicity tests to assess lethality, and longer term chronic toxicity tests to determine effects on growth, reproduction, and other abnormalities (Lindsay, 1993). In Alberta, acute toxicity tests are required for all pulp mills (AEP, 1993).

4.1.4.3.2 Inorganic Chemical Challenges. Chlorate is an inorganic concern in the effluent of bleaching mills that use chlorine dioxide, because a certain amount of chlorine dioxide is transformed back into chlorate which in turn is converted to chlorite (Lindsay, 1993). Chlorate can be lethal to an ecosystem and is a human health concern if found in drinking water (Lindsay, 1993). Inorganic sulphur compounds such as sulphate may also be present in effluents from bleached kraft mills. This sulphate can lead to the formation of sulphides under anoxic or anaerobic conditions, which are very toxic (McCubbin and Folke, 1993). However, the pulp mills in the NRBS area have biologically treated effluents that render this contaminant insignificant in their discharges (McCubbin and Folke, 1993).

Pulp mill effluents generally do not have high levels of nitrogen, phosphorus or trace metals (Lindsay, 1993; McCubbin and Folke, 1993). In fact, often nutrient elements are even added to the waste stream to ensure that biological waste treatment processes are optimized (Lindsay, 1993; McCubbin and Folke, 1993).

4.1.4.3.3 Organic Chemical Challenges. Organic solids are a major problem associated with pulp mill effluents for two main reasons. First, high levels of organic solids have the potential to deplete the dissolved oxygen levels in the receiving water (Lindsay, 1993). Second, chlorine compounds that are utilized in bleached kraft pulp mill processes combine with organic materials to produce chlorinated organics.

Table 7 is a list of organic chemicals that may be found or formed in either bleached kraft pulp mills or mechanical pulp mills or both. The chlorinated methanes in Table 7 are principally formed during hypochlorination but the discharge to a receiving water would be limited because these organics would likely be purged to the air during biological aeration (McCubbin and Folke, 1993). The unsubstituted phenolics listed in Table 7 that may be found in either bleached or mechanical operations are easily degradable. However, the more chlorine substitution that occurs (in bleached kraft mills) that more difficult the substance is to biodegrade (McCubbin and Folke, 1993). The chlorine substituted constituents typically originate during the bleaching process but can also be formed at other times. At the same time, unit processes at different stages of the pulping process, such as oxygen delignification, result in the elimination of some of these chlorinated organics. The polychlorinated dioxins and furans listed in Table 7 are also formed in the chlorination stage of the pulping process. 2,3,7,8 TCDD and 2,3,7,8 TCDF are the most toxic and best known of the dioxins and furans (McCubbin and Folke, 1993). Control of the discharge of these substances is imperative for the welfare of the ecosystem and human health. One method of controlling these discharges is by the reduction or elimination of chlorine usage in bleaching. Although some of the resin and fatty acids listed in Table 7 originate as naturally

Table 7. Organic Parameters Found in Pulp Mill Operations

TYPE OF ORGANIC	PARAMETER	Found in Kraft Mills	Found in Mechanical Mills
CHLORINATED METHANES	Methylene Chloride	Yes	
	Chloroform	Yes	Yes
	Bromodichloromethane	Yes	
PHENOLICS	Phenol, guaiacol, syringol and others	Yes	Yes
	2,4-dichlorophenol	Yes	
	2,4,6-trichlorophenol	Yes	
	2,3,4,6-tetrachlorophenol	Yes	
	(2,5-; 3,4-; 4,6-; 4,5-) dichloroguaiacols	Yes	
	(3,4,6-; 3,4,5-; 4,5,6-;) trichloroguaiacols	Yes	
	Tetrachloroguaiacol	Yes	
	Chlorinated catechols	Yes	
	Chlorinated syringols	Yes	
	Chlorinated vanillins	Yes	
DIOXINS AND FURANS	2,3,7,8 TCDD (Dioxin)	Yes	
	2,3,7,8 TCDF (Furan)	Yes	
	Octachlorodibenzo-p-dioxin	Yes	Yes
RESINS AND FATTY ACIDS	Abietic Acid	Yes	Yes
	Chlorodehydroabietic Acid	Yes	
	Dehydroabietic Acid	Yes	Yes
	Isopimaric Acid	Yes	Yes
	Levopimaric Acid	Yes	Yes
	Neoabietic Acid	Yes	Yes
	Pimaric Acid	Yes	Yes
	Oleic Acid	Yes	Yes
	Dichlorodehydroabietic Acid	Yes	
NON-TRADITIONAL PARAMETERS	Steroids	Yes	Yes
	Chelating substances		Yes

(Adapted from McCubbin and Folke, 1993)

occurring compounds that are found in wood, these organics are often responsible for a pulp mill effluent's failure of a toxicity test (McCubbin and Folke, 1993). Also, these resins and fatty acids can add to the solubility of other toxic substances so that toxicity in compounded (Lindsay, 1993). The final organic group listed in Table 7 are miscellaneous non-traditional parameters. Steroids are found in both kraft and mechanical mills. Steroids are present in wood extractives and are suspected to have sub-lethal toxic effects on certain water dwelling animals if discharged in sufficient quantity. Chelating substances may be discharged from mechanical mills that use hydrogen peroxide. This is because chelating agents such as EDTA are used to shield hydrogen peroxide from metallic ions. Fortunately, if a chelating agent, such as EDTA, is discharged with the effluent, it is abiotically degradable (McCubbin and Folke, 1993).

Many of the organic compounds described above have been implicated as possible fish tainting compounds. Kenefick and Hrudey (1994) cite alkylphenols, thiophenol, chlorophenols, guaiacol and catechol, chlorinated acids, phenols, organochlorine compounds, chloroanisoles, and veratroles as organic constituents that may cause off-flavours in fish. Furthermore, microbial metabolism chlorophenols results in the formation of chloroanisoles which are even more likely to cause tainting in fish (Paasivirta et al., 1983). McCubbin and Folke (1993) also mention that natural processes (such as microbial metabolism) can result in the formation of different types of organochlorines than those mentioned in Table 7.

Based on the above discussion and reference to Table 7, it is evident that the discharge of pulp mill effluent would result in a significant organic challenge to the receiving stream, if it was not treated first. However, pulp mills in the NRBS area are required to vigorously treat their wastewaters so that contaminant levels are reduced to the guidelines stipulated in the mills licenses to operate.

4.1.4.3.4 Microbial Challenges. Although *Klebsiella* species have been associated with pulp mill waste (Emde *et al.*, 1994), generally, microorganisms are not a problem affiliated with the discharge of pulp mill wastes.

4.2 TREATED DRINKING WATER

From the above discussion on the challenges to raw water quality from natural sources, agricultural activities, municipal discharges, and industrial activities that take place in the Northern River Basins, it can be said that the raw water source itself can be a challenge to treated drinking water. That is, the characteristics of the raw water supply are one of the determinants of the type of treatment applied to produce a safe supply of potable water for consumers. There are numerous treatment technologies available on the market, and as many configurations of the chosen processes. Although, finished water quality is dependent on the treatment processes chosen, the operation and optimization of the facility are just as critical. Therefore, to ensure a high quality drinking water, the raw water should be of the best possible quality and the operation and the treatment applied should be optimized. As will become evident in the discussion below, many of the challenges can be either exacerbated by poor decisions regarding the treatment or remediated by good decisions and competent operators. For the purpose of this discussion on the physical, chemical and microbial challenges that exist for treated drinking water in Section 4.2 , the focus is on conventionally treated water, as was defined to consist of coagulation, flocculation, sedimentation, filtration, disinfection and distribution steps. A separate discussion of the challenges to distributed drinking water and specifically the challenges to the distribution systems in the Northern River Basins will follow in Section 4.3.

4.2.1 Physical Challenges. There are a variety of physical challenges to treated drinking water. One such challenge is related to the decisions involved in the operation of a drinking water treatment facility. This starts from the time that the raw water supply is selected. The selection of a source water and the treatment processes to be applied often involves balancing economic considerations against raw water quality (Environmental Health Directorate, 1993). For instance, a nearby water sources may be a poor quality one and another source some distance away may be more desirable. It is therefore necessary to balance the costs of transporting and storing water to the costs of doing more extensive treatment (Environmental Health Directorate, 1993). Economic decisions such as these are even more pronounced for smaller communities that are found in the NRBS area because the population base to sustain expensive operations may be insufficient. Related to these economic challenges is the actual operation of the facility once it is constructed. A competent knowledgeable operator is required so that the water treatment processes that are chosen are optimized for the best quality water possible.

There are also physical challenges to treated drinking water that are a factor of the water itself. As discussed above in the section on raw water challenges, cold water in the winter time is a challenge to finished water quality because treatment efficiency of some unit processes is decreased for cold water. Therefore, the plant operator must be aware of the necessary changes to unit processes for cold temperatures. Another physical challenge that acquires more attention than cold winter waters is the aesthetic appeal of treated drinking water. The public demands water that looks and tastes good. Common complaints about treated water are about the taste, colour, odour and appearance. For example, taste, colour and odour in a water supply may be the result of insufficient treatment to remove iron, manganese, hydrogen sulphide or substances from bacteria and phytoplankton (Environmental Health Directorate, 1993). Other times, taste and odour flavours may be the result of the treatment processes themselves manifested in flavours from the chemicals used; such as is the case with chlorine. In any event, consumers generally rate the quality of their drinking water based on the aesthetic characteristics, and since the water treatment industry is ultimately consumer driven, aesthetically pleasing water is necessary.

Turbidity should also be addressed as a physical challenge to treated drinking water. Turbidity on its own does not necessarily result in health concerns. However, turbidity has been shown to limit disinfection effectiveness (Environmental Health Directorate, 1993) and has been related to the effectiveness of the treatment facility in the removal of microbial contaminants (Prince *et al.*, 1995a). Therefore, it is desirable to have the lowest turbidity possible.

4.2.2 Inorganic Chemical Challenges. The inorganic challenges associated with treated water are essentially the same as would challenge raw water. However, the coagulation step in conventional water treatment involves the addition of coagulants. The inorganic coagulants commonly used are the Al^{3+} and Fe^{3+} ions, that are usually added in the form of alum ($Al_2(SO_4)_3^{\Sigma}$ $18H_2O$) and ferric chloride ($FeCl_3^{\Sigma}$ $6H_2O$), respectively (Environmental Health Directorate, 1993). The purpose of the addition of these chemicals is so that they will adsorb to particles to neutralize repulsive charges (Environmental Health Directorate, 1993), thereby promoting the conglomeration of particles. A challenge to this process itself is that it is strongly influenced by pH. Another inorganic challenge associated with the use of alum is that aluminum is contributed to water by this process and some public concern has been raised in this regard. The amount of aluminum remaining in solution depends very much on pH. With effective filtration for particulate aluminum, maintaining the pH within the normal water treatment range should not cause excessive levels of aluminum (Environmental Health Directorate, 1993). In water treatment plants where fluoridation is practiced, there is the potential of complexation of aluminum with fluoride

(Environmental Health Directorate, 1993). The fluoridation process itself can also be an inorganic challenge for treated drinking water. Proper levels of fluoride in drinking water protect consumers against dental caries, but excessive levels have been found to cause adverse health effects (AWWA, 1990).

Some inorganic constituents are formed during disinfection processes in drinking water facilities. Chlorine (the most common disinfectant used in drinking water applications (AWWA, 1990)) disinfection in the presence of ammonia, results in the formation of inorganic chloramines. Generally, the presence of chloramines have not been associated with adverse health effects except for hemodialysis patients (AWWA, 1990). Chlorine dioxide is another disinfectant that can be used in drinking water treatment. Inorganic chlorite, chlorate and chloride are the predominant reaction products associated with chlorine dioxide disinfection (AWWA, 1990). Toxic effects have been attributed to both chlorite and chlorate. In addition to the formation of inorganic material in treated drinking water, other inorganic constituents in water can influence the effectiveness of the disinfection process. For example, the presence of iron and manganese reduces strong oxidizing agents such as chlorine, chlorine dioxide and ozone so that they are less effective (Environmental Health Directorate, 1993).

4.2.3 Organic Chemical Challenges. The removal of organic matter from the raw water is a challenge to treated drinking water because organic material can interfere with the coagulation, flocculation and disinfection processes of conventional treatment (Environmental Health Directorate, 1993). Volatile synthetic organics are difficult to remove because they do not readily adsorb to particles (like the non-volatile organics do) so that they are not efficiently removed by flocculation and filtration and their volatility is not sufficiently greater than water to promote removal by volatilization (Environmental Health Directorate, 1993).

The organic disinfection-by-products associated with the utilization of chlorine in drinking water treatment have been receiving increased attention in recent years. The Environmental Health Directorate (1993) compiled a list of chlorination disinfection-by-products that included a number of haloacetonitriles, haloketones, haloacetic acids, aldehydes, phenols, benzenes, polycyclic aromatic hydrocarbons (PAH's), chlorinated resorcinols, chlorinated cyclopentendiones, furanones and oxo-butanoic acids and trihalomethanes (THM's). Trihalomethanes are a group of chemicals which are characterized by halogen substituted carbon compounds (WHO, 1993). Recent studies have indicated that THMs can account to up to 50% by weight of disinfection-by-products from chlorination (Environmental Health Directorate, 1993). Chloroform is the most commonly occurring constituent of the THMs (WHO, 1993) and has been implicated as a carcinogen (Environmental Health Directorate, 1993). As a result of this, research is being conducted on the utilization of alternative disinfectants in drinking water treatment.

Advanced treatment processes exist such as air stripping, activated carbon adsorption, and membrane processes that can be used to remove many of the organic compounds found in water supplies. However, sometimes process modifications are just as effective and have better economies of scale.

4.2.4 **Microbial Challenges.** There are several microbial challenges associated with treated drinking water. One challenge is that in the GCDWQ, facilities are only required to sample for Total Coliform and Fecal Coliform indicator organisms and for the general bacterial concentration in the form of a coliform bacterial background count or a heterotrophic plate count. With reference to Appendix C, it is obvious that there are many more microorganisms than can be assessed by these indicator assays. The use of coliform bacteria as indicator organisms has been questioned because monitoring for coliform bacteria has failed to prevent waterborne disease outbreaks (Batik *et al.*, 1984). Furthermore, coliform monitoring may not indicate community wide, endemic illness caused by drinking water (Payment *et al.*, 1991) and they have been shown to be inadequate indicators for protozoan cysts and enteric viruses (Sobsey, 1989) suggesting that the current microbial guideline values may not be rigorous enough in terms of protecting public health. The AWWA (1981) recognizes this challenge as well:

> "Coliform organism identification is used as an indication of fecal contamination of water supplies and is widely employed for routine surveillance. Negative results are usually interpreted as assurance that water is free of enteric pathogens. This interpretation must be reevaluated, as outbreaks of waterborne disease have occurred in water systems where coliforms have either not been detected or have not been found to exceed standards."

However, reasons for the limited analyses may be a result of the limitations in microbial detection technology, which can be difficult, expensive, and non-existent for many microbial contaminants (Emde *et al.*, 1994). Therefore, an assessment of the indicator organisms is better than no assessment at all. New strategies to microbial monitoring in drinking water supplies looks at optimizing current treatment processes so that barriers to pathogenic microbes are established and turbidity continues to be one of the most critical parameters in the assessment of treatment process performance.

Another microbial challenge for treated drinking water has to do with the actual removal or inactivation of the microorganisms in the treatment processes utilized. Treatment does not necessarily remove all pathogenic organisms to the same degree that it removes coliforms. For example, viruses can penetrate through rapid sand filters more readily than coliform bacteria and some viruses and cysts appear to be more persistent in water and more resistant to disinfection (Sobsey, 1989; Zhou, 1995). Therefore, depending on the type of microorganism, different challenges occur at different stages in the treatment process. Another microbial challenge related to the treatment process is the practice of recycling backwash water to the front of the plant. This practice has been linked to the transmission of waterborne diseases because pathogenic organisms (especially giardia and cryptosporidium) are effectively removed by filtration. Therefore, cysts removed during filtration become concentrated in the backwash water and eventually, with continuous recycling, the system could become overloaded so that neither filtration nor disinfection would be effective at removing the organisms. Although this process is being phased out, it still occurs in some locations in the NRBS area.

4.3 DISTRIBUTED DRINKING WATER

The maintenance and design of a distribution system is important in delivering high quality water to the consumers. The effort spent on providing the highest raw water quality and providing the highest level of treatment is futile if water quality deteriorates in improperly designed or poorly maintained distribution systems. The distribution systems that exist in the Northern River Basins Study area includes: (1) piped infrastructure systems that deliver water directly to homes; (2) water truck delivery to underground or basement cisterns; (3) water truck delivery to water barrels or other water containing devices; and (4) self hauling of treated water to the point of consumption. The physical, chemical and microbial challenges to distributed drinking water are discussed with reference to particular challenges faced by the study area distribution systems.

4.3.1 Physical Challenges. The cost of distributing drinking water can be high, particularly for some of the remote and scattered communities that may be found in the NRBS area. Piped infrastructure to distant homes is not an economically viable alternative, particularly for small population bases. Therefore water delivery trucks carry truckloads to these locations and fill up cisterns and water barrels. The utilization of cisterns and water barrels means that the supply of water is not 'unlimited' at the point of use such as is the case with piped distribution systems. This is particularly the situation for homes that rely on 45 gallon barrels to suffice their domestic water supply until the next time that the barrel is filled. Health data indicate that a minimum of 90 L of water per person per day is required to maintain health (Brocklehurst *et al.*, 1985) and this would not be satisfied for families using barrels. Brocklehurst *et al.*, (1985) state that "any trucked delivery system to small barrels, tanks or pails is insufficient in terms of health, and does not provide a sufficient quantity of water."

Taste and odour problems can also occur as a result of the distribution of drinking water. Leaching of metals from pipes and reservoirs can cause flavours in water and also some potential health concerns. Stagnant waters in cisterns and barrels may also develop tastes and odours from leaching or from the growth of yeasts and molds if the disinfection residual is inadequate.

4.3.2 Inorganic Chemical Challenges. Corrosion is a great challenge to drinking water distribution systems. Although corrosion is not solely a function of inorganic chemicals, the inorganic properties of the water are one of the factors that influence corrosion. Physical and biological factors are also influential. In other words, the corrosive tendency of water is dependent on physical, chemical and microbial characteristics in the distribution system as well as the nature of the material that is contacted (AWWA, 1990). In any case, dissolved substances in water have an important effect on corrosion (AWWA, 1990). An increased rate of corrosion is expected in waters which have: (1) low pH; (2) high dissolved oxygen; (3) high chlorine residuals; (4) high TDS; (5) the presence of chloride or sulfate or hydrogen sulphide; (6) corrosion enhancing biofilms attached to the distribution network; and (7) high velocities especially at sites of a change of direction (AWWA, 1990). On the contrary corrosion rates are expected to be less when the water has the following characteristics: (1) pH is high; (2) alkalinity is low to moderate (although high alkalinity may promote corrosion); (3) hardness is present so that calcium carbonate is precipitated; and (4) phosphate containing substances form protective films (AWWA, 1990). It should be noted that some parameters can either protect pipes from or promote corrosion. Examples of this are metallic components. Iron, zinc and manganese have been found to form protective coatings, while copper has been found to cause pitting which is a form of corrosion (AWWA, 1990). Although the deposition of solid precipitates such as calcium carbonate protects surfaces from corrosion, too much of a deposit can constrict flow. This is especially likely in waters in which the facility practices water softening. Therefore, although the water utility does not desire corroded pipes, plugged pipes are also undesirable. As a result a number of corrosion indices have been developed in an attempt to characterize corrosion potential of a water supply (Environmental Health Directorate, 1993). Although these indices are useful measures that indicate corrosivity, careful monitoring of the distribution system itself is still necessary.

4.3.3 Organic Chemical Challenges. While natural colour and organic matter can decrease corrosion by coating pipe surfaces, other organics can also complex metals and accelerate corrosion (AWWA, 1990). Another organic chemical challenge to distributed water is that undesirable organic components of pipes, coatings, linings and joint adhesives, such as polynuclear aromatic hydrocarbons, have been shown to leach into water during the transmission of drinking water (AWWA, 1990).

4.3.4 Microbial Challenges. Pathogenic microorganism contamination can occur after water leaves the treatment plant. This may occur through contamination of the safe drinking water supply by a source of contamination such as backflow in a water supply line, or regrowth of microorganisms in water distribution systems (Zhou *et al.*, 1995). Backflow, or cross-contamination, is a design problem or can be the result of deteriorating infrastructure. Regrowth of microorganisms can occur as a result of insufficient residual chlorine concentration in the distribution system or the eventual consumption of the residual chlorine from chlorine demanding substances in stagnant waters such as at end points in pipes or perhaps from water that has been in a water barrel or cistern for a lengthy period of time.

The growth of microorganisms within distribution systems is a microbial challenge that results in the deterioration of the water quality. Microorganisms have the ability to attach to solid surfaces such as particulates, submerged pipes, storage reservoirs, filter media etc (Emde *et al.*, 1994). This ability to attach, or the formation of biofilms, allows the microorganisms to take advantage of increased nutrient levels at the solid-liquid interface (Costerton, 1987). Emde *et al.*, (1994) suggest that the problems associated with the formation of biofilms are related to public health concerns that occur as a result of:

1. an increased resistance of attached organisms to disinfectants and chemicals (Costerton *et al.*, 1987);
2. possible harboring and eventual shearing off of pathogens into the treated water (Emde and Smith, 1992); and
3. water quality changes that result from the addition or removal of chemicals and microorganisms from the bulk water phase (Emde and Smith, 1992).

An effective means to try to control biofilm development is through a distribution system flushing program. Also, in areas where water distribution trucks carry water to barrels and cisterns, regular disinfection of the water containers (truck, barrels and cisterns) should be carried out.

In summary, challenges exist for raw water supplies in the Northern River Basins Study area as well as for the treated water and the distributed drinking water supply. The protection of the raw water source and the proper and optimal treatment and distribution of drinking water should provide high quality drinking water for people in the NRBS area.

5.0 AESTHETIC QUALITY OF DRINKING WATER IN THE NORTHERN RIVER BASINS

Taste, odour, turbidity, colour, hardness, and staining comprise some of the aesthetic components of drinking water (Tate and Arnold, 1990). Basically, the aesthetic quality of drinking water is the perception of how water looks, tastes, smells and feels to the consumer; hence, the sensory perception of drinking water. It is essentially this sensory evaluation of drinking water that is used as the basis by which consumers judge the safety of their drinking water. Generally, the turbidity, colour, hardness and staining are physically and visually troublesome in drinking water. Tastes and odours are somewhat different and are the sensory evaluations of off-flavours (perceived "bad" tastes and smells) in drinking water. Tastes are accumulations of a group of sensory responses from olfactory receptors in the upper nasal cleft, gustatory receptors on the tongue and other skin receptors throughout the nasal cavity. Taste receptors allow for the perception of four basic taste qualities: salt, sour, sweet and bitter (Montgomery, 1985). The perception of odours is a much more sensitive mechanism and is a result of messages sent to the olfactory bulb in the brain through nerve fibres whose ends are located in the olfactory epithelium at the roof of the nasal cavity (Montgomery, 1985). There are two theories about exactly how odours are perceived. One is that similar odours have similar shapes and there are receptor sites in the nose that have corresponding depressions or slots where molecules can attach. The other theory is that the olfactory epithelium functions as a gas chromatograph distinguishing between various compounds (Montgomery, 1985). Whatever the mechanism, the aesthetic qualities of a water supply are important in a consumer's judgement of the effectiveness of the water utility in supplying safe drinking water.

As has been mentioned in the previous section, the aesthetic quality of a water supply is affected by both natural and anthropogenic influences. Figure 11 is a schematic of the natural and man-made sources of taste and odour in water that play a role in the study area. In this classification by Lin (1976), tastes and odours in water are either natural or man-made or a combination of both. Lin points out that off-flavours result from the presence of gases, salts, minerals, aquatic organisms, industrial discharges, wastewater effluent, non-point source run-off, the water treatment process itself and organisms in the distribution system. Lin also points out that naturally occurring taste and odour compounds are the most common, but objectionable situations as a result of man-made sources of tastes and odours are often the most troublesome (Kenefick and Hrudey, 1994).

One of the greatest limitations in the assessment of tastes and odours in water is that since the perception of tastes and odours is largely subjective, there are varying descriptors used by different individuals. This is particularly the case for human sensory analyses, but it should be noted that there are also more quantitative assessments using analytical instruments for the assessment of taste and odour compounds in water samples. Further discussion of the analytical methods will be discussed separately. In order to establish some consistency within the analyses of water samples by trained off-flavour analyzers, "flavour wheels" have been established to aid in the characterization of natural waters (Kenefick and Hrudey, 1994). The flavour wheel prepared by the International Association on Water Pollution Research and Control presented in Figure 12 is the most current one used in the industry. In this wheel, the compounds listed on the outside are some of the possible causes for the taste and odour descriptors shown. However, these lists are not intended to be inclusive, especially given the large number of possible odour causing chemicals (Kenefick and Hrudey, 1994).

A brief review of some of the taste and odour producing compounds that may be found in the Northern River Basins Study area from both natural and anthropogenic activities follows. A summary of some of the naturally occurring odours that may be found in the Northern River Basins is discussed below followed by a discussion of some of the man-made odourous compounds that may be found in the NRBS area.

Table 8 is a compiled list of the odour descriptor and associated microorganism responsible for some of the naturally occurring biological odours in water.

Table 8. Biological Sources of Taste and Odour in Water

Organism	Odour Descriptor
green algae	grassy, musty, fishy
blue-green algae	grassy, vegetable, earthy, musty, rotten, sulphur
diatoms	spicy, geranium, grassy
flagellates	cucumber, fishy, violet, musty, grassy
fungi	earthy
bacteria	sulphur, rotten egg
actinomycetes	earthy, musty, potato-bin

(Adapted from Kenefick and Hrudey, 1994)

Some of these same microorganisms are responsible for the production of other odour causing compounds.For example, geosmin, 2-methylisoborneol (MIB) b-cyclocitral, hydrocarbons, aromatics, fatty acids, amines, sulphur compounds, terpenoids, esters, 3-methylindole, dimethyl trisulphide, dimethyl tetrasulphide, dimethyl pentasulphide, methylmercaptan, dimethyl sulfide, isobutyl mercaptan, butyric acid among numerous others are reported to be a result of natural microbial processes (Kenefick and Hrudey, 1994). Non-caretenoids, unsaturated hydrocarbons, aldehydes, ketones, alcohols, thio compounds, terpenoids, phenols, and aromatic hydrocarbons were

Figure 11. Sources of Taste and Odour in Water (Lin, 1976)

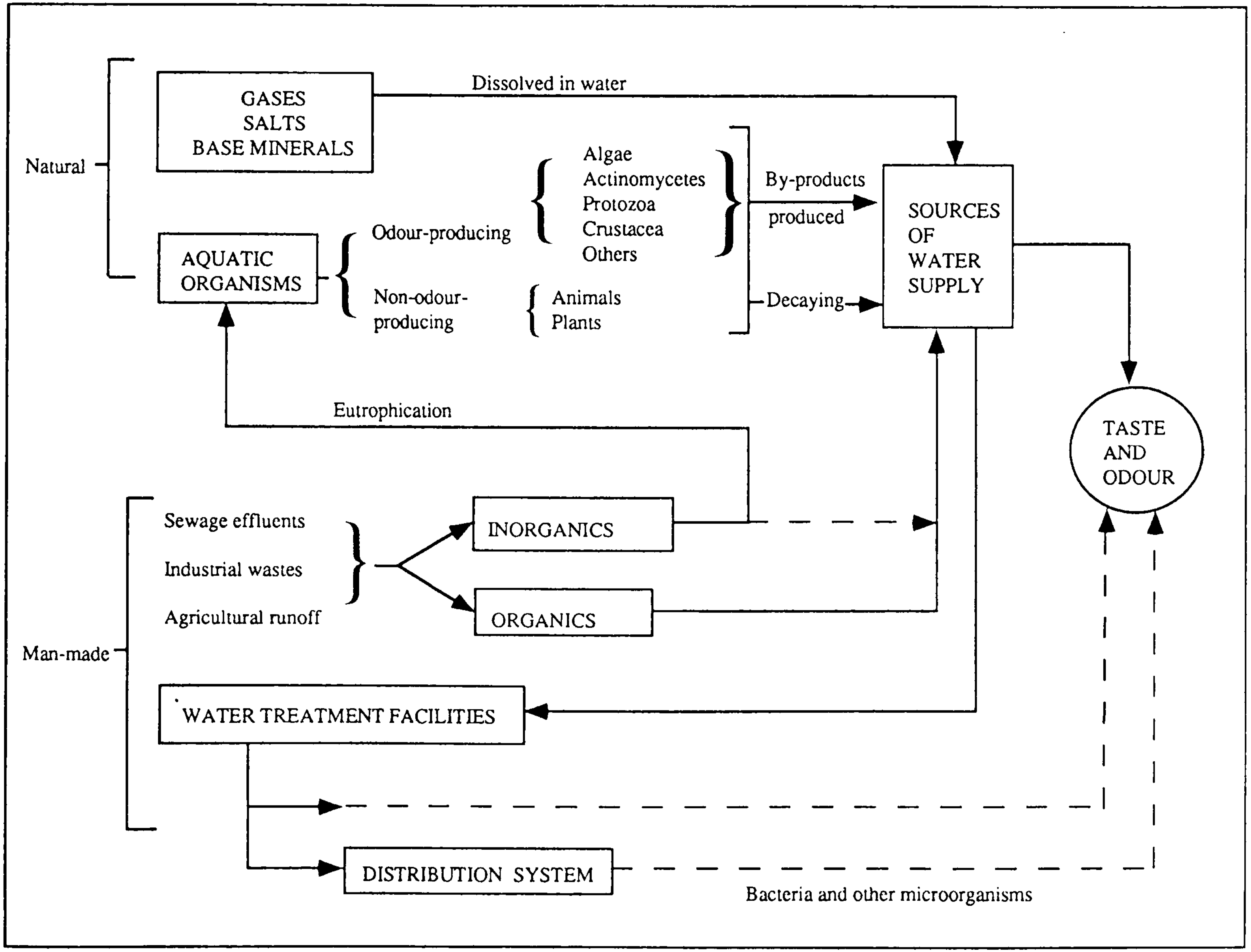
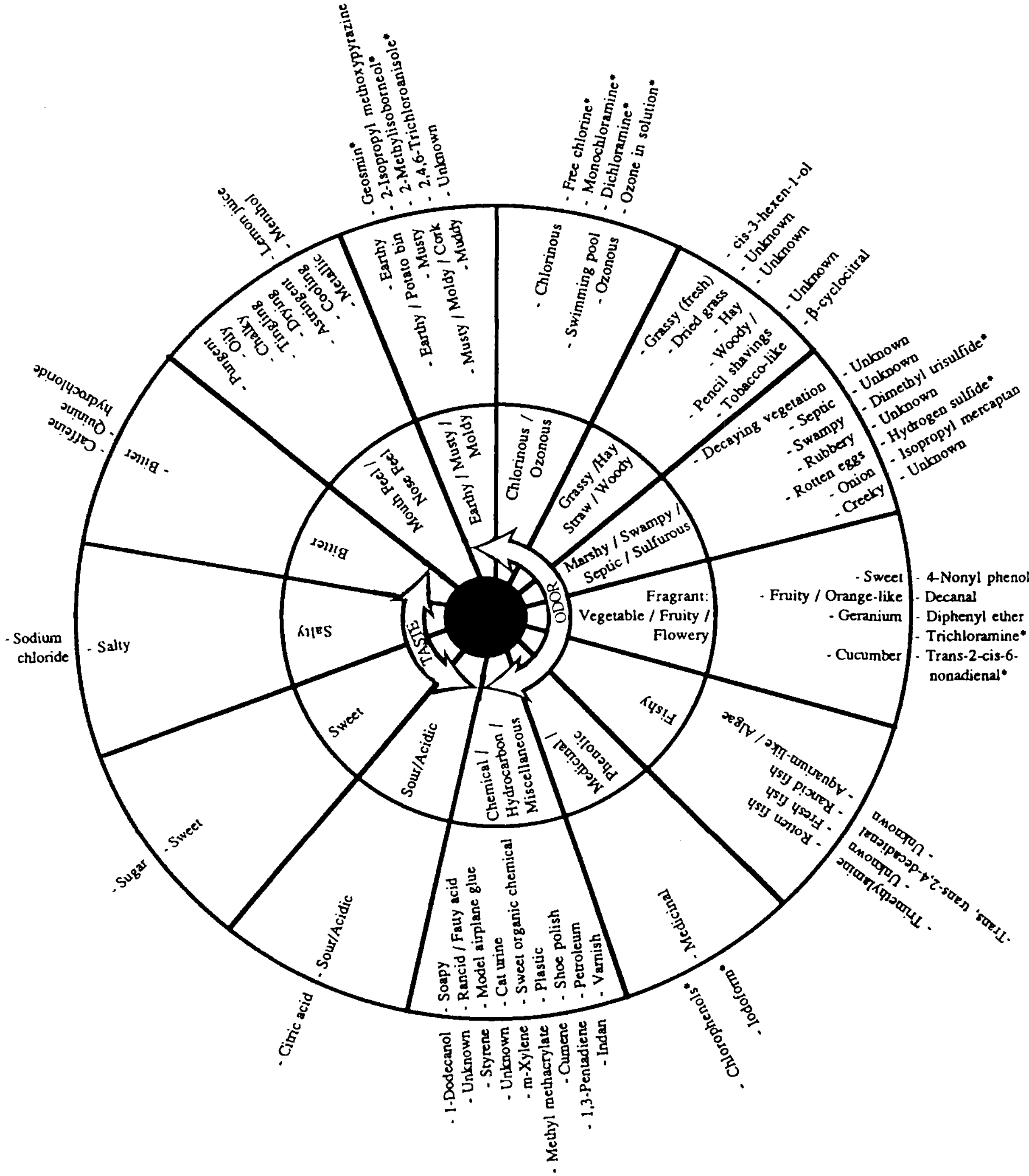


Figure 12. Flavour Wheel



listed by Jüttner (1988) as biogenic odourful compounds. Geosmin and MIB have been targetted by numerous researchers as primary naturally occurring taste and odour imparting substances in water (Kenefick and Hrudey, 1994). Inorganic chemical constituents have also been found to emit odours. An example is the natural presence of hydrogen sulphide (Lin, 1976) that has a distinctive rotten egg odour. Metallic elements also have distinctive odours such as the ferric smell associated with iron. Once again, the list presented of naturally occurring flavourful compounds is not exhaustive. Nonetheless, it is included to provide informational background for further discussion of tastes and odours in water.

The anthropogenic sources of off-flavour compounds that may be found in water is just as extensive as the naturally occurring ones. The anthropogenic challenges to water quality presented in Section 4.1 were from agricultural activities, municipal discharges, industrial effluents and the water treatment process itself. In addition to the physical, chemical and microbial challenges that takes place, each of these activities also contributes off-flavours to raw water supplies. A brief discussion of the potential taste and odour imparting substances from agriculture, municipal activities, industry in the area and water treatment follows. First, in terms of agricultural activities, pesticides and pesticide constituents may contribute to off-flavours. Second, municipal discharges also impart taste and odour substances to water supplies. Hydrocarbons and phenolics from street runoff and the presence of phenols, aromatic hydrocarbons, chlorinated anisoles and other chlorinated organics have been associated with intense odours from municipal sewage effluents (Kenefick and Hrudey, 1994). Third, the specific compounds responsible for off-flavours in waters as a result of pulp mill discharges are not well understood (Kenefick and Hrudey, 1994). Based on the results presented by Kenefick and Hrudey (1994), possible tainting compounds from pulping effluents include: chlorinated phenols, chlorinated guaiacols, dichlorovanillin, chlorinated catechols, chlorinated syringols, chlorinated syringaldehydes, chlorinated acids, phenols, anisoles, and veratroles and possibly odourous organosulphur compounds. Other studies have found that although chlorinated phenolics themselves are not expected to contribute off-odours to recipient waters, but the microbial metabolism of chlorophenols results in the formation of chloroanisoles which are much more odourous and more likely to cause tainting. Finally, there are also many taste and odour problems associated with drinking water treatment processes. Intense odours develop are a result of the compounds formed during oxidative reactions in the disinfection practice (Kenefick and Hrudey, 1994). Also, it has long been known that the chlorination of raw water supplies has been found to magnify taste and odour problems as a result of the formation of chlorinated phenols from the trace levels of phenols found in raw water and the magnification of other off-flavours in water. Furthermore, rubber, polyurethanes, epoxydic resins and polyvinylchloride pipes found in distribution systems can also contribute (from oxidation and by release of additives) to off-flavours in drinking water.

From the above discussion on the potential naturally occurring and anthropogenic sources of taste and odour compounds, the type and number of such compounds in any given supply would be difficult to determine and characterize with certainty This is especially true because combinations of odourous compounds can result in interactions between the odours and the resulting odour is often greater than the sum of the components (Rosen *et al.*, 1963). This phenomenon is known as odour synergism (Kenefick and Hrudey, 1994). Nonetheless, efforts to determine and characterize off-flavours in water continues and there are several methods used in such characterizations. The review by Kenefick and Hrudey (1994), Study of Water and Fish Tainting in Northern River Basins - A Review, discusses a number of analytical and sensory methods used in the study of taste and odour. Interested readers are referred to this document for more information about each of them. However, a brief summary of the analytical and sensory methods employed by the Drinking Water Component in the assessment of the aesthetic quality of water in the NRBS area are briefly described.

The purely sensory evaluation of water samples was carried out using the Flavour Profile Analysis (FPA) procedures in Standard Methods (APHA, 1992). This method involves having a trained panel of three to eight people evaluate the sensory (odour) characteristics of the water using intensities and odour descriptors such as those found in the flavour wheel in Figure 12. The second method used by the Drinking Water Component in the analytical assessment of odours was closed loop stripping analysis (CLSA) extraction followed by gas chromatography with mass selective detector (GC-MS) for selected ions. The third method used integrates both sensory and analytical components and is called olfactory gas chromatography (OGC). In olfactory GC analysis, a trained operator injects the sample into the GC and continuously monitors (i.e. sniffs) an outlet port recording elution time, intensity and odour description for each "peak." Each of these methods have their limitations, but each provides valuable information about potential off-flavours in drinking water. The results obtained in the Pre-AlPac and Post-AlPac sampling will be discussed with reference to these methods.

5.1 ANALYTICAL ASSESSMENT

The focus of the Drinking Water Component's analytical assessment of the aesthetic quality of water in the NRBS area was on the Athabasca River. At the onset of the study in 1993, the Athabasca River received point source effluents from the Hinton bleached kraft mill, three CTMP mills (Alberta Newsprint; Millar Western; Slave Lake Pulp), the Suncor oil sands extraction and upgrading plant and numerous municipal effluents. Prior to the second half of the study in 1994, the Alberta Pacific Forest Industries (AlPac) bleached kraft mill came on stream. Therefore, one of the objectives of this study was to assess the impact that the second kraft mill had on the Athabasca River.

Samples collected during both the pre-AlPac and post-AlPac phase of the study included industrial effluent samples, municipal effluent samples, tributary, mainstem Athabasca River and treated water samples as listed in Table 9 and illustrated in Figure 13. The pre-AlPac samples were collected in February and March, 1993, and the post AlPac samples were collected in February and March, 1994. All of the water and effluent samples were collected at the time of travel of the Athabasca River. The collection of samples during the winter time represents worst case conditions due to the ice cover and low river flows.

These results for both the Pre and Post AlPac sampling are summarized below in terms of the findings from the: (1) CLSA/GC-MS analyses; (2) olfactory GC analyses; and (3) flavour profile analyses. The target odour compounds assessed for by the CLSA/GC-MS method included:

- 1-clorodecane (internal standard)

- 2-isopropyl-3-methoxy pyrazine (IPMP)
- 2-isobutyl-3-methoxy pyrazine (IBMP)
- 2-methylisoborneol (MIB)
- 2,4,6-trichloroanisole (2,4,6-TCA)
- 2,3,6-trichloroanisole (2,3,6-TCA)
- geosmin
- 3,4,5-trichloroveratrole (3,4,5-TCV)

These compounds were chosen on the basis that they are known odour compounds (Kenefick *et al.*, 1994a).

5.1.1 Pre-AlPac

The CLSA analytical results from the Pre-AlPac aesthetic assessment demonstrated a number of trends. None of the target compounds were detected upstream of Hinton. Downstream of the combined effluent discharge at Hinton, 3,4,5-TCV was detected in mainstem samples all the way to the Firebag River. 3,4,5-TCV was also detected in the Fort McMurray raw and treated water samples. Most of the mainstem samples also showed the presence of geosmin (biogenic sources) and 2,4,6-TCA. The tributary samples generally contained less odour causing compounds than the mainstem and in most cases, only geosmin was detected. Most of the target odour compounds were not detectable in the diluted effluent samples collected. CLSA/GC-MS results for the mainstem and tributary samples are presented in Figure 14 and 15 respectively. These CLSA/GC-MS results were confirmed by running total ion chromatographs on each samples, whereby similar trends were observed.

Results from the OGC analyses showed the presence of moderate to strong 2,4,6-TCA odours in mainstem Athabasca River samples (including the site upstream of Hinton) all the way to the Firebag River and 3,4,5-TCV showed up occasionally at weak to moderate intensities. There were also two unidentified musty cork odour peaks that showed up consistently at weak to moderate intensities and there were both a sulfur and crude oil smells that were strong in the upper reaches but diminished by Fort McMurray. There were also a variety of other miscellaneous odour peaks that did not occur in a consistent pattern. Tributary samples had fewer and less intense odour peaks than the mainstem samples. Odours detected in the Hinton combined effluent sample included the pyrazine (IPMP and IBMP), and unidentified compounds with sulphurous and musty cork odours. A woody, sewage and spicy odour was also detected by one analyst. The municipal wastewater effluents were low in target odour peaks but waxy, flowery, soapy, woolly, spicy, cucumber smells were reported for these effluents. The CTMP mill effluents were all low in odour peaks and the treated drinking water samples had few low intensity peaks. It was determined in this OGC analysis that the analysts demonstrated that some odour peaks were identified by OGC analyses but not by instrumental flame ionization, thereby verifying the greater sensitivity of the human nose (Kenefick *et al.*, 1994a).

The flavour profile analysis exploits the sensitive human nose as a detector. The flavour panel results indicated that the Hinton combined effluent is likely the dominant source of odour in the mainstem Athabasca River from Hinton to upstream of Smith. Descriptors used to describe the Hinton combined effluent included: rancid, sewage, decay, woody, pulp and paper, swampy and earthy.

Table 9. Pre-AlPac and Post Al-Pac Aesthetic Assessment Sample Information

Time of Travel (days)	Code	Site	Type of Sample	Pre-AlPac Sample	Post-AlPac Sample
1	ARHWY40	Entrance	Mainstem	Yes	Yes
1	HCEFF	Hinton Combined Effluent	Combined Sewage and Bleached Kraft Effluent	Yes	Yes
1	AROBED	Obed	Mainstem	Yes	Yes
3	ARUSBERL	Upstream of Berland River	Mainstem	Yes	
3	BERLAND	Berland River	Tributary	Yes	
5	ARWFALL	Windfall	Mainstem	Yes	Yes
5	ANCEF	Alberta Newsprint Effluent	CTMP Effluent	Yes	Yes
6	MCLEOD	McLeod River	Tributary	Yes	
6	MWEF	Millar Western Effluent	CTMP Effluent	Yes	Yes
6	WCSTPEF	Whitecourt Sewage Plant	Sewage Effluent	Yes	Yes
6	ARBLUER	Blue Ridge	Mainstem	Yes	Yes
12	ARUSPEMB	Upstream of Pembina River	Mainstem	Yes	Yes
12	PEMBINA	Pembina River	Tributary	Yes	Yes
14	ARUSSMTH	Upstream of Smith at Highway 2	Mainstem	Yes	Yes
14	LESSERSL	Lesser Slave River near Athabasca River confluence	Lake Sample	Yes	Yes
14	SLPEF	Slave Lake Pulp Effluent	CTMP Effluent	Yes	Yes
18	ARATHA	Athabasca	Mainstem	Yes	Yes
18	ATHSTPEF	Athabasca Sewage Plant	Sewage Effluent	Yes	Yes
19	ARUSALPA	CUpstream of AlPac	Mainstem		Yes
19	ALPACEFF	AlPac Effluent	Bleached Kraft Effluent		Yes
22	ARUSLAB	Upstream of LaBiche River	Mainstem		Yes
22	LABICHE	LaBiche River	Tributary		Yes
23	ARLMM	Upstream of Lake McMillan	Mainstem		Yes
25	ARUSHOUSE	Upstream of House River	Mainstem		Yes
25	HOUSE	House River	Tributary		Yes
25	ARUSGR	Upstream of Grand Rapids	Mainstem	Yes	
26	ARDSGR	Downstream of Grand Rapids	Mainstem	Yes	
29	ARUSFMCM	Horse River Upstream of Fort McMurray	Mainstem	Yes	Yes
29	FMCMRAW	Fort McMurray Raw Water	Raw Drinking Water	Yes	Yes
29	FMCMFIN	Fort McMurray Finished Water	Finished Drinking Water	Yes	Yes
29	FMCMSTP	Fort McMurray Sewage Effluent	Sewage Effluent	Yes	Yes
30	CLEARWAT	Clearwater River	Tributary	Yes	Yes
30	SUNCOREF	Suncor Effluent	Oil Sands Effluent	Yes	Yes
32	ARUSFRBG	Upstream Firebag River	Mainstem	Yes	Yes
38	LAKATHFC	Lake Athabasca off Fort Chip	Lake Sample	Yes	
38	ARBIGPCM	Upstream of Big Point Channel Mouth	Mainstem		Yes
38	FCHIPRAW	Fort Chip Raw Water	Raw Drinking Water		Yes
38	FCHIPFIN	Fort Chip Finished Water	Finished Drinking Water	Yes	Yes

The codes in this table correspond with the sites sampled in the map in Figure 13.

Figure 13. Aesthetic Assessment Sampling Map

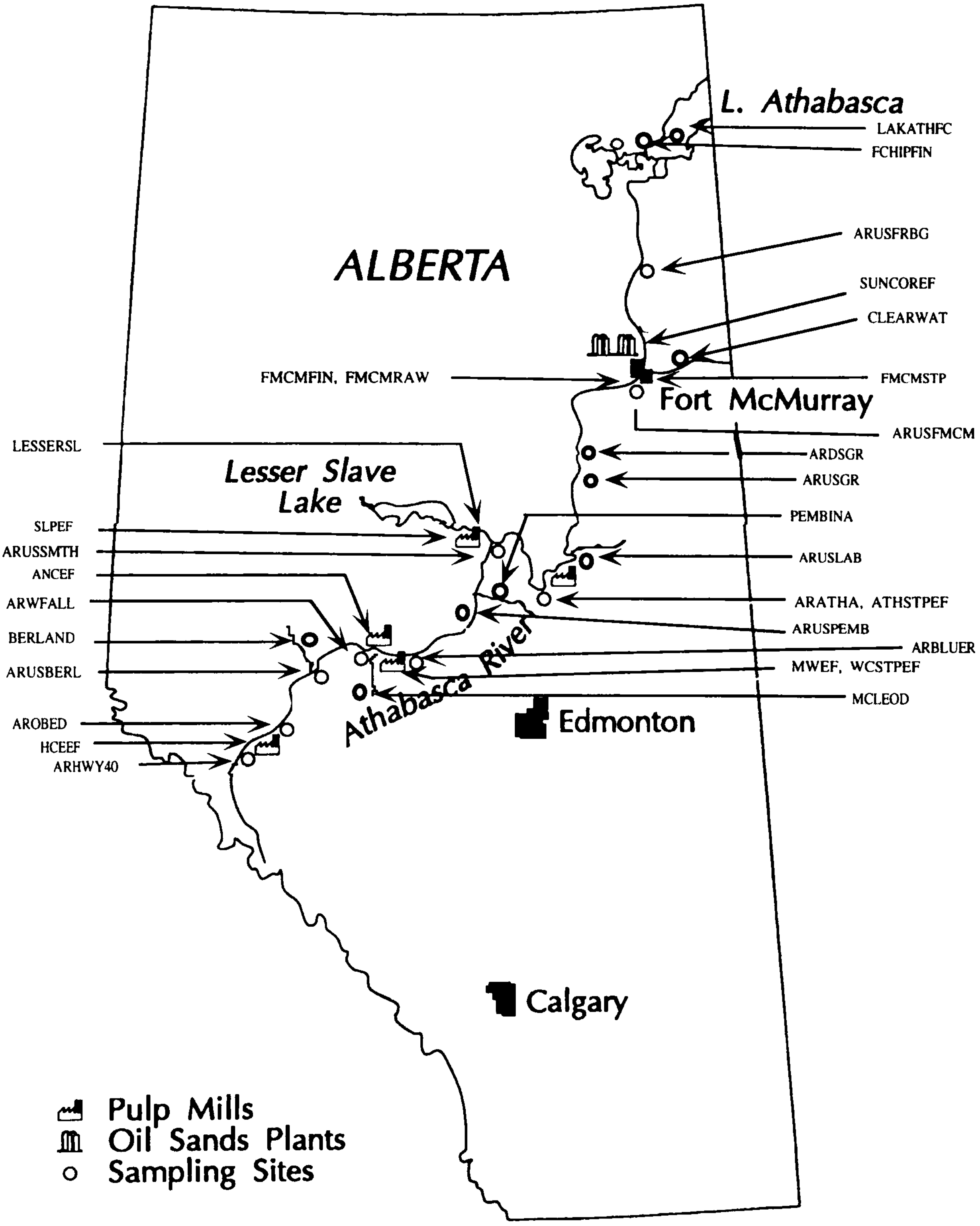


Figure 14. CLSA/GC-MS Results for Pre-AlPac Mainstem Athabasca River Samples

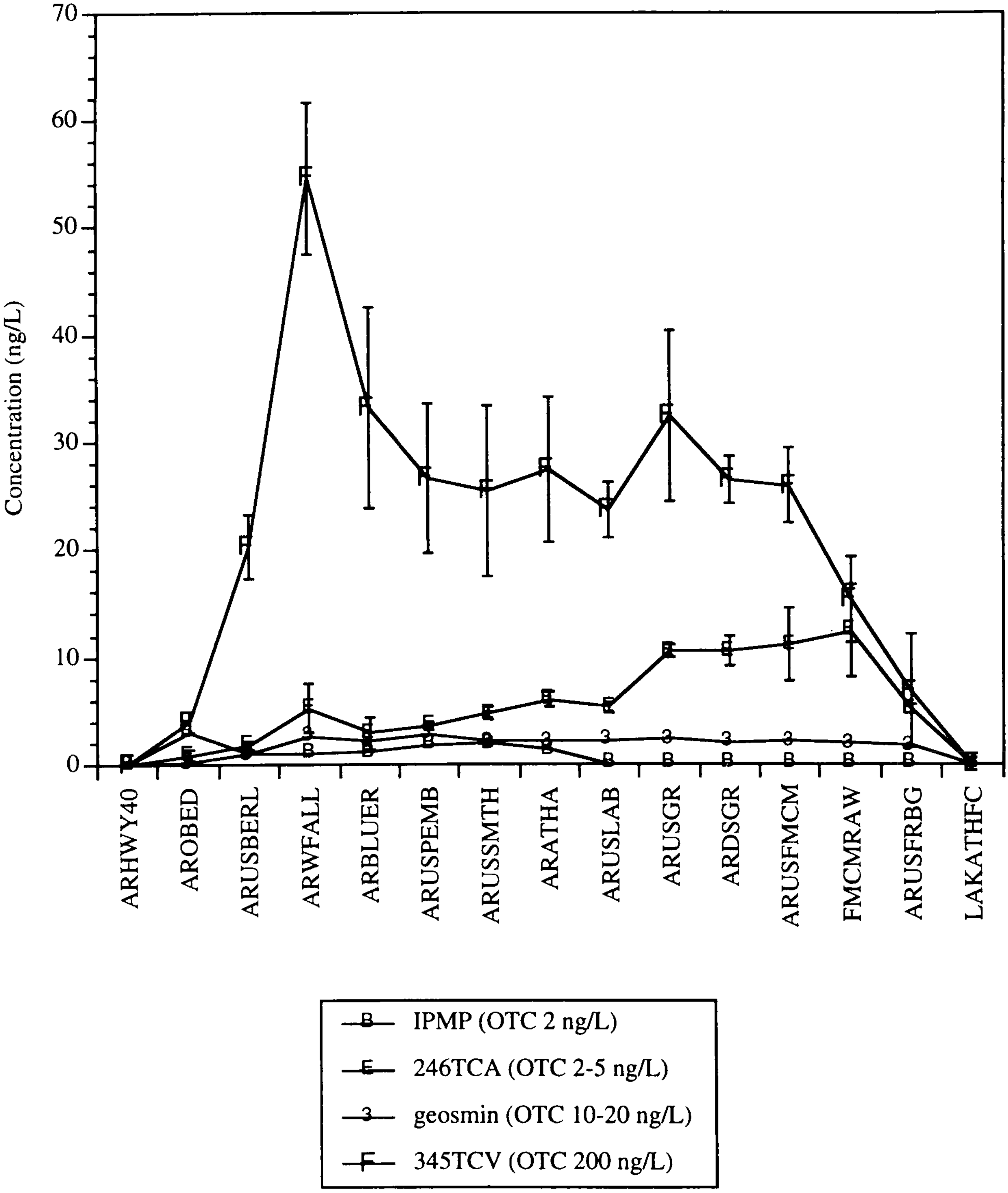
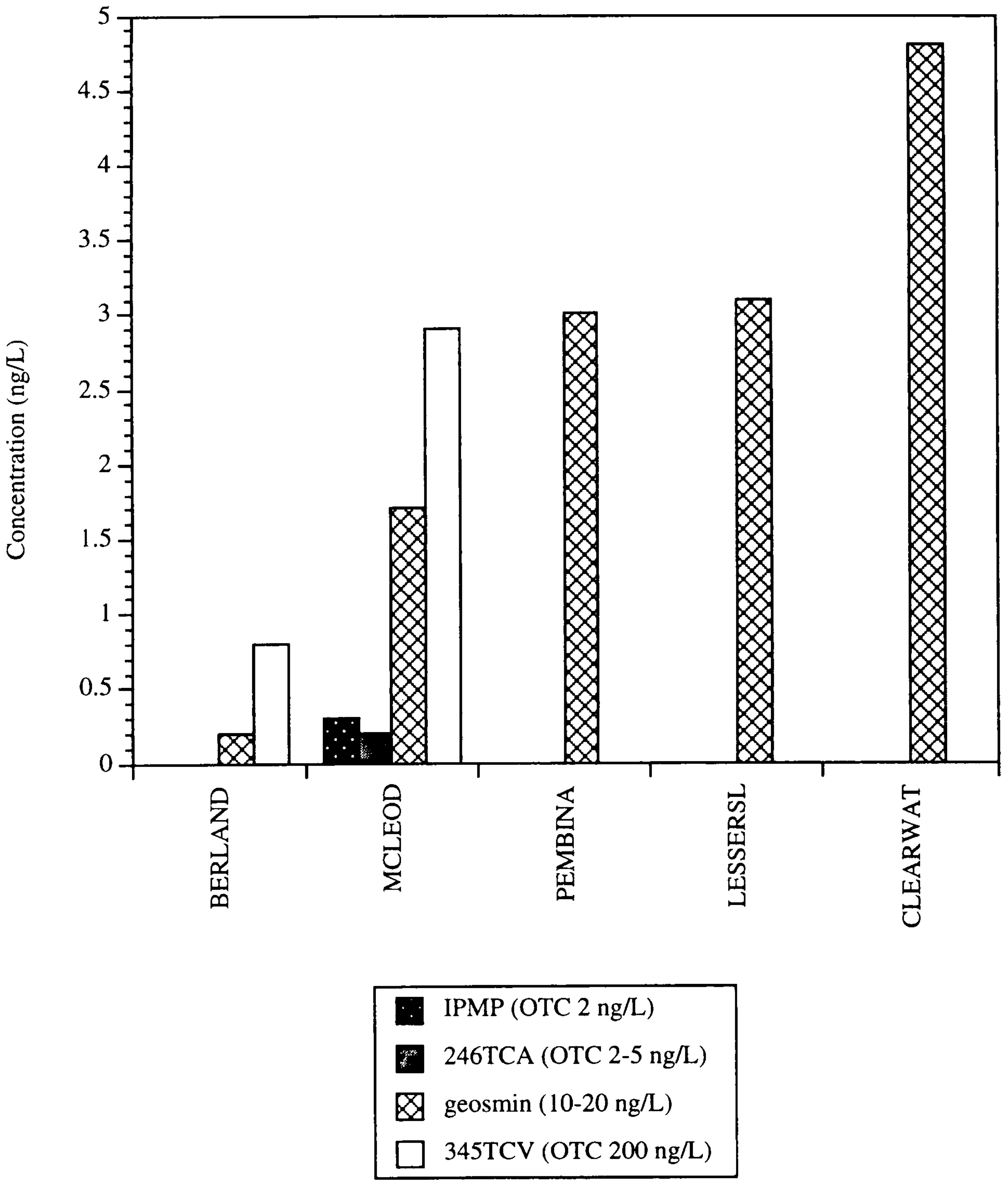


Figure 15. CLSA/GC-MS Results for Pre-AlPac Tributary Samples



The other types of effluent samples were found to be slightly more odourous than tributary samples. The Suncor effluent was recognized by the flavour panel as having a particularly distinctive and relatively strong odour. However, with the exception of a possible sulphur descriptor, the impact on the Athabasca River from the Suncor effluent is uncertain. The treated water samples assessed by the FPA had strong chlorine odours that would have masked any other subtle odours that may have been present.

Table 10 summarizes the results from the Pre-AlPac odour assessment for each analytical method applied in terms of the kilometers downstream from the Hinton combined effluent discharge and presents the data in a concise format so that the results from the Pre-AlPac sampling can be compared with the results from the Post-AlPac sampling.

5.1.2 Post AlPac

The Post AlPac sampling schedule was carried out in February and March 1994 after the Alberta Pacific Forest Industries bleached kraft mill came on stream and also after the Hinton bleached kraft mill altered their process so that more condensate was recovered and the bleaching process was changed to 100 % chlorine dioxide substitution from 45 % (Kenefick *et al.*, 1995). Both were influential factors in the aesthetic assessment of water in the Athabasca River basin.

A summary of the results obtained from the Post Al-Pac odour analysis of the mainstem Athabasca River upstream and downstream of both mills is presented in Table 11. The comparison of the results presented in Table 10 and Table 11 allows for anassessment of the odour profile changes that occurred in the duration between the two sampling periods. The results from the Post-Al-Pac sampling session will be discussed in terms of the changes that took place between 1993 and 1994.

The flavour profile results were similar between the two years except that the Hinton Weldwood effluent odour was less intense and the descriptors changed to include woody and resinous (Kenefick *et al.*, 1994b). The AlPac effluent had an odour described by the flavour panel as rubber, chemical, muddy, musty, nutty and earthy that was similar to the Hinton combined effluent odour but less offensive (Kenefick *et al.*, 1994b). The FPA results for all of the samples collected in the Post-AlPac sampling session are included in Appendix E with the Pre-AlPac results. The results for the samples other than collected on the mainstem are presented in this appendix. The other pulp mill effluents had low odour intensities, as did the sewage treatment plant effluents. The Suncor effluent had a strong hydrocarbon, chemical odour but the impacts on the Athabasca River could not be determined. Once again, the odours of most of the tributary samples were minor and likely contributed little to the mainstem.

The conclusions reached based on the FPA results are that the Hinton combined effluent likely remains the most distinct source of odour contributed to the mainstem Athabasca River (Kenefick *et al.*, 1994b). However, the odour intensities are much less than they were in the samples collected in 1993. It is difficult to assess the impact that the Alberta Pacific effluent has on the Athabasca River for a couple of reasons.

Table 10. Summary of the Distribution of Odour in the Athabasca River Mainstem (Winter 1993 Pre-AlPac Operation)

Distance Downstream of Hinton (km)	FPA Average Intensity* (most common descriptor)	OGC Peaks consistently Detected (Average Intensity)**					Target Compounds Detected by GC-MS (Concentration in ng/L)			
		IBMP	IPMP	246TCA	sulphur	geosmin	IPMP	246TCA	geosmin	345TCV
Upstream	0.4 (odourless)	1.5	ND	1.5	ND	ND	ND	ND	ND	ND
Hinton Effluent	2.1 (sewage)	ND	2	4.5	3	ND	ND	4	ND	27
20	1.4 (sewage)	ND	4	3.5	2.5	ND	3	1	ND	4
240	1.5 (pulp and paper)	ND	2	4	ND	2	1	3	2	33
400	1.8 (pulp and paper)	ND	2	4	ND	ND	2	4	3	27
550	1.2 (pulp and paper)	ND	3	3	ND	ND	1	6	2	27
650	1.6 (septic)	ND	2	2.5	ND	1.5	7	ND	2	24
950	1.4 (pulp and paper)	ND	1.5	3	ND	ND	ND	13	2	26
1100	1.2 (earthy)	ND	4	4	ND	2.5	ND	5	2	7
1200	0.5 (earthy)	ND	2	ND	ND	ND	ND	ND	ND	ND

(Adapted from Kenefick *et al.*, 1995)

Table 11. Summary of the Distribution of Odour in the Athabasca River Mainstem (Winter 1994 Post-AlPac Operation)

Distance Downstream of Hinton (km)	FPA Average Intensity* (most common descriptor)	OGC Peaks consistently Detected (Average Intensity)**						Target Compounds Detected by GC-MS (Concentration in ng/L)		
		IBMP	IPMP	MIB	246TCA	sulphur	geosmin	DMDS	thiophene	geosmin
Upstream	0.4 (odourless)	2	2	ND	ND	ND	ND	ND	ND	9
Hinton Effluent	1.3 (septic)	ND	ND	ND	ND	ND	ND	ND	ND	ND
20	1.5 (septic)	2	3	ND	2	3	ND	28	ND	ND
240	1.3 (septic)	4	3	ND	ND	ND	ND	9	2	ND
400	1.3 (septic)	2	ND	ND	ND	ND	ND	ND	1	8
550	1.3 (septic)	ND	2	ND	ND	ND	ND	2	ND	ND
AlPac Effluent	1.4 (rubber/chemical)	ND	2	4	ND	2	ND	ND	ND	ND
650	1.4 (septic)	ND	ND	4	ND	ND	ND	9	ND	ND
750	1.5 (woody)	ND	ND	ND	ND	ND	ND	12	3	ND
950	1.6 (septic)	3	ND	2	ND	ND	2	ND	ND	ND
1100	1.0 (septic)	3	2	ND	ND	ND	ND	ND	ND	ND
1200	1.1 (septic)	ND	ND	ND	ND	ND	ND	ND	ND	ND

(Adapted from Kenefick et al., 1995)

* With a scale maximum of 3.0
**consistently detected = average intensity greater than 1 on a 6 point scale
ND = Not Detected
IBMP = 2-isobutyl-3-methoxy pyrazine
IPMP = 2-isopropyl-3-methoxy pyrazine
MIB = 2-methylisoborneol
246TCA = 2,4,6-trichloroanisole
345TCV = 3,4,5-trichloroveratrole
DMDS = dimethyl disulphide

First, there is already bleached kraft mill effluent in the river upstream of the mill and second, the process of the upstream mill (Weldwood at Hinton) was changed, so that the baseline data collected in 1993 was not as useful for comparative purposes. These two factors also affect the results obtained from the OGC and GC-MS analyses.

In the Post AlPac assessment, the results from the CLSA/GC-MS analysis demonstrated a number of interesting findings. 3,4,5-TCV was detected consistently in the mainstem Athabasca River samples downstream of Hinton as far down as 1100 km. 2,4,6 TCA was also detected consistently. However, in the post-AlPac assessment, the mainstream river samples downstream of Hinton did not show detectable levels of the target compounds that were found in 1993 (Kenefick *et al.*, 1995). As a result of the sulphurous odours detected in the pre-AlPac samples, organosulphide target compounds were added to the assessment and low levels of thiophene and/or dimethyl disulphide were found up to 750 km downstream of Hinton. This may be the result of the sewage component of the Weldwood effluent at Hinton because the other sewage effluents also had these substances as did the CTMP effluents (Kenefick *et al.*, 1995). These results suggest a correlation of these odours with biological treatment processes.

The OGC results differ sharply in 1993 and 1994. There was a significant reduction in the odour peaks detectable as a result of the process changes that occurred at the Weldwood pulp mill in Hinton. The mainstream Athabasca samples showed weak to moderate levels of musty pyrazines (IPMP or IBMP) odours as far as 1100 km downstream of Hinton. Musty, camphorous MIB was detected as far downstream as Fort McMurray, possibly the result of the AlPac effluent. The finished drinking water supplies analyzed showed no peaks at Fort McMurray and only 246TCA was detected at Fort Chipewyan.

5.1.3 Discussion

In both the 1993 Pre-AlPac and the 1994 Post-AlPac assessment, the combined bleached kraft mill and sewage effluent at Hinton, was responsible for major odours to the Athabasca River. The odour was detected as far as 1100 km downstream. The low temperatures and the ice cover allow the odour to be transported such as distance and lower levels would be expected in warmer summer conditions. The odour from the Hinton combined effluent disappeared upon conventional treatment, possibly due in part to masking by chlorine (Kenefick *et al.*, 1995). Distinctive odours were detected in the AlPac effluent, the sewage treatment plant effluents and the Suncor oil sands effluent. However, due to the dilution in the river, and the background levels present from the Hinton plant, it is difficult to assess the individual odour impacts using the current methods. Each of the analytical methods used has its strengths and weaknesses. OGC analyses give semi-quantitative statements about the spatial distribution of odours in a sample (Kenefick *et al.*, 1995). GC-MS results give quantitative numbers but all of the correct target compounds must be known for a thorough assessment which is not the case for the odours in the Athabasca River. Finally, the FPA results give an overall odour and intensity based on human sensory perception, but individual components cannot be distinguished with this method. However, the qualitative assessment of the water samples obtained from the FPA analyses are probably the most useful in terms of the aesthetic assessment of water supplies as would be expected from NRBS residents themselves. Further discussion of qualitative aesthetic assessments of drinking water supplies is included in the following section.

5.2 QUALITATIVE ASSESSMENT

In the qualitative assessment of the aesthetic quality of drinking water in the Northern River Basins, results from work carried out by the Drinking Water Component as well as by some of the other scientific components of the NRBS study are presented. In addition to the analytical experimental design of the aesthetic quality of drinking water in the Athabasca River Basin, the Drinking Water Component was also involved in other qualitative assessments. This included sniffing of both conventional and non-conventional water samples collected, as well as conducting informal interviews with the residents of the study area about their perceptions regarding drinking water quality.

5.2.1 Conventional and Non-Conventional Samples

Table 12 is a summary of the taste and odour results from the site visits to 38 conventional drinking water treatment facilities in the NRBS area. During these site visits, samples of the raw, treated and distributed water were qualitatively analyzed for the overall odour description as well as the intensity perceived. In addition, the plant operators were asked about taste and odour complaints received. The odour descriptors used to describe the raw water varied from nothing to fishy to swampy to chemical etc. The descriptors used for the treated and distributed drinking water were more uniform
with chlorine as a common odour. In the treated water samples, chlorine was described as the odour in 28 of 31 (87%) samples. In the distributed samples, chlorine was an odour descriptor for 12 of 21 (57%) samples. This suggests that chlorine odours may dissipate in the distribution system. This trend is also observed by comparing treated and distributed samples from the same site. Although some other odours (chemical, fishy, soda, grassy, swampy, unknown) were detected in some of the conventionally treated samples, such odour descriptors were more common in distributed water. This suggests a possibility of leaching in the distribution systems. The taste and odour complaints reported by the operator of the given facility are also listed in Table 12. Common complaints received were a result of seasonal water turnover events, biological problems and the flavour of chlorine.

A similar odour assessment was carried out on the non-conventional drinking water samples collected during the three field excursions. The descriptors used by the site investigator varied depending on the source of the supply. Raw surface water sources, such as would be expected from streams, rivers, lakes, dugouts and reservoirs, were described as muddy, woody, grassy, salty, sulphur/rotten egg, swampy, chemical and non detectable odour. The ground water samples collected were described as having a characteristic iron flavour and another sample had a musty bullrush smell. The snow water samples collected ranged from undetectable odours to a rocky smell. The bottled water sample descriptors were sweet, rainy, plastic and none. Conventionally treated water sample collected for comparative purposes were described with chlorine indicators. A sample of conventionally treated water after being treated with a point-of-use device no longer had a chlorine odour associated with it.

These results obtained from both the conventional and non-conventional samples are highly subjective. However, this is to be expected in qualitative aesthetic assessments. The perceptions of

Table 12. Conventional Drinking Water Samples Taste and Odour Assessment

Site	Raw Water Odour (intensity)	Treated Water Odour (intensity)	Distributed Odour (intensity)	Water Taste and Odour Complaints[**] (Operator Comments)
Athabasca	none (0)	chlorine (1)	chlorine (1)	Yes (in spring)
Barrhead	sweet (0.1)	chlorine (2)	NA	Yes (water tainted in raw reservoir)
Berwyn	NA	NA	NA	No
Cadotte Lake	mint (1)	chemical (3)	NA	Yes (both summer and winter)
Colinton	NA	NA	NA	Yes (chlorine tastes)
Cynthia	NA	NA	NA	Yes (chlorine tastes)
Desmarais	grassy (0.1)	chlorine and swampy (1)	swampy/grassy (1)	Yes (fishy smell in the spring)
Edson	sulphur (3)	none (0)	none (0)	No (because plant de-gasses)
Fairview	none (0)	chlorine (2)	chlorine (1.5)	No
Falher	grassy (1)	chlorine/grassy (1)	NA	Yes (bottled water is popular)
Fort Chipewyan	none (0)	chlorine (0.5)	NA	Yes (due to pond turnover)
Fort MacKay	pine (0.1)	chlorine (0.5)	chlorine + ?? (1)	No
Fort McMurray	NA	chlorine (1)	chemical (0.5)	Yes (spring pond turnover)
Fort Vermilion	none (0)	chlorine (0.5)	NA	No
Fox Creek	rotten eggs (2)	NA	muggy chemical (1)	No
Gift Lake	chemical/grassy (0.1)	chlorine (1)	NA	Yes (associated with algae blooms)
Grande Cache	NA	NA	NA	Yes (in spring and summer)
Grande Prairie	none (0)	chlorine (2)	chlorine (1)	Yes (chlorine)
Grimshaw	NA	chemical (0.5)	chemical (0.5)	Yes (chlorine)
High Level	fishy (2.5)	fishy (1.5)	fishy (2)	Yes (due to algae in the fall)
High Prairie	?? (0.01)	chlorine (2)	chlorine (1)	No
Hinton	NA	chlorine (1)	chlorine (1)	Not sure
Janvier	musty/grassy (0.5)	chlorine (2)	?? (0.1)	No (some algae problems)
Jasper	none (0)	chlorine (0.1)	NA	None (a few last year)
Lac La Biche	grassy (0.01)	chlorine (1.5)	NA	No (there were two years ago)
Manning	grassy (0.5)	chlorine (1)	NA	Yes (with pond turnover)
Peace River	slight (0.1)	chlorine (0.5)	chlorine (0.5)	Yes (a little)
Peerless Lake	lakey (0.1)	chlorine (1)	NA	Yes (spring runoff)
Sexsmith	rotten eggs (3)	soda (0.01)	NA	Yes (a few about sulphur)
Slave Lake	swampy (2)	chlorine (1)	grassy/fishy (1)	Yes (worst in the spring and fall)
Smith	none (0)	something ?? (0.1)	chlorine (0.5)	No
Swan Hills	Swampy-woody (1.5)	chlorine	NA	Yes (fishy smell)
Tangent	swampy (2)	swampy (0.5)	swampy (1)	Yes (spring turnover)
Teepee Creek	NA	NA	chemical/heavy (1)	Yes
Wandering River	grassy (2)	grassy (0.1)	grassy (1.5)	NA
Westlock	NA	chlorine (1)	chlorine (0.5)	Yes (related to algae)
Whitecourt	musty (0.5)	chlorine (1.5)	musty pine (1)	None

[*] Odour intensity is on a scale with a maximum of 3.0 and is descriptor is based on the assessment by a single investigator rather than a flavour panel as suggested in Standard Methods (APHA, 1992). The assessment was carried out on samples collected during site visits in the summer of 1994.

[**] Taste and odour complaints as reported by the treatment facility operator.

?? = odour descriptor unknown

NA = information not attained

NRBS residents regarding their drinking water is also subjective and qualitative, but as mentioned earlier, the water treatment industry is reliant on these consumers, and the public health of consumers is reliant on the water industry. Therefore, it is important to address their perceptions. Both aesthetic and health related concerns of study area residents are discussed in the next section.

5.2.2 Resident's Perceptions

In the guiding question dictating the work of the Drinking Water Component, reference was made to the concentration of contaminants in water and fish. The assessment of contaminants in fish flesh and other aquatic organisms was thoroughly assessed by the Contaminants Component of the Northern River Basins Study. However, Kenefick and Hrudey (1994) also reviewed the literature regarding fish tainting substances and reported information from personal communications with study area residents regarding fish taint in the NRBS area. Interested readers are referred to this review and the results from the Contaminant Component for further information regarding fish tainting.

There were other informal anecdotal interviews carried out by the Drinking Water Component that addressed resident's perceptions of drinking water in the study area. Several of the people interviewed expressed an uneasiness about the practice of using chlorine in drinking water treatment. Besides the bad taste and odour associated with chlorine, people interviewed also associated a health risk with the consumption of chlorinated drinking water. Health effects reported to be a result of chlorine in drinking water included: vein clogging; allergic reactions; onset of cancer; and general gastrointestinal illnesses (Armstrong *et al.*, 1995). There were also people living in remote areas who were interviewed and who relied on non-conventional drinking water supplies. These residents were not so concerned about chlorine, rather, the poor quality of the lake and rivers in the area were more important to them. More often than not, those interviewed attributed the pollution in the waters to the industrial activities of pulp mills and the oil sands operations. Residents living in remote areas near Fort Chipewyan often mentioned the bad tasting brown foam that developed in their cup from the water used in the preparation of tea or coffee (Armstrong *et al.*, 1995). It is interesting to note that during these interviews, microbial pathogens in drinking water sources were not a concern to those interviewed.

Domestic water consumption was one of the areas addressed in the telephone survey of 718 NRBS residents conducted by the Other Uses Component. In addition to many other topics assessed in the survey, the interviewers asked residents about their perceptions regarding drinking water. The water quality concerns that were raised in this survey were segregated into those associated with non-conventional water sources and those related to conventional municipal sources. Table 13 presents the results of the drinking water concerns of the NRBS respondents obtained by the Other Uses Component.

Table 13. NRBS Resident's Drinking Water Quality Concerns.

Water Supply	Chlorine	Bad Taste or Smell	Spring Taste or Smell	Minerals	Biotic Concerns	Sediments	General
Conventional	24.9%	22.0 %	19.7 %	12.3 %	4.6 %	3.0 %	13.5 %
Wells	0.0 %	10.0 %	6.5 %	68.4 %	0.0 %	6.0 %	9.1 %
Lake Water	0.0 %	48.9 %	31.4 %	0.0 %	19.7 %	0.0 %	0.0 %
River Water	24.4 %	25.7 %	40.7 %	0.0 %	0.0 %	0.0 %	9.1 %
Dugouts	0.0 %	57.5 %	7.8 %	6.1 %	6.1 %	0.0 %	0.0 %

(Adapted from Reicher and Thompson, 1995)

The type of water quality concerns appear to be related to the source of water being consumed. Chlorine in conventional drinking water was cited as a water quality concern by about 25 % of those interviewed. Chlorine was not a concern to those that consumed well water, lake water or dugout water. However, chlorine was also a concern for river water consumers. An explanation for this may be that some of the respondents, knowing that their raw drinking water supply was from the river, answered that they consumed river water rather than municipal water. Minerals were by far the greatest concern for those that relied on groundwater for consumption. Bad smells and tastes were reported for each type of water supply listed and was the greatest for dugouts followed by lake water, river water, conventional water and then wells. There were not any biotic concerns cited for well water consumers and river water consumers. However, respondents consuming lake water did report a biotic concern; as did those that relied on conventional plant water and dugouts for consumption.

Although some of the concerns raised by NRBS residents throughout the course of the study may be benign and not pose a substantial risk to health, some of these concerns may be valid and could represent a real threat to health. Therefore, the aesthetic quality of drinking water cannot be ignored.

6.0 ANALYSIS OF WATER QUALITY

6.1 RAW WATER

The evaluation of raw water quality is based on historical data collected by AEP, data collected by the drinking water group of the NRBS and data on organic parameters collected by the contaminants group of the NRBS. Much of the AEP data has been summarized in other reports for that group. Only a few parameters have concise limits recommended for raw drinking water quality because much depends on the treatment systems used. For this reason the discussion on raw drinking water quality is generally qualitative rather than quantitative. Where possible the data on raw water quality in the NRBS area is compared to applicable raw water standards for conventional water treatment and for some parameters comparisons are made to treated water standards as a conservative estimate of quality.

6.1.1 Physical Challenges

The physical challenges to raw drinking water include the parameters of temperature, colour, odour, turbidity and total dissolved solids. None of the physical parameters have recommended limits for use as raw drinking water, however all have limits in treated drinking water with turbidity being the only one that has an MAC limit in the treated drinking water. The levels of turbidity, colour and odour are of concern in the raw water because the associated levels in the treated water are important. As mentioned raw water temperature has an effect on the degree of difficulty to treat the water with very cold water being difficult to treat. The level of concern caused by these physical challenges to the drinking water of a community are quite different if the community uses ground water than if the community uses surface water.

Facilities using surface water as a drinking water source generally find substantial variation in the physical parameters in the raw water. Communities that draw the raw water straight from the river find turbidity can change daily with rain events and the other parameters that vary seasonally. Many communities have large raw water storage capacities which allow them to draw from the river once or twice per year to avoid low flow conditions of the raw water source. In these facilities the physical parameters are fairly constant except for the temperature which varies seasonally and turbidity, taste and odour which can change during thermal inversions. At the facilities that draw directly from the river the winter season is generally associated with low and constant turbidities and temperatures and higher TDS. If the colour and odour is naturally occurring, then the winter raw water quality will have lower levels, whereas if the origin of river colour and odour is anthropogenic, then the levels may be constant. The summaries of the AEP data on the Peace, Athabasca and Smoky-Wapiti Rivers show that the only physical parameters that are of concern to drinking water are colour and odour (Noton *et al.* 1989, Shaw *et al.*, 1990, Noton *et al.*, 1992, Noton *et al.* 1995). Noton *et al.* (1992) found that TDS levels in the Wapiti River during the low flow winter conditions exceeded the aesthetic objectives of the GCDWQ. The reports also state that the pulp mill activities on these rivers have a significant impact on these areas of concern. While there is limited data on the raw water quality of the communities on the smaller surface water systems (small shallow lakes, streams, surface runoff), based on the site visits these waters are generally of lower quality with respect to the physical parameters than the larger rivers.

Facilities using ground water as a raw water source are not faced with fluctuation in the physical parameter levels. Communities using ground water have determined whether or not the particular ground water is suitable for a drinking water source and the physical parameters should have been investigated. Ground water supplies are advantageous in terms of microbial risks and the cost of treatment (usually minimal treatment) so as a result there are some facilities that use ground waters that are marginal or do not meet the aesthetic objectives. In general, the raw ground water in the NRBS area is adequate in terms of physical parameters and there are a few sites that are marginal in terms of aesthetic objectives.

6.1.2 Inorganic Chemical Challenges

There is limited data on the levels of inorganic parameters for the raw water used by ground water facilities. Reference can be made to the assessment of treated ground waters in section 6.2.2 for coverage of this topic.

The historical data from the AEP summaries shows the concentration of the inorganic parameters in the water column of the Peace, Athabasca and Smoky-Wapiti systems are well within the MAC values in CDQWG (Noton *et al.* 1989, Shaw *et al.*, 1990, Noton *et al.*, 1992, Noton *et al.* 1995). There were concentrations of manganese during low flow condition in the Smoky-Wapiti Rivers that exceeded the aesthetic objectives in CDWQG.

6.1.3 Organic Chemical Challenges

Ground water supplies generally have a very low level of organic content. There are instances where ground water supplies are contaminated with organic chemicals from the surface but these are rare in Alberta and the drinking water component is unaware of any in the NRBS area.

With respect to surface water, much of the investigation that has been carried out by AEP and other components of the NRBS focuses on the contaminant levels in the sediments or the fish because generally these are the media the organic contaminants partition to. There was some sampling done on the water column as part of the NRBS Contaminant Component studies. Most water column samples were below analytical detection limits for most contaminants. For a few contaminants some were found to be slightly above detection limits. In most cases these contaminants are not regulated by the GCDWQ and as a result each contaminant would require an individual health hazard/risk assessment.

6.1.4 Microbiological Challenges

The analysis of the raw water quality uses total and fecal coliform counts to indicate raw water quality.

The data collected by the NRBS on coliforms indicates that all ground water facilities tested had zero coliforms in the raw water samples (Prince *et al.*, 1995b). This is as expected because ground waters that are not under the direct influence of surface waters should have very low bacterial counts (AEP, 1988). As expected, the coliform data from the surface water facilities identified TC in 26 of the 28 raw water samples and found FC in 19 of 29 raw water samples. The average count in the samples was 20 cfu/100 mL and 4 cfu/100 mL for TC and FC respectively and there were 8 samples where TC were uncountable because they were either too numerous to count or confluent growth (Prince *et al.*, 1995b). The recommendation for TC counts in raw drinking water is 5000 cfu/100 mL for conventional treatment and 500 cfu/100 mL for direct filtration facilities (Zhou *et al.*, 1995). For the sites where TC values were determined the raw water quality is adequate for a conventional treatment plant and there were four sites that exceeded the 500 cfu/100 mL guideline for a direct filtration plant. Of the four sites over the 500 cfu/100 mL value all were equipped with conventional treatment except at Peerless Lake were the clarifier was broken down and the plant was essentially a direct filtration plant. Comment cannot be made on the raw water quality based on total coliforms at the 8 sites where the colonies were uncountable.

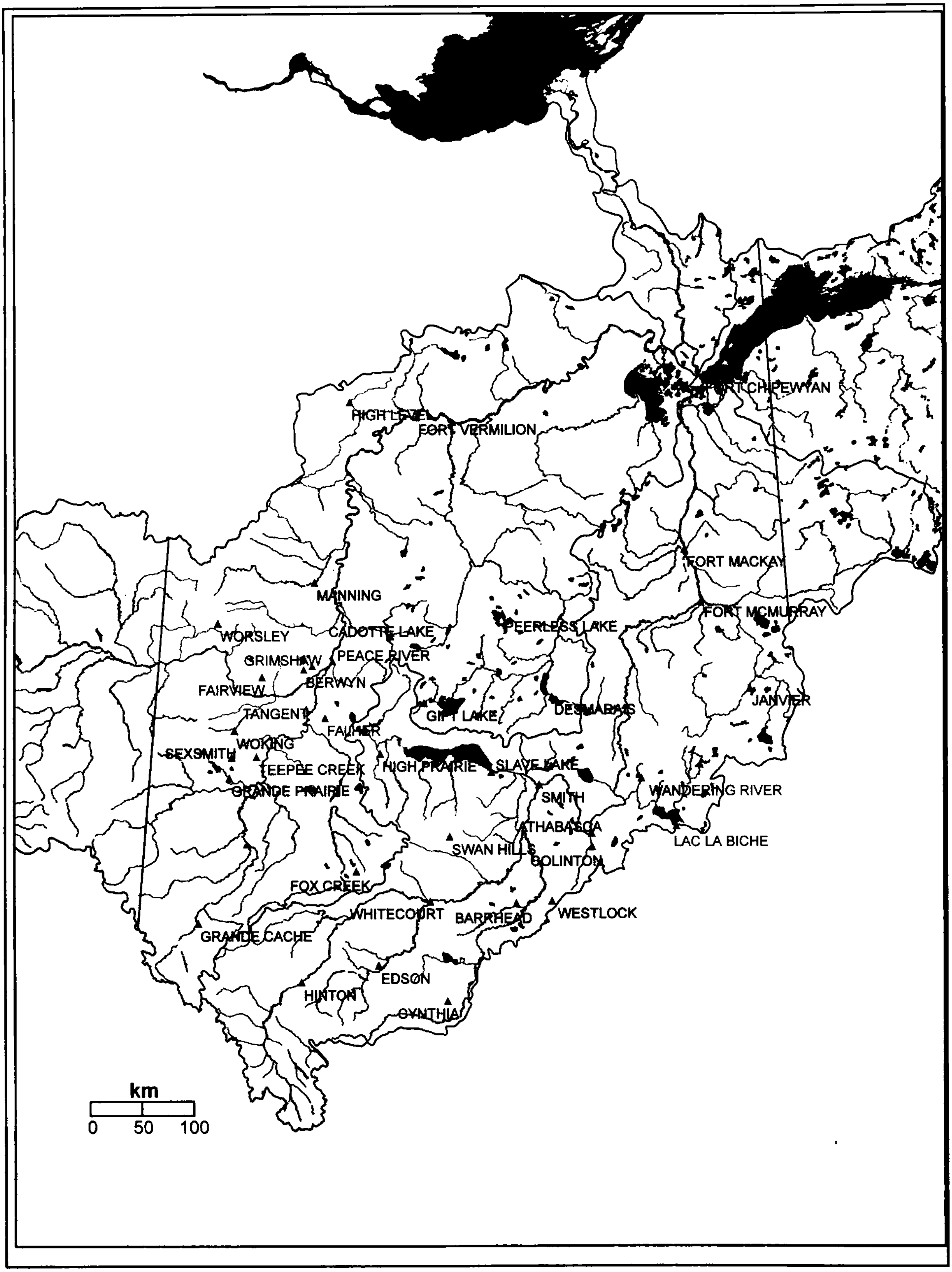
Historical data on several of the larger rivers in the NRBS area has been reported by AEP. Total coliform counts averaged 100 cfu/100 mL and no samples exceeded 1000 cfu/100 mL from seven samplings of 20 sites along the Peace River and its' tributaries in 1988-89 (Shaw *et al.*, 1990). This indicates that microbially the raw water in the Peace River meets recommendations of conventional drinking water treatment facilities. Data on the Wapiti-Smoky River systems under low flow conditions in 1987-1991 showed that the average TC and FC counts were roughly 500 and 20 respectively (Noton *et al.*, 1992). There was only one sample in that time period that exceeded the guideline for TC of 5000 cfu/100 mL. This indicates that raw water quality in the Wapiti-Smoky River system generally complies with the raw drinking water guideline even in the low flow condition where the impact for discharges to the river should be the greatest. Noton *et al.* (1989) summarized winter water quality data collected on the Athabasca River between 1988 to 1989 and reported the median TC and FC concentration were roughly 50 and 10 counts/100mL with the lowest values upstream of Hinton and the higher values near Lake Athabasca. No samples were reported that exceeded raw water quality recommendations for a conventional water treatment plant. Further work by Noton *et al.* (1995), summarized the water quality monitoring on the Athabasca River between 1990 to 1993 and again did not have a sample that exceeded the raw water quality guidelines with the average TC and FC counts of roughly 100 and 10 counts/100mL respectively.

The review of historical data on the Peace, Athabasca, and Wapiti-Smoky river systems shows that microbially these rivers are of good quality to be used as a raw water source for a conventional drinking water plant. The analysis of the microbial quality of the raw water from the site visits showed a trend that smaller facilities had poorer raw water quality than larger ones. While this trend was not statistically significant due to the limited number of sites, it correlates well with the fact that the larger communities, which generally have access to the larger river systems, have better raw water quality microbially than the smaller communities which utilize smaller water bodies and sometimes surface runoff for their drinking water source. In general the communities taking their raw drinking water from the larger river systems in the NRBS area have a better raw water quality microbially, than the communities utilizing the smaller systems, like small lakes and surface runoff.

6.2 TREATED AND DISTRIBUTED DRINKING WATER

Treated and distributed drinking water quality in the Northern River Basins Study area is presented below based on both historical water quality information databases and also based on site visits to the conventional drinking water treatment facilities shown in Figure 16.

Figure 16. Conventional Drinking Water Treatment Facilities Sites Visited



6.2.1 Physical Challenges

As discussed, physical characteristics of drinking water include parameters like colour, pH, temperature, total dissolved solids, turbidity, taste and odour. Of these parameters only turbidity is regulated with a MAC limit due to its' association with the microbial quality of the drinking water and the related health implications. Typical treatment processes in the NRBS area are primarily concerned with controlling turbidity, colour, pH, taste and odour while temperature and TDS are not controlled and are largely dependent on raw water conditions. The parameters of taste and odour are difficult to completely control and are somewhat a function of raw water quality. As discussed in the previous section, communities on the larger rivers generally have good raw water quality with respect to the physical parameters while communities on the small surface water sources struggle with physical aesthetic parameters. The parameter of turbidity warrants an in-depth analysis due to the health implications associated with it. The following is a summary of existing data and data collected during the NRBS study.

6.2.1.1 Site Visit Turbidity Data. The turbidity data collected from the site visits has been sorted and summarized based on community status (town or hamlet etc.), sample type (raw, treated or distributed) and type of source water for the facility (surface or ground water). The summary is in Table 14. The standard for turbidity in treated water is 1 NTU 95% of the time. The samples taken during the site visits were grab samples and compliance with the guidelines could no be determined based on one sample. A turbidity value over the standard of 1 NTU in the treated water does give a strong indication that the facility may have difficulty meeting the turbidity standard at times. The table lists the number of samples over 1 NTU in the distributed water and it should be noted that the standard in the distributed water is 5 NTU and it is an aesthetic objective.

The table also shows that there were six sites where the treated water turbidity was over the 1 NTU limit. Four of the sites are small communities (hamlets and water points) with both water points visited in the group being over 1 NTU. The other sites were a town and a city. There appears to be a trend in the average turbidity in that towns have lower turbidity than the hamlets or water points. The only statistically significant relationship found is that the water points have a higher average turbidity than both the hamlets and the towns at a 95% confidence level. The turbidity data indicates that 6 of the 32 treated water samples taken were above the 1 NTU limit which would indicate that these sites may have difficulty meeting the standards. The results also show that the average turbidity from the treated water samples taken at water points were significantly higher the averages of those taken at hamlets and towns.

6.2.1.2 Summary of Existing Turbidity Data. The 389 turbidity samples from AEP's Treated Water Survey were collected from the distribution systems of the facilities so that the GCDWQ standard of 1 NTU does not apply. However, it is still enlightening to compare the means of the turbidity for communities with population greater than 500 to those less than 500. Table 15 is the summary of the comparison. The table shows that surface water facilities with populations greater than 500 have significantly lower turbidity (a=0.02) than facilities less than 500 population. The difference in the ground water facilities was not statistically significant.

Table 14. Site Visit Turbidity Data Summary

ALL SITES VISITED

RAW WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	turb
All Sites	38	3.6	176	0.08	na	na
Cities	2	9.6	-	-	na	na
Towns	20	2.8	329	0.02	na	na
Vilages	1	0.2	-	-	na	na
Hamlets	13	4.9	55	0.45	na	na
Water Points	2	10.9	-	-	na	na

TREATED WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	32	0.4	3.2	0.05	6	19%
Cities	2	0.5	-	-	1	50%
Towns	17	0.3	1.7	0.04	1	6%
Vilages	0	-	-	-	-	-
Hamlets	11	0.5	4.0	0.06	2	18%
Water Points	2	1.9	-	-	2	100%

DISTRIBUTED WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	36	0.4	2.9	0.06	6	17%
Cities	2	0.5	-	-	1	50%
Towns	19	0.3	2.2	0.04	2	11%
Vilages	1	0.2	-	-	0	0%
Hamlets	13	0.6	4.8	0.07	3	23%
Water Points	0	-	-	-	-	-

SURFACE WATER SITES VISITED

RAW WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	30	6.4	164	0.25	na	na
Cities	2	9.6	-	-	na	na
Towns	15	6.5	399	0.11	na	na
Vilages	0	-	-	-	na	na
Hamlets	11	5.2	70	0.38	na	na
Water Points	2	10.9	-	-	na	na

TREATED WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	29	0.4	3.0	0.05	5	17%
Cities	2	0.5	-	-	1	50%
Towns	15	0.3	1.7	0.04	1	7%
Vilages	0	-	-	-	-	-
Hamlets	10	0.4	3.3	0.05	1	10%
Water Points	2	1.9	-	-	2	100%

DISTRIBUTED WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	27	0.4	2.3	0.06	4	15%
Cities	2	0.5	-	-	1	50%
Towns	14	0.3	1.3	0.06	1	7%
Vilages	0	-	-	-	-	-
Hamlets	11	0.5	4.6	0.05	2	18%
Water Points	0	-	-	-	-	-

GROUND WATER SITES VISITED

RAW WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	THM
All Sites	8	0.4	22	0.01	na	na
Cities	0	-	-	-	na	na
Towns	5	0.2	7	0.01	na	na
Vilages	1	0.2	-	-	na	na
Hamlets	2	3.8	-	-	na	na
Water Points	0	-	-	-	na	na

TREATED WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	3	0.4	-	-	1	33%
Cities	0	-	-	-	-	-
Towns	2	0.2	-	-	0	0%
Vilages	0	-	-	-	-	-
Hamlets	1	1.6	-	-	1	100%
Water Points	0	-	-	-	-	-

DISTRIBUTED WATER						
		Turbidity				
	Number of Sites	Ave	upper 95% C. I.	lower 95% C. I.	number > 1 NTU	0
All Sites	9	0.5	9	0.03	2	22%
Cities	0	-	-	-	-	-
Towns	5	0.4	45	0.00	1	20%
Vilages	1	0.2	-	-	0	0%
Hamlets	2	1.3	-	-	1	50%
Water Points	0	-	-	-	-	-

Table 15. Treated Water Survey Turbidity Data

Type of Facility	Population	Number of Sites	Geometric Mean of Site Average Turbidities	Lower 95% Confidence in Mean	Upper 95% Confidence in Mean	Lower 95 Percentile	Upper 95 Percentile	Alpha Value from t test Comparisons
Surface Water	Pop. > 500	29	0.50	0.38	0.66	0.1	2.4	2%
	Pop < 500	37	0.79	0.57	1.09	0.1	6.1	
Ground Water	Pop. > 500	4	0.27	0.12	0.61	0.0	9.2	26%
	Pop < 500	13	0.41	0.22	0.76	0.0	5.2	
All Sites	Pop. > 500	33	0.46	0.36	0.61	0.1	2.3	5%
	Pop < 500	50	0.66	0.49	0.89	0.1	5.8	

6.2.2 Inorganic Challenges

The evaluation of existing data showed that all the samples taken were well within the health regulated guidelines with respect to inorganic parameters except for samples taken from a community using ground water that exceeded the fluoride limit due to naturally occurring fluoride. There are several examples of facilities, particularly ground water facilities, exceeding the aesthetic limits on total dissolved solids and sodium and a few surface water facilities that exceeded aesthetic limits on manganese and iron. The historical data shows that inorganic challenges to drinking water are not a concern in the NRBS area in terms of health related guidelines except for some ground water systems where naturally occurring fluoride may exceed limits. There are some facilities that do not meet aesthetic objectives with respect to inorganic parameters.

6.2.3 Organic Chemical Challenges

The evaluation of existing data showed historically the only organic chemical to exceed MAC limits in the sampling done by AEP in the treated water survey was trihalomethanes (Prince *et. al*, 1995a). For this reason the focus of the challenge of organic chemicals to drinking water in the NRBS area is on these THMs.

THMs are a group of chemicals which are characterized by halogen-substituted single carbon compounds. With respect to drinking water four of these compounds tend to be important: bromoform, dibromochloromethane, bromodichloromethane and chloroform. The most commonly occurring constituent is chloroform (WHO 1993).

The guideline value is based on health effects related to the various compounds. It should be noted however that THMs may also act as indicators for the presence of other chlorination by products. Neither bromoform nor dibromochloromethane have been classified as to their carcinogenicity to humans by the International Agency for Research on Cancer (WHO, 1993). The category to which they have been assigned is used for agents for which evidence of carcinogenecity is inadequate in humans and is inadequate or limited in experimental animals. Thus, bromodichloromethane and chloroform are classed as agents which are possible carcinogenic to humans.

The guideline value of 100 ug/L is based on an excess risk of 10^{-5} (WHO, 1993), Although the number of sites which exceed the THM guideline is of concern, the risks to health from these by-products are small in comparison with the risks associated with inadequate disinfection. As a result the WHO (1993) states that if local circumstances require that a choice must be made between meeting either microbial guidelines or guidelines for disinfectants or disinfectant by-products, the microbiological quality must always take precedence. Efficient disinfection must never be compromised. Generally however, with proper treatment both requirements can and should be met. The level of disinfection by-products can be reduced by optimizing the treatment process. Removal of organic substances prior to disinfection reduces the formation of these by-products.

6.2.3.1 **Site Visit THM Data**. The trihalomethane (THM) data has been sorted by the status of the community (town or hamlet etc.), the type of sample (treated or distributed) and the type of source water (ground or surface). The raw water was not analyzed for THMs since they are formed as by-products of chlorine disinfection and are therefore not an issue in raw water. The summary of the data is presented in Table 16.

The standard for THM is an annual average of 100 ug/L on at least four samples taken quarterly at any point in the system. The table shows that over half the samples taken from the distribution systems of the facilities visited were over the 100 ug/L standard. There was one of the four distribution samples taken from a ground water facility that was over the limit and 12 of the 21 samples taken from surface water facilities were over the limit. The standard is based on an average of four samples so compliance to the standard cannot be assessed, however it indicates there may be problems at a number of surface water communities. There is not a significant relationship with the THM data and the status of the community with 60 % of both the towns and hamlets exceeding the standard in the distributed samples and neither of the watering points exceeding the standard. This would indicate that the levels of THMs are not related to the size of community but does seem to be a concern for many communities in the NRBS area.

6.2.3.2 **Summary of Existing THM Data**. Figure 17 is a figure taken from the Review and Synthesis of Existing Information (Prince *et al.*, 1995a) and it demonstrates the distribution of site average chloroform (one of the THMs) values. The THM standard changed at about the time that these treated water survey samples were taken. The previous standard was 350 ug/L meaning that these site averages were in compliance at the time of sampling. If the levels of THMs in the drinking water in the NRBS remain unchanged, the figure indicates that the current standard of 100ug/L would be exceeded in 20 of the 62 surface water sites (it should be noted that these site averages are not based on 4 annual samples). Table 17 is a summary of the THM values from the 460 NRBS area samples in the Treated Water Survey. The table summarizes the samples by the status of the community and whether it is a ground or surface water source and compares to see the number and percent of samples that exceed the 100 ug/L limit (again the old standard of 350 ug/L applies to these samples). This gives an indication that if water quality does not improve with regard to THMs the percent of the surface water sites that may have difficulty meeting standards is 0% of cities, 8% of towns, 34% of villages, 42% of hamlets and 50% of watering points and Metis settlements (the last two categories are based on only a few samples). The ground water sites were not as big a concern with regard to THMs with only 1 of the 66 samples being over the current limit. Based on historical data, there seems to be a trend that generally the smaller surface water communities will have more difficulty with the THM standards than the larger ones (towns and cities).

Table 16. Site Visit Trihalomethane Data

SUMMARY OF THM DATA FROM ALL SITES

TREATED WATER						
	Number of Sites	Mean ug/L	Upper 95 percentile	Lower 95 percentile	Number > 100 ug/L	Percent > 100 ug/L
All Sites	25	81.2	389	16.96	10	40%
Cities	1	41.4	-	-	0	0%
Towns	12	67.1	307	14.69	4	33%
Vilages	-	-	-	-	-	-
Hamlets	10	127.0	631	25.56	6	60%
Water Points	2	38.0	-	-	0	0%

DISTRIBUTED WATER						
	Number of Sites	Mean ug/L	Upper 95 percentile	Lower 95 percentile	Number > 100 ug/L	Percent > 100 ug/L
All Sites	25	97.6	516	18.44	13	52%
Cities	1	44.9	-	-	0	0%
Towns	13	70.7	437	11.43	6	46%
Vilages	-	-	-	-	-	-
Hamlets	11	153.2	545	43.02	7	64%
Water Points	-	-	-	-	-	-

SUMMARY OF THM DATA FROM SURFACE WATER SITES

TREATED WATER						
	Number of Sites	Mean ug/L	Upper 95 percentile	Lower 95 percentile	Number > 100 ug/L	Percent > 100 ug/L
All Sites	22	84.0	378	18.69	9	41%
Cities	1	41.4	-	-	0	0%
Towns	10	77.1	340	17.49	4	40%
Vilages	-	-	-	-	-	-
Hamlets	9	119.3	634	22.43	5	56%
Water Points	2	38.0	-	-	0	0%

DISTRIBUTED WATER						
	Number of Sites	Mean ug/L	Upper 95 percentile	Lower 95 percentile	Number > 100 ug/L	Percent > 100 ug/L
All Sites	21	113.8	458	28.23	12	57%
Cities	1	44.9	-	-	0	0%
Towns	10	95.1	431	21.00	6	60%
Vilages	-	-	-	-	-	-
Hamlets	10	149.3	575	38.75	6	60%
Water Points	-	-	-	-	-	-

SUMMARY OF THM DATA FROM GROUND WATER SITES

TREATED WATER						
	Number of Sites	Mean ug/L	Upper 95 percentile	Lower 95 percentile	Number > 100 ug/L	Percent > 100 ug/L
All Sites	3	63.1	134274443	0.00	1	33%
Cities	-	-	-	-	-	-
Towns	2	33.6	-	-	0	0%
Vilages	-	-	-	-	-	-
Hamlets	1	223.1	-	-	1	100%
Water Points	-	-	-	-	-	-

DISTRIBUTED WATER						
	Number of Sites	Mean ug/L	Upper 95 percentile	Lower 95 percentile	Number > 100 ug/L	Percent > 100 ug/L
All Sites	4	43.6	4877	0.39	1	25%
Cities	-	-	-	-	-	-
Towns	3	26.3	20576	0.03	0	0%
Vilages	-	-	-	-	-	-
Hamlets	1	198.1	-	-	1	100%
Water Points	-	-	-	-	-	-

Figure 17. Treated Water Survey Site Average Chloroform Distribution

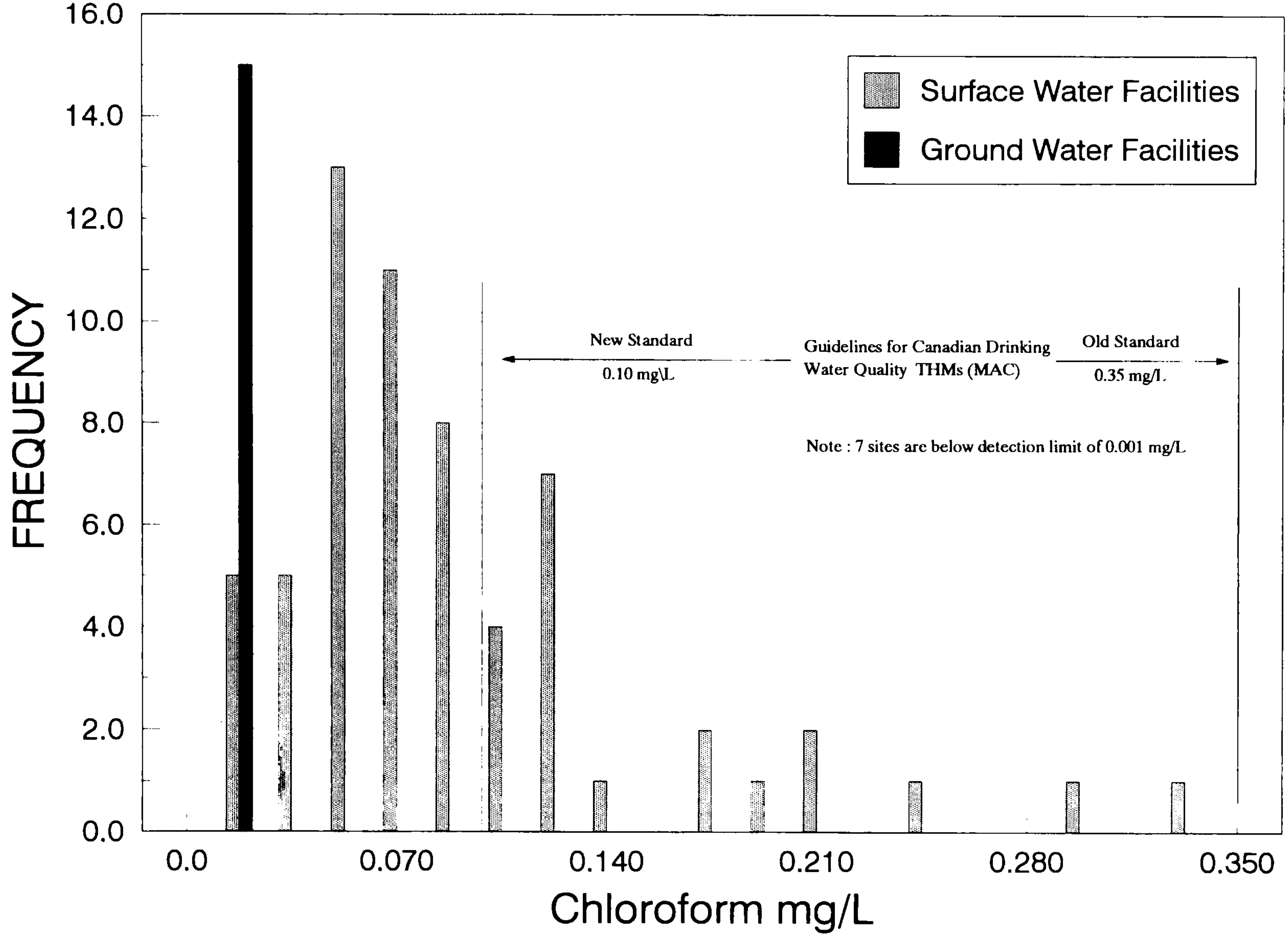


Table 17. Treated Water Survey Trihalomethane Summary

	All NRBS Sites					Surface Water Sites					Ground Water Sites				
	Total Samples	Number Above 100 ug/L*	Percent Above 100 ug/L*	Geometric Mean ug/L	Upper 95% Confidence in Mean	Total Samples	Number Above 100 ug/L*	Percent Above 100 ug/L*	Geometric Mean ug/L	Upper 95% Confidence in Mean	Total Samples	Number Above 100 ug/L*	Percent Above 100 ug/L*	Geometric Mean ug/L	Upper 95% Confidence in Mean
City	58	0	0%	9	12	58	0	0%	9	12	0	-	-	-	-
Town	209	15	7%	23	28	196	15	8%	28	33	13	0	0%	2	2
Village	59	16	27%	35	54	47	16	34%	73	95	12	0	0%	2	3
Hamlet	89	33	37%	45	62	76	32	42%	60	82	13	1	8%	8	20
Water Point	9	3	33%	29	109	6	3	50%	82	245	3	0	0%	3	17
Metis Settlement	8	4	50%	97	128	8	4	50%	97	128	0	-	-	-	-
Total	460	71	15%	25	29	394	70	18%	32	37	66	1	2%	6	9

*This is the new standard, when these samples were taken the standard was 350 ug/L and there are only 3 samples in the NRBS area over this limit

6.2.4 Microbiological Challenges

The microbial data from historical databases and the data collected for the NRBS study are summarized in this section. The historical data in this analysis came from an Alberta Environmental Protection database of microbial sampling (270,000 samples in all of Alberta, with 72 000 in the NRBS area).

Currently the strategy for controlling the microbial quality of drinking water is based on turbidity and the presence and quantity of indicator organisms like total and fecal coliforms and heterotrophic plate counts. The success of this strategy is evident historically by the dramatic decline in epidemic and endemic waterborne diseases like typhoid fever and cholera (Sobsey *et al.*, 1993). There are some pathogenic microorganisms that are not well represented by TC, FC and HPC indicators, such as *Giardia* (responsible for beaver fever). New strategies are evolving to control these other waterborne risks to public health. These new strategies look at several of the current treatment processes as barriers to pathogenic microbes and continue to use turbidity as the critical parameter to assess treatment process performance. The importance of turbidity as a parameter to indicate microbial quality of drinking water is evident in the USEPA using turbidity to justify pathogen removal credits in their most recent standards (Letterman, 1994b). In these standards maximum credits are earned with turbidity of £ 0.5 NTU 95% of the time.

It should be noted that the risk associated with microbial contaminants are normally much greater than those associated with chemical contaminants. The World Health Organization (1993) state that "the potential consequences of microbial contamination are such that its control must always be of paramount importance and must never be compromised."

There is also concern that current guidelines based on indicator organisms and turbidity may not be rigorous enough. Endemic and community wide gastrointestinal illness have been attributed to drinking water meeting current guidelines (Sobsey *et al.*, 1993).

6.2.4.1 Site Visit Microbial Data. The results of the sampling done for the NRBS found one of the 9 ground water sites and one of the 28 surface water sites had coliforms in the treated or distributed water. This is a concern and requires further investigation which includes resampling. However, further investigation could not be done under this study and therefore a definitive conclusion should not be drawn from these samples. This is an indication however of potential problems but conclusions should be based on the greater weight of evidence that lies in the historical data.

The treated and distributed samples all complied with standards except for a watering point using surface water with direct filtration and a village using ground water without chlorination. Additionally there are some concerns due to the occurrence of fecal streptococcus in the treated water of six sites. The microbial quality of the water related to the status of the community (town or hamlet etc.) did not provide significant distinctions. While the two water points visited had some of the lowest quality raw water and one of the sites did not meet requirements of treated water standards, there was not enough data to establish the significance of this trend.

6.2.4.2 Summary of Existing Microbial Data. The microbiological standards in the GCDWQ were checked against the large AEP database of microbial data for compliance. Pertinent sections of the GCDWQ were given previously and are referred to below.

The AEP database gives information taken from microbial analysis records in the form of either affirmative or negative indications of the following categories:

1. 0 < TC > 10;
2. TC >10;
3. FC > 0;
4. too numerous to count;
5. confluent growth (overgrown);
6. samples late for analysis;
7. broken bottles; and,
8. incorrectly labeled.

Note, no actual numbers were given and only the month and year of the sample date are known. The last three categories were excluded from the analysis.

A summary of the microbial database for the NRBS area and all of Alberta is presented in Tables 18 and 19 (Prince *et al.*, 1995b). The tables list the number of samples taken and number in the categories mentioned previously. The percent of samples that were coliform positive and the percent of sample that were poor (defined later) are calculated. It is interesting to note that the ground water facilities with no disinfection have a high incidence of coliform positive samples. There is also a trend of higher percent of coliform positive samples with the smaller communities and a lower percent coliform positive with the larger communities.

The database showed that several samples had total coliform concentrations greater than 10 cfu/100mL or positive fecal coliform counts, but there is not enough information to draw definitive conclusions with respect to the GCDWQ. To investigate whether no more than 10 % of samples were coliform positive (Item 3b in the GCDWQ) the percent of samples from a site that were coliform positive over a calendar year were calculated. Tables 20 and 21 show a summary of the sites that had more than 10 % of samples coliform positive (exceeding standards). Table 20 shows that the smaller communities have more sites exceeding standards than the larger ones with 30 % of the water points exceeding standards in 1994.

Figure 18 and Figure 19 show the graphical representation of this data in the NRBS area and all Alberta. As indicated by the figures, communities that have the highest percent of coliform positive samples are those with populations less than 500. The World Health Organization and the USEPA standards for microbial quality of drinking water stipulate that no more than 5% of the microbial samples from a water system can have the presence of coliforms (WHO, 1993 and USEPA, 1994) which is more stringent than the GCDWQ standard. As mentioned the situation is common to the NRBS area and all Alberta. Goodrich *et al.* (1992) found a similar situation in the United States.

Table 18. Microbial Database Summary (NRBS Area)

Status	Type	Total Samples	Satisfactory Samples	Doubtful 0<TC<10	Unsat. FC > 0	V TC > 10	TNTC	Confluent Growth	24 -48 hr Old	Too Old > 48 hr	No Lable	Broken	% Poor* Samples
Hamlet	surface	14883	13909	122	37	25		280	347	107	51	5	3.2%
	ground	4817	4475	32	3	3		99	153	46	6		3.0%
	no Cl2	2055	1876	80	3	2		60	28	5	1		7.2%
Village	surface	4045	3811	31	7	2		30	146	7	10	1	1.8%
	ground	1781	1693	6	1			17	36	9	18	1	1.4%
	no Cl2	708	684	4				5	12			3	1.3%
Town	surface	11988	11505	91	17	10		61	247	37	15	5	1.5%
	ground	1989	1849	13	4			32	62	7	22		2.6%
	no Cl2	1022	945	39	2	3		11	13	5	4		5.5%
City	surface	6390	6268	32	3			17	52		4	14	0.8%
Water Point	surface	3693	3151	182	41	31		219	57	10	2		13.1%
	ground	1628	1530	30				38	20	7	1	2	4.3%
	no Cl2	3592	3203	182	22	5		99	68	5	5	3	8.8%
Metis Settlement	surface	238	232						4	1	1		0%
	ground												-
	no Cl2	295	283	2		1		2	2	1	4		1.7%
School	surface	615	558	18	3	3		14	16	1	2		6.4%
	ground	973	918	7		3		20	20	4	1		3.2%
	no Cl2	210	164	11				34	1				21.5%
Other	surface	1724	1645	8	3			9	37	7	15		1.2%
	ground	130	126					1		3			0.8%
	no Cl2	414	363	14	15			17	5				11.2%
Sub-division	surface												-
	ground	572	548	2				4	15	3			1.1%
	no Cl2												-
Industry	surface	1908	1715	15	12	9		28	53	3	71	2	3.6%
	ground	131	118					7	6				5.6%
	no Cl2	59	52	1				5	1				10.3%
Regional	surface												-
Hutterite Colony	surface												-
	ground												-
	no Cl2	1	1										0%
Provicial Park	surface	1868	1577	88	9	13		118	48	13	2		12.6%
	ground	2017	1884	25	1	8		52	30	3	11	3	4.4%
	no Cl2												-
Mobile Home Park	surface	203	181	6	1			7	4	3	1		7.2%
	ground	558	494	10	1	3		34	7	2	6	1	8.9%
	no Cl2	182	161	9				7	4	1			9.0%
Summer Village	surface												-
	ground												-
	no Cl2	28	25	1				1	1				7.4%
Airport	surface	668	648	5	4			3	6	2			1.8%
	ground												-
	no Cl2												-
National Park	surface	74	69	1				1	3				2.8%
	ground												-
	no Cl2												-
71459	surface	48297	45269	599	137	93		787	1020	191	174	27	3.45%
	ground	14596	13635	125	10	17		304	349	84	65	7	3.24%
	no Cl2	8566	7757	343	42	11		241	135	17	14	6	7.59%
	Total	71459	66661	1067	189	121		1332	1504	292	253	40	3.9%

% Poor = (Doubtful + Unsat. + V +TNTC + Confluent) / (Total - old samples - No lable - Broken)

Table 19. Microbial Database Summary (All of Alberta)

Status	Type	Total Samples	Satisfactory Samples	Doubtful 0<TC<10	Unsat. FC > 0	V TC > 10	TNTC	Confluent Growth	24 -48 hr Old	Too Old > 48 hr	No Lable	Broken	% Poor* Samples
Hamlet	surface	30339	28370	231	87	35		657	603	230	104	22	3.4%
	ground	14712	13771	94	14	7		323	325	133	42	3	3.1%
	no Cl2	7957	7229	236	23	8		256	122	40	41	2	6.7%
Village	surface	17390	16223	147	42	5		204	542	116	86	25	2.4%
	ground	15468	14468	48	8	4		280	450	93	105	12	2.3%
	no Cl2	8363	7711	173	4	17		180	198	37	33	10	4.6%
Town	surface	39837	38302	237	56	22		231	659	178	116	36	1.4%
	ground	12249	11450	65	22	6		113	387	115	80	11	1.8%
	no Cl2	2887	2642	94	4	7		47	60	21	11	1	5.4%
City	surface	75211	74087	235	55	23		100	472	98	93	48	0.6%
Water Point	surface	4526	3894	200	45	31		270	67	14	4	1	12.3%
	ground	2174	1990	59	23	3		57	28	8	3	3	6.7%
	no Cl2	4649	4005	212	22	11		264	116	9	7	3	11.3%
Metis Settlement	surface	565	532	8	1	2		8	7	2	5		3.4%
	ground	947	907		2			12	14	6	6		1.5%
	no Cl2	295	283	2		1		2	2	1	4		1.7%
School	surface	1442	1315	35	12	3		20	26	5	26		5.1%
	ground	1909	1770	13		3		70	42	9	2		4.6%
	no Cl2	1684	1415	41	1			153	49	11	14		12.1%
Other	surface	4818	4650	22	11	2		24	73	13	23		1.3%
	ground	3043	2884	25	6	7		28	42	16	33	2	2.2%
	no Cl2	618	484	22	23	3		75	11				20.3%
Sub-division	surface	3257	3199	21	9	1		2	4	10	11		1.0%
	ground	1921	1834	13	3	1		16	32	14	8		1.8%
	no Cl2	412	376	11	3	1		9	6	5	1		6.0%
Industry	surface	3934	3565	81	22	10		69	77	19	86	5	4.9%
	ground	131	118					7	6				5.6%
	no Cl2	80	70	1				8	1				11.4%
Regional	surface	699	678	2	4	1		2	8	1	3		1.3%
Hutterite Colony	surface												-
	ground	24	18	2	1			3					25.0%
	no Cl2	50	33	6	2			7	1		1		31.3%
Provicial Park	surface	3180	2824	97	12	15		147	60	15	10		8.8%
	ground	3536	3320	39	2	11		86	53	8	14	3	4.0%
	no Cl2	405	335	18	1	3		38	3	3	4		15.2%
Mobile Home Park	surface	453	419	8	1			14	7	3	1		5.2%
	ground	558	494	10	1	3		34	7	2	6	1	8.9%
	no Cl2	546	501	11	1			10	10	3	10		4.2%
Summer Village	surface												-
	ground												-
	no Cl2	229	184	4				9	1	2	29		6.6%
Airport	surface	668	648	5	4			3	6	2			1.8%
	ground	279	263	7	1			6	2				5.1%
	no Cl2												-
National Park	surface	802	756	3	1			6	23	4	9		1.3%
	ground												-
	no Cl2												-
TOTAL	surface	187121	179462	1332	362	150		1757	2634	710	577	137	1.97%
	ground	56951	53287	375	83	45		1035	1388	404	299	35	2.81%
	no Cl2	28175	25268	831	84	51		1058	580	132	155	16	7.42%
	Total	272247	258017	2538	529	246		3850	4602	1246	1031	188	2.7%

% Poor = (Doubtful + Unsat. + V +TNTC + Confluent) / (Total - old samples - No lable - Broken)

Table 20. Summary of Sites with More than 10 % Coliform Positive

YEAR	NRBS																											
	OTHER TYPES				WATER POINTS				HAMLETS				VILLAGES				TOWNS				CITIES				ALL SITES			
	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	9	36	206	962	3	47	776	11447	0	15	0	6440	2	23	3663	69199	0	2	0	61597	14	125	4645	149645
1989	6	34	230	1402	11	37	278	1162	3	52	261	12170	0	16	0	6413	0	23	0	70764	0	2	0	60906	20	167	769	157669
1990	3	38	0	1402	12	37	137	1162	2	52	312	12170	0	16	0	6413	1	23	1256	70896	0	2	0	61256	18	171	1705	158151
1991	5	49	200	3902	9	37	194	1162	0	53	0	12220	0	16	0	6413	0	25	0	80357	0	2	0	62048	14	185	394	170954
1992	2	55	100	3769	8	36	193	1082	0	54	0	12300	0	17	0	6546	0	25	0	79850	0	2	0	62977	10	191	293	171376
1993	1	46	100	3114	5	35	165	852	1	51	80	11877	0	18	0	7010	0	25	0	79984	0	2	0	62977	7	179	345	170666
1994	6	46	300	3114	10	35	281	852	2	50	230	11669	0	18	0	7010	0	25	0	80619	0	2	0	63948	17	178	811	172064

YEAR	ALL ALBERTA																											
	OTHER TYPES				WATER POINTS				HAMLETS				VILLAGES				TOWNS				CITIES				ALL SITES			
	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	11	49	363	1367	9	124	1241	50390	4	116	1219	44618	3	115	5146	321839	0	15	0	1568442	27	425	7969	1986807
1989	20	230	355	14635	17	51	278	1390	12	127	1169	50476	2	115	380	44648	1	111	642	314667	0	15	0	1592694	51	642	2824	2030791
1990	15	242	322	24869	14	51	137	1390	9	132	853	51390	4	118	1028	44648	2	111	2798	323790	0	15	0	1639914	42	662	5125	2089911
1991	11	286	260	28741	10	48	214	1390	0	139	0	51140	1	117	251	44648	1	111	1542	324799	0	15	0	1658782	24	700	2267	2113410
1992	11	295	290	28634	9	47	193	1310	2	143	408	51271	2	118	648	44781	2	111	2139	330563	0	15	0	1689198	27	711	3678	2149616
1993	1	245	100	23526	6	47	165	1080	1	138	80	50709	3	118	1248	44706	0	111	0	333162	0	15	0	1712736	11	662	1593	2169778
1994	9	247	300	22370	13	47	381	1080	4	137	314	50631	0	119	0	44706	2	112	2139	340416	0	15	0	1728743	27	665	3134	2192461

Table 21. Summary of Sites with More than 10 % Coliform Positive (Other Types Category)

YEAR	NRBS																															
	Hutterite Colonies				Industries				Mobile Home Parks				Other				Provincial Parks				Schools				Sub-divisions				Summer Villages			
	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	1	5	130	1030	0	4	0	0	0	5	0	0	5	19	100	349	0	1	0	23	0	0	0	0
1990	0	0	0	0	0	0	0	0	0	5	0	1030	0	4	0	0	2	7	0	0	1	20	0	349	0	1	0	23	0	1	0	0
1991	0	0	0	0	2	11	0	2500	1	5	200	1030	0	4	0	0	1	7	0	0	1	20	0	349	0	1	0	23	0	1	0	0
1992	0	0	0	0	0	12	0	2500	0	5	0	1030	0	5	0	0	0	8	0	0	2	22	100	216	0	2	0	23	0	1	0	0
1993	0	0	0	0	0	11	0	2500	0	2	0	450	0	5	0	0	0	8	0	0	1	17	100	141	0	2	0	23	0	1	0	0
1994	0	0	0	0	1	11	0	2500	1	2	300	450	0	5	0	0	1	8	0	0	2	17	0	141	0	2	0	23	1	1	0	0

YEAR	ALL ALBERTA																															
	Hutterite Colonies				Industries				Mobile Home Parks				Other				Provincial Parks				Schools				Sub-divisions				Summer Villages			
	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	2	15	95	1355	0	0	0	0	2	13	130	2530	3	27	0	1257	2	19	0	100	10	127	130	7193	1	28	0	1622	0	1	0	578
1990	3	16	96	1451	0	0	0	0	0	12	0	2130	0	33	0	1260	4	22	0	10303	5	128	213	7539	3	29	13	1608	0	2	0	578
1991	1	18	60	1511	3	41	0	3812	1	12	200	2130	1	28	0	1260	1	22	0	10303	4	130	0	7539	0	33	0	1608	0	2	0	578
1992	3	18	190	1511	3	42	0	3838	0	12	0	2130	1	29	0	1260	0	25	0	10303	4	132	100	7406	0	34	0	1608	0	3	0	578
1993	0	12	0	1321	0	40	0	3538	0	5	0	1250	0	35	0	1260	0	27	0	10303	1	91	100	3668	0	32	0	1608	0	3	0	578
1994	0	12	0	1321	2	40	0	3538	1	5	300	1250	0	37	0	1710	3	27	0	10303	2	90	0	2640	0	34	0	1608	1	2	0	0

Figure 18. Frequency of Coliform Positive Samples in all NRBS Area (1988-94) **Total sites 217**

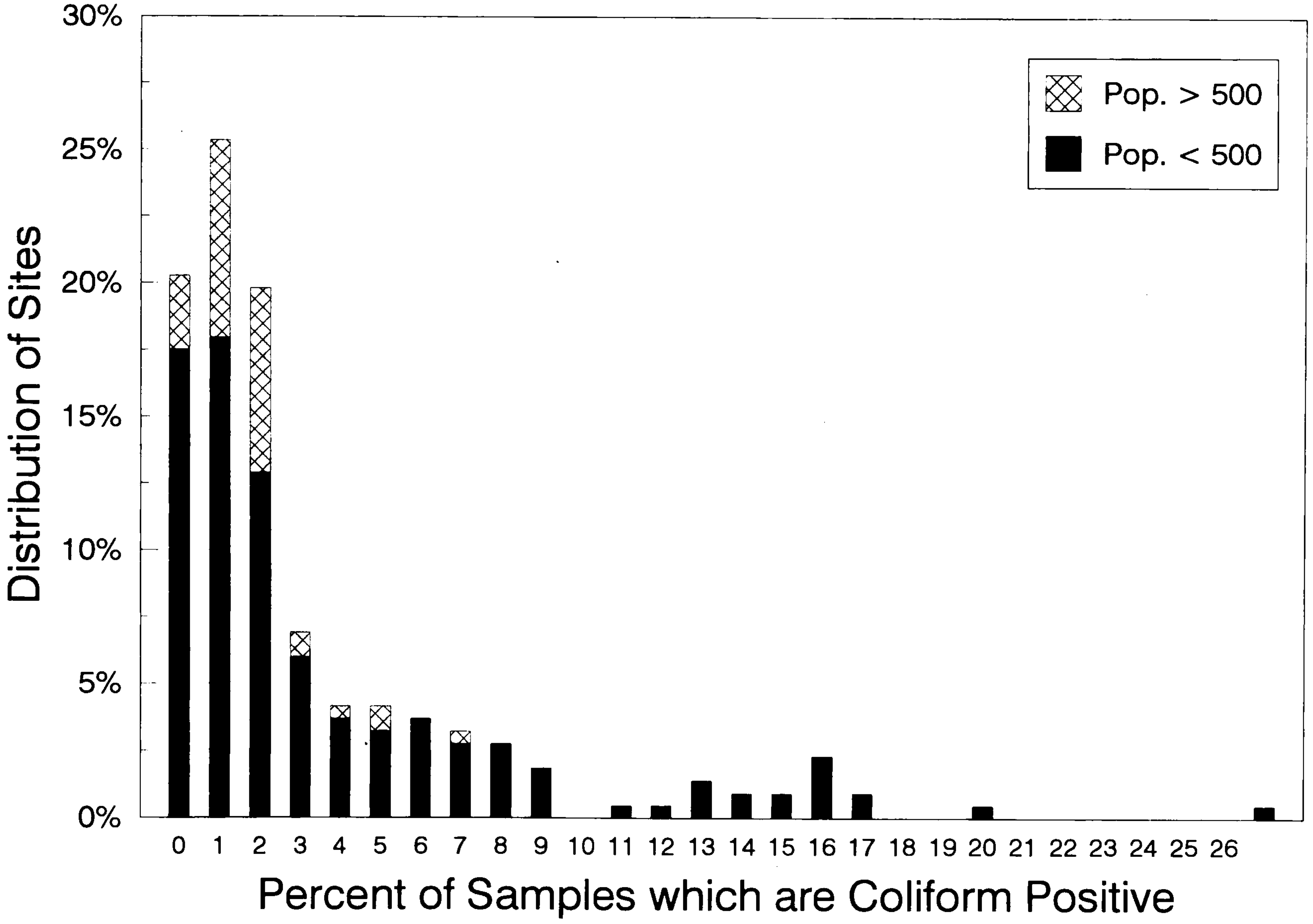
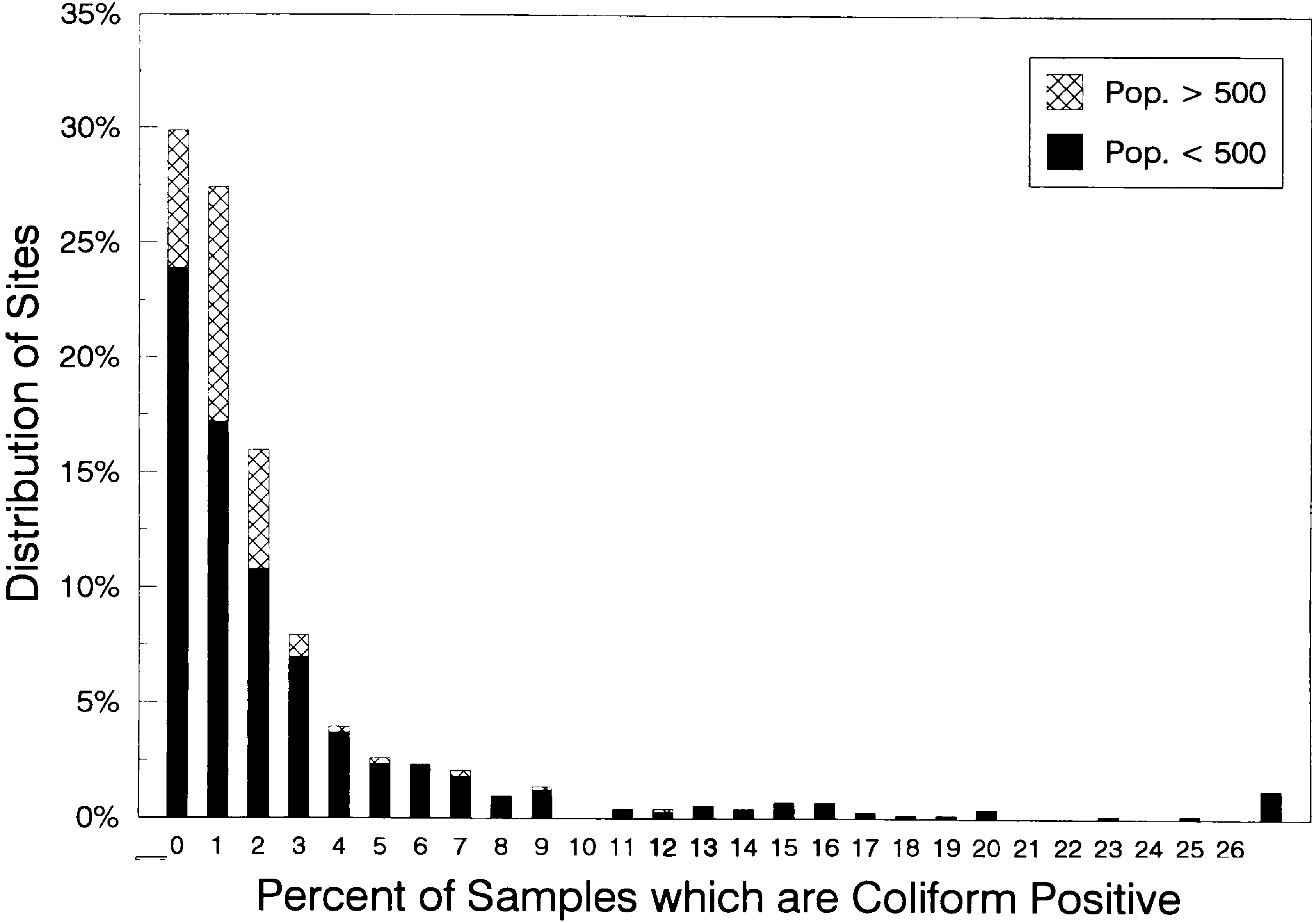


Figure 19. Frequency of Coliform Positive Samples in all Alberta (1988-1994) **Total sites 735**



In the lab analysis for TC and FC a situation can arise where other bacteria overgrow the plates making it impossible to identify the presence of coliforms. As stated in the excerpt of GCDWQ in section 3 above this is considered an unsatisfactory sample and the reoccurrence of these samples should be investigated and corrected. The rate of recurrence of overgrown samples and coliform positive samples was combined and referred to as the "Percent Poor" and summarized in Tables 22 and 23 and Figures 20 and 21. While the use of the 10 % limit in Table 22 and Table 23 was an arbitrary choice and does not reflect standards exactly, a strong arguement can be made that the facilities over the 10 % Poor limit are a concern and have a problem. The Figures 20 and 21 and Tables 22 and 23 demonstrate that there is a more pronounced difference between large and small communities with this comparison. There were 45% of the watering points that had over 10 % poor samples in 1994. The figures also show that more small communities have shifted to the right (higher % poor) than have the larger communities, which is similar for all of Alberta.

Also of concern in the assessment of historical data was that a number of communities had a drinking water with a poor microbial quality for a number of years in a row.

6.3 NON-CONVENTIONAL DRINKING WATER

Since not everyone in the Northern River Basins Study area consumes drinking water from a conventional drinking water treatment facility, an assessment of the quality of some of the non-conventional sources of drinking water was also necessary. Armstrong *et al.*, (1995) classified non-conventional drinking water supplies in the NRBS area as being one from one of the following groups:

- Self-hauled conventionally treated drinking water
- Surface water (including lakes, rivers, streams, creeks, dugouts, watering points)
- Groundwater (including wells and springs)
- Environmental water (including rainwater, water from snow or ice, muskeg water, birch tree water)
- Bottled water
- Point-of-use treated water (any of the above supplies (including conventional drinking water) further treated at the point-of-use with a treatment device or a treatment process)

To the best knowledge of the Drinking Water Component, and with the exception of the raw water quality data that was discussed in Section 6.1, there were no databases with non-conventional drinking water quality data. As a result, most of the information regarding the quality of non-conventional drinking water supplies was based on site visits to remote communities in the study area. As shown in Figure 22, three field trips were taken to assess the utilization and quality of non-conventional drinking water supplies. During these site visits, samples of non-conventional drinking water were collected and informal interviews of residents were carried out regarding

Table 22. Sites and Population Served With More Than 10% Poor Samples in a Single Year

NRBS

YEAR	OTHER TYPES				WATER POINTS				HAMLETS				VILLAGES				TOWNS				CITIES				ALL SITES			
	Sites >10%	Sites Total	Pop. >10%	Pop Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop >10%	Pop Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	18	36	505	962	9	47	2570	11447	1	15	704	6440	2	23	3663	69199	0	2	0	61597	30	125	7442	149645
1989	13	34	630	1402	16	37	404	1162	8	52	1222	12170	0	16	0	6413	0	23	0	70764	0	2	0	60906	37	167	2256	157669
1990	6	38	200	1402	17	37	435	1162	5	52	793	12170	0	16	0	6413	1	23	1256	70896	0	2	0	61256	29	171	2684	158151
1991	11	49	350	3902	15	37	414	1162	1	53	56	12220	0	16	0	6413	0	25	0	80357	0	2	0	62048	26	185	820	170954
1992	7	55	250	3769	9	36	203	1082	3	54	381	12300	0	17	0	6546	0	25	0	79850	0	2	0	62977	19	191	834	171376
1993	1	46	100	3114	10	35	185	852	2	51	136	11877	0	18	0	7010	1	25	1414	79984	0	2	0	62977	14	179	1835	170666
1994	8	46	300	3114	15	33	281	852	3	50	399	11669	1	18	672	7010	0	25	0	80619	0	2	0	63948	26	178	1652	172064

ALL ALBERTA

YEAR	OTHER TYPES				WATER POINTS				HAMLETS				VILLAGES				TOWNS				CITIES				ALL SITES			
	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop Total	Sites >10%	Sites Total	Pop. >10%	Pop Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	23	49	662	1367	35	124	5227	50390	13	116	4204	44618	5	115	7221	321839	0	15	0	1568442	76	425	17314	1986807
1989	40	230	1225	14635	28	51	532	1390	30	127	3728	50476	14	115	4291	44648	6	111	4485	314667	0	15	0	1592694	120	642	15021	2030791
1990	31	242	1678	24869	22	50	455	1390	20	132	2029	51390	8	118	2129	44648	3	111	4364	323790	0	15	0	1639914	81	662	10064	2089911
1991	29	286	1095	28741	18	47	442	1390	8	139	627	51140	7	117	2735	44648	1	111	1542	324799	0	15	0	1658782	63	700	6441	2113410
1992	28	295	745	28634	14	46	331	1310	12	143	1439	51271	5	118	1910	44781	2	111	2139	330563	0	15	0	1689198	61	711	6559	2149616
1993	9	245	100	23526	14	45	305	1080	10	138	729	50709	5	118	2063	44706	1	111	1414	333162	0	15	0	1712736	39	662	4611	2169778
1994	22	247	800	22370	22	43	501	1080	14	137	1256	50631	11	119	3812	44706	3	112	5939	340416	0	15	0	1728743	68	665	12308	2192461

* Poor samples are those meeting the follow * Poor samples are those meeting the following criteria :

Fecal Coliforms > 0
Total Coliforms > 0
Colonies too numerous to count
Confluent growth

Table 23. Sites and Population Served With More Than 10% Poor Samples in a Single Year (Other Types Category)

YEAR	NRBS																															
	Hutterite Colonies				Industries				Mobile Home Parks				Other				Provincial Parks				Schools				Sub-divisions				Summer Villages			
	Sites >10%	Sites Total	Pop >10%	Pop. Total	Sites >10%	Sites Total	Pop >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	3	5	530	1030	1	4	0	0	1	5	0	0	8	19	100	349	0	1	0	23	0	0	0	0
1990	0	0	0	0	0	0	0	0	1	5	200	1030	0	4	0	0	3	7	0	0	2	20	0	349	0	1	0	23	0	1	0	0
1991	0	0	0	0	2	11	0	2500	2	5	350	1030	0	4	0	0	3	7	0	0	3	20	0	349	0	1	0	23	1	1	0	0
1992	0	0	0	0	0	12	0	2500	1	5	150	1030	1	5	0	0	1	8	0	0	4	22	100	216	0	2	0	23	0	1	0	0
1993	0	0	0	0	0	11	0	2500	0	2	0	450	0	5	0	0	0	8	0	0	1	17	100	141	0	2	0	23	0	1	0	0
1994	0	0	0	0	1	11	0	2500	1	2	300	450	0	5	0	0	2	8	0	0	3	17	0	141	0	2	0	23	1	1	0	0

YEAR	ALL ALBERTA																															
	Hutterian Colonies				Industries				Mobile Home Parks				Other				Provincial Parks				Schools				Sub-divisions				Summer Villages			
	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop. >10%	Pop. Total	Sites >10%	Sites Total	Pop >10%	Pop. Total	Sites >10%	Sites Total	Pop >10%	Pop. Total
1988	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1989	5	15	165	1355	0	0	0	0	6	13	930	2530	4	27	0	1257	5	19	0	100	19	127	130	7193	1	28	0	1622	0	1	0	578
1990	3	16	96	1451	0	0	0	0	1	12	200	2130	3	33	0	1260	8	22	0	10303	12	128	791	7539	3	29	13	1608	1	2	578	578
1991	3	18	190	1511	5	41	300	3812	2	12	350	2130	2	28	0	1260	5	22	0	10303	11	130	255	7539	0	33	0	1608	1	2	0	578
1992	4	18	190	1511	5	42	0	3838	1	12	150	2130	2	29	0	1260	3	25	0	10303	12	132	400	7406	1	34	5	1608	0	3	0	578
1993	0	12	0	1321	2	40	0	3538	0	5	0	1250	4	35	0	1260	2	27	0	10303	1	91	100	3668	0	32	0	1608	0	3	0	578
1994	1	12	0	1321	4	40	500	3538	1	5	300	1250	0	37	0	1710	6	27	0	10303	6	90	0	2640	3	34	0	1608	1	2	0	0

* Poor samples are those meeting the following criteria :

Fecal Coliforms > 0
Total Coliforms > 0
Colonies too numerous to count
Confluent growth

Figure 20. Percent Poor Microbial Samples in the NRBS Area (1988-1994)

Total sites 217

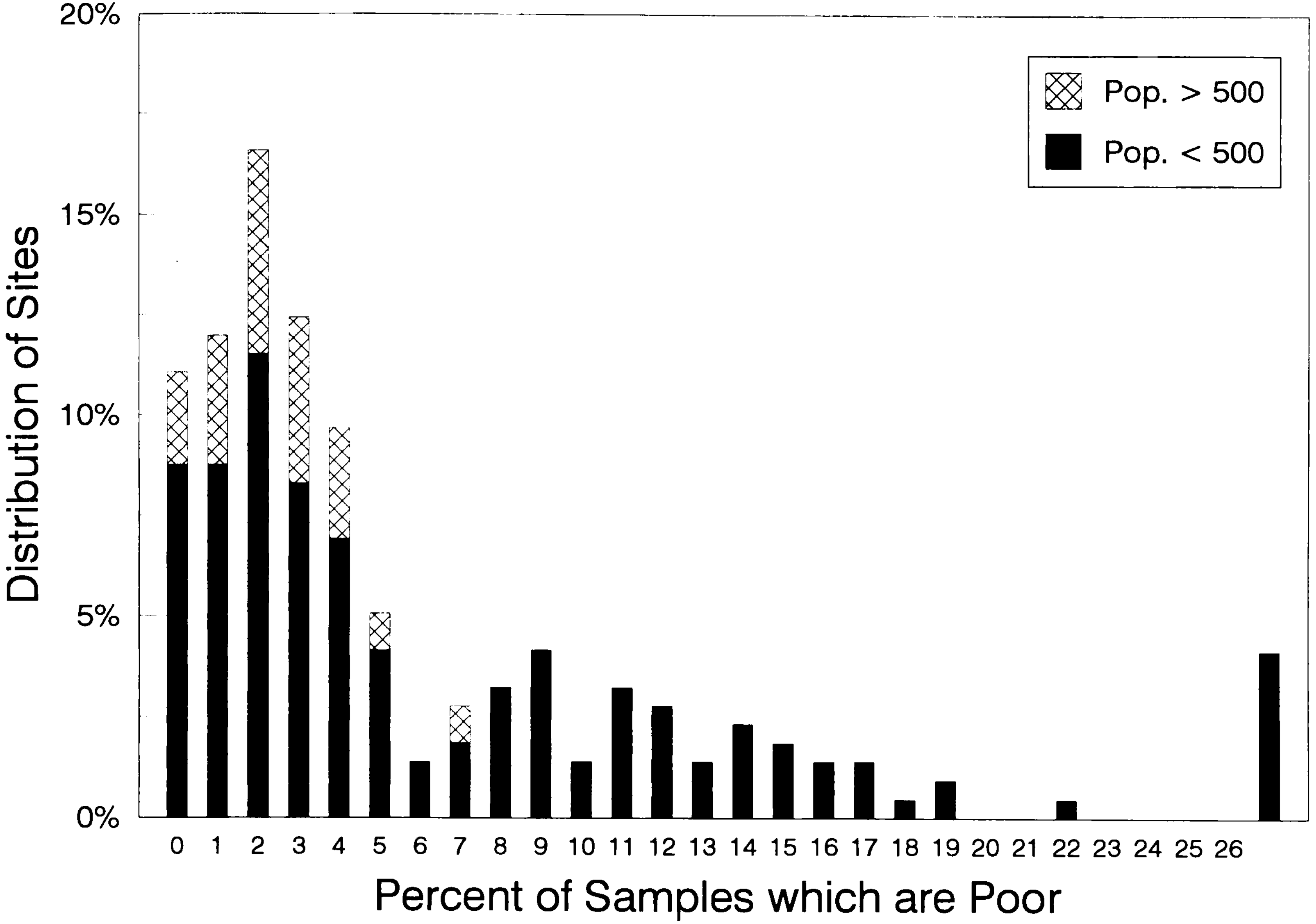


Figure 21. Percent Poor Microbial Samples in all Alberta (1988-1994)

Total sites 735

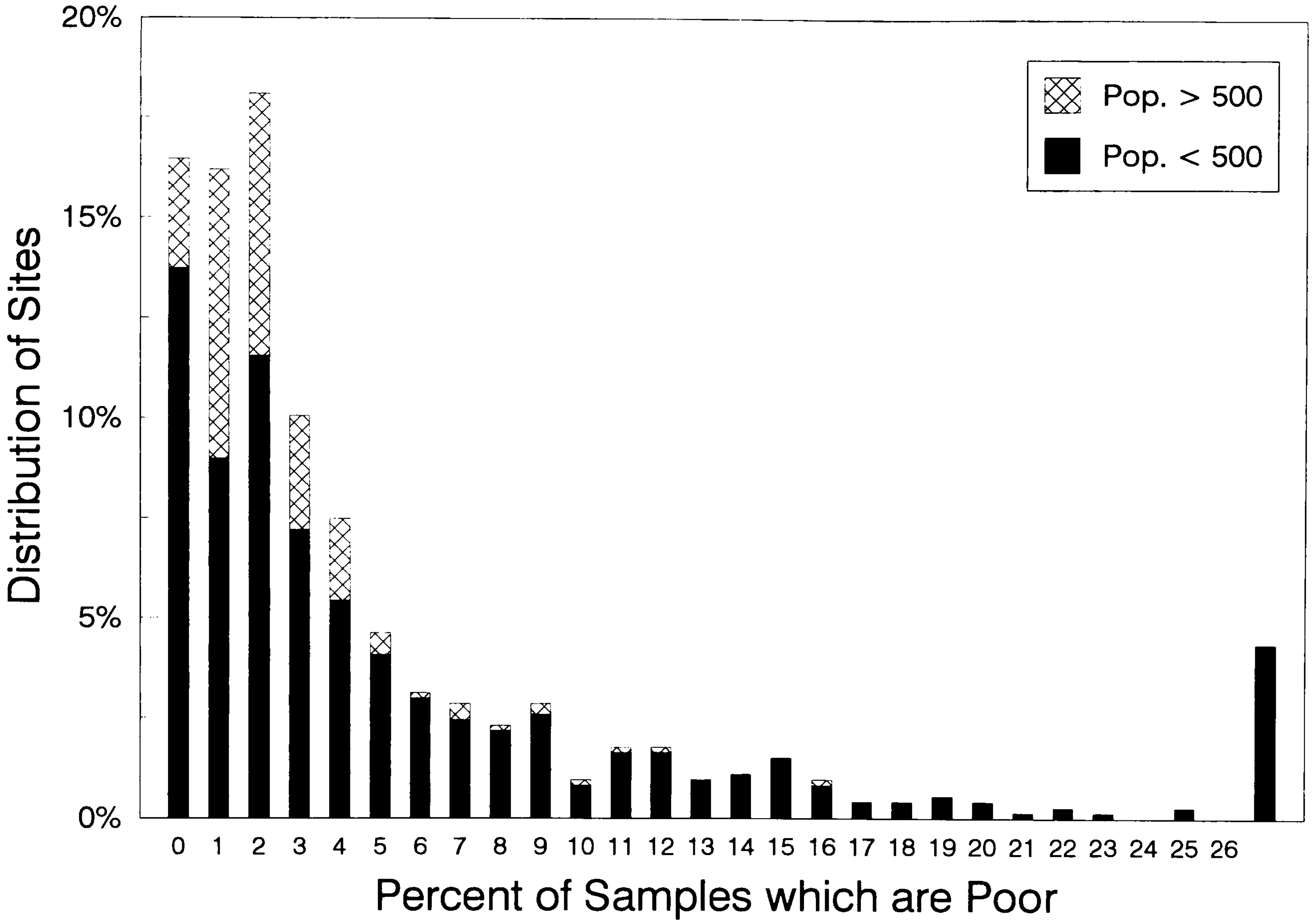
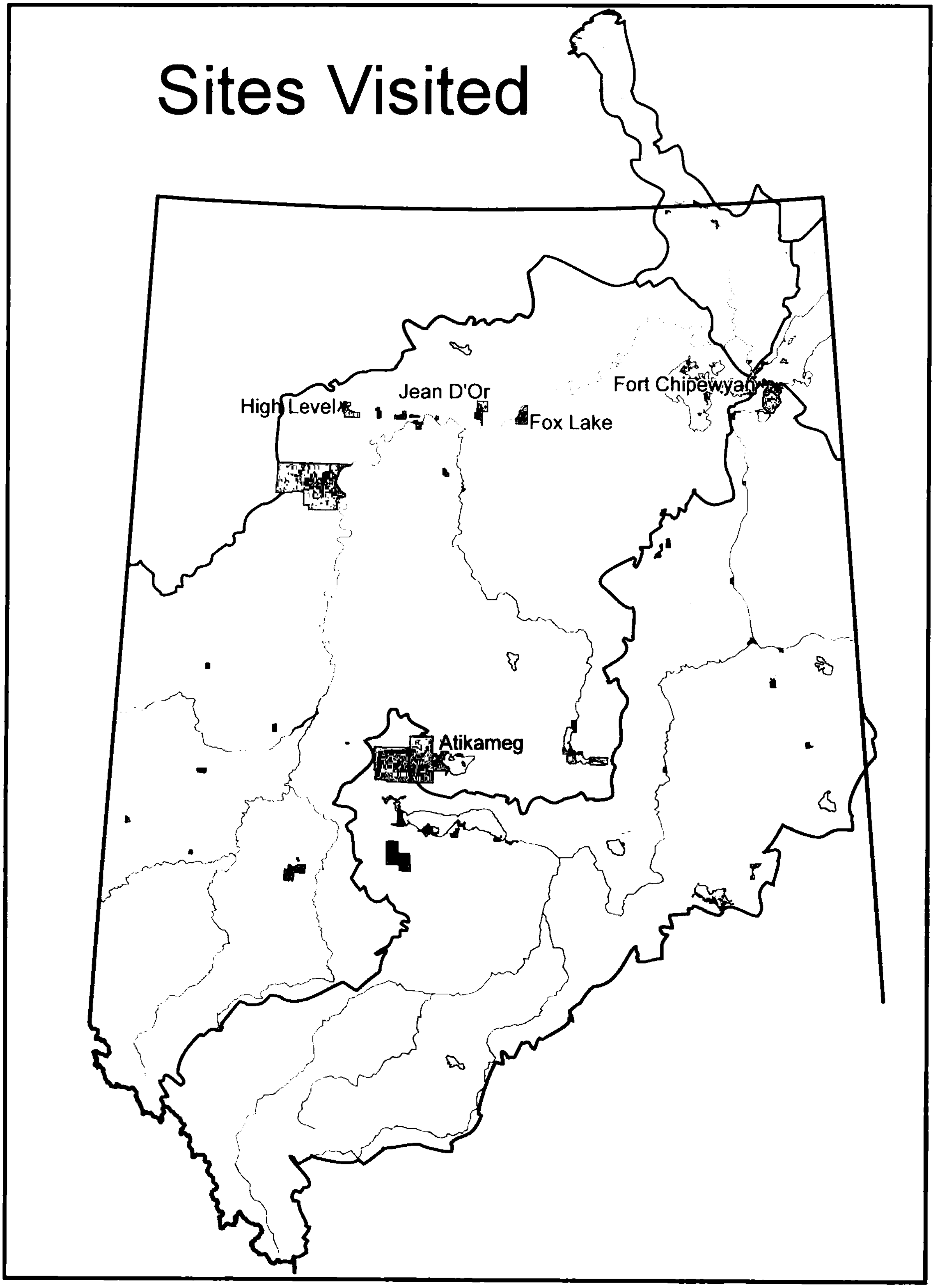


Figure 22. Sites Visited in Assessment of Non-Conventional Drinking Water Supplies



drinking water perceptions, non-conventional drinking water consumption, and non-conventional drinking water treatment methods utilized. A total of 28 people were interview and a total of 20 samples of non-conventional drinking water were collected and analyzed for physical, chemical and microbial parameters during the field work. Although it is recognized that this is a relatively small number of samples, it still represents some baseline data from which further studies may be carried out. The results from the sampling component and relevant explanations given by the study area residents are presented below. Each type of non-conventional drinking water is discussed below in terms of the physical, chemical and microbial challenges that influence the sample. The actual results of the physical, chemical, and microbial analysis performed on the non-conventional water samples are included in Appendix F. The results of the sample analyses are discussed with reference to the guideline values in the GCDWQ. However, it should be noted that non-conventional drinking water samples are generally not considered a community drinking water supply and are therefore the standards on these supplies are not legally enforceable.

6.3.1 Self-Hauled Treated Drinking Water

Some NRBS residents that live in remote rural areas in the study area haul conventionally treated drinking water in small pails from somewhere in the distribution system, such as the Health Unit or the school, to the place of consumption. The reason that this self-hauled conventionally treated drinking water is included as a non-conventional source of drinking water is because the direct distribution step from the plant (either piped or trucked delivery) is missing. Brocklehurst *et al.*, (1985) describe the self-hauling procedure as being inconvenient and placing a heavy burden on haulers, which would tend to keep water consumption low especially in the winter. Studies have shown that those who must haul water will almost never have all of the water necessary for ordinary demands and decreased quantity of water has been implicated with poorer health (McJunkin, 1982). Microbial risks are also associated with self-hauled drinking water because the storing of drinking water increases the likelihood of bacterial generation; and the longer it is stored, the poorer quality it is likely to be (Gabler *et al.*, 1988). Compliance with GCDWQ parameters was not determined for this non-conventional drinking water supply.

6.3.2 Surface Water

Lakes, rivers, creeks and other surface water reservoir are the source of non-conventional drinking water for some NRBS residents and have the same challenges as would be expected for any raw water supply as described in Section 4.1 and in Section 6.1. In the case of lake, river and creek water collection for drinking water supplies, small water containers are filled up and transported to the point of consumption. In the surface water samples collected, physical, chemical and microbial parameters exceeded MAC, IMAC and AO limits set in the GCDWQ. Turbidity values ranged from a low of 3 NTU to greater than 100 NTU with an average of 23 NTU. The aesthetic objective of 15 TCU for colour was also exceeded for each sample. There were some inorganic chemical challenges in the surface water samples analyzed. The health related guideline for mercury was exceeded in 3 of the samples collected. It should be noted that this violation was for samples collected in an area where naturally occurring mercury levels are high. Manganese and iron concentrations also exceeded AOs in the GCDWQ. The greatest challenge to the surface water samples collected was a result of microbial factors. All of the samples collected were positive for total coliforms. Due to the limited samples taken and the lack of consecutive samples, compliance with GCDWQ cannot be established with certainty, but it can be said that coliforms were detected indicating the possibility of fecal contamination. A variety of other organisms were found in the surface water samples to a varying degree including fecal coliforms in two samples, fecal streptococci, *Klebsiella*, yeasts, molds, and generally high levels of background bacteria. Total organic carbon levels in the surface water samples collected ranged from 5.0 to 29.0 mg/L.

6.3.3 Groundwater

There were two groundwater samples collected during the assessment of non-conventional drinking water. One was from an open flowing spring and the other was from a well protected enclosed groundwater well. Microbially, both the spring and well met the MACs established for microorganisms in the GCDWQ. However, the levels of some of the other parameters found in these two samples are a cause for concern. Inorganic chemical challenges for groundwater supplies are indicated by level of iron and manganese that exceed the AOs in the GCDWQ. Once again, the mercury level was above the MAC for a sample collected in the John D'Or Prairie area that has naturally high levels of mercury. Although ammonia is not regulated in the GCDWQ, ammonia can present an inorganic challenge for groundwater supplies and may indicate contamination. The level of ammonia found in the groundwater well samples is higher than expected and may indicate contamination. Organic challenges to groundwater wells occur with infiltration of organic chemicals such as pesticides. The measure of the total organic carbon in the groundwater was 20.7 and 5.4 for the surface spring and well, respectively.

The results obtained from the site visit samples are consistent with the values expected in the literature. Generally, groundwater is free from pathogenic microorganisms (although this is not inclusive). However, as a result of the proximity to the soil and bedrock, erosion of inorganic chemicals is common, and often inorganics such as nitrates and high total dissolved solids are a challenge.

6.3.4 Environmental Water

During the site visits, Drinking Water Component researchers were told about several non-conventional sources of drinking water from environmental sources other than surface waters and groundwater. This included water obtained from the muskeg, birch trees, rainwater, melted snow and melted ice. The method of collection for each of these sources was described by the NRBS residents interviewed and the methods are summarized in the report by Armstrong *et al.*, (1995). The utilization of these environmental drinking water supplies is seasonal-dependent. Of course, the snow and melted ice collected for drinking water purposes is done in the winter months. The ice collecting season is over when the ice is no longer safe to walk or drive on and the end of the "good quality snow water" collecting season is in the early spring at the first sign of tiny bugs (Chalifoux, 1995). However, once spring arrives the birch trees can be tapped. The birch tree water collection season lasts only a for very short period; typically one to two weeks (St. Arnault, 1994). Rainwater collection occurs in the basins by some people from late spring, throughout summer and into autumn (St. Arnault, 1994). Muskeg water is collected in the late spring and during the summer (Fraser, 1994).

Unfortunately, the non-conventional drinking water site visits only coincided with the snow and ice collection season, and so samples of the other types of environmental water were not analyzed. Although no literature was found on the quality of muskeg water and birch tree water, there was some information on rainwater quality. A USEPA (1974) document stated that although precipitation in the form of rain, snow, hail and sleet contains trace amounts of mineral matter, gases and other substances, it has virtually no impurities. However, once the precipitation reaches the earth, chemical and microbial pollutants are introduced from human contact and contact with collection surfaces (Mayo and Mashauri, 1991). Therefore, rainwater quality is influenced by the quality of the precipitation, deposition on the collection surfaces and the introduction of contaminants into the system (Mayo and Mashauri, 1991).

The snow samples collected for drinking water had some physical, chemical and microbial challenges upon comparison with the GCDWQ. Physical parameters exceeding GCDWQ included the MAC for turbidity, and the aesthetic objectives for pH and colour. The conductivities were much lower than for surface and ground water samples. Iron was the only inorganic chemical constituent measured for which there was an excess. It is possible that the collection and melted container contributed some iron and colour to the sample. The snow water samples collected both showed the presence of total coliform organisms. Although, definite conclusions about the compliance with the GCDWQ cannot be established with certainty, the detection of coliforms does indicate that the snow is potentially contaminated with pathogenic organisms. Yeasts and molds were also found in the snow water samples.

6.3.5 Bottled Water Samples

Bottled water consumption in North America is increasing at a rate of 25 % per year (Wilson, 1991) and it has been hypothesized that the sale of bottled water has skyrocketed anywhere the public suspects the local water supply is contaminated. There are a variety of types of bottled water on the market including still water, sparkling water, spring water, pharmaceutical grade purified water, mineral water, distilled water and plain bottled water (Gabler *et al.*, 1988). In Canada, bottled water is considered a food product so it is not regulated under the GCDWQ regulations. Rather, the Food and Drug Act has a clause that *recommends* GCDWQ limits, but these are not legally enforceable.

Two brands of bottled water from the NRBS area were analyzed for physical, chemical and microbial parameters. The turbidity of both bottled water samples was less than 0.5 NTU which meets the health related 1.0 NTU guideline value. The AO for iron was exceeded in both bottled water samples. No coliform organisms were detected in either bottled water sample. However, the heterotrophic plate counts were greater than 500 cfu/mL for both samples indicating that this high count could be inhibiting the growth of coliform colonies and according to the GCDWQ, the water sample should be re-sampled. This high general bacterial population is consistent with values found in the literature. Bottled waters can also have associated organic challenges. Organics can leach from plastic bottles that are often used to sell the water.

6.3.6 Point-of-Use Treated Water

Any of the above non-conventional drinking water supplies just discussed could potentially be further treated at the point of consumption by a variety of methods. There are innumerable point-of-use devices on the market to treat potable water supplies in the home and just as many drinking water treatment processes. Further discussion and an assessment of some of the potential treatment processes and devices that could be used in the NRBS area is found in Section 7.2.

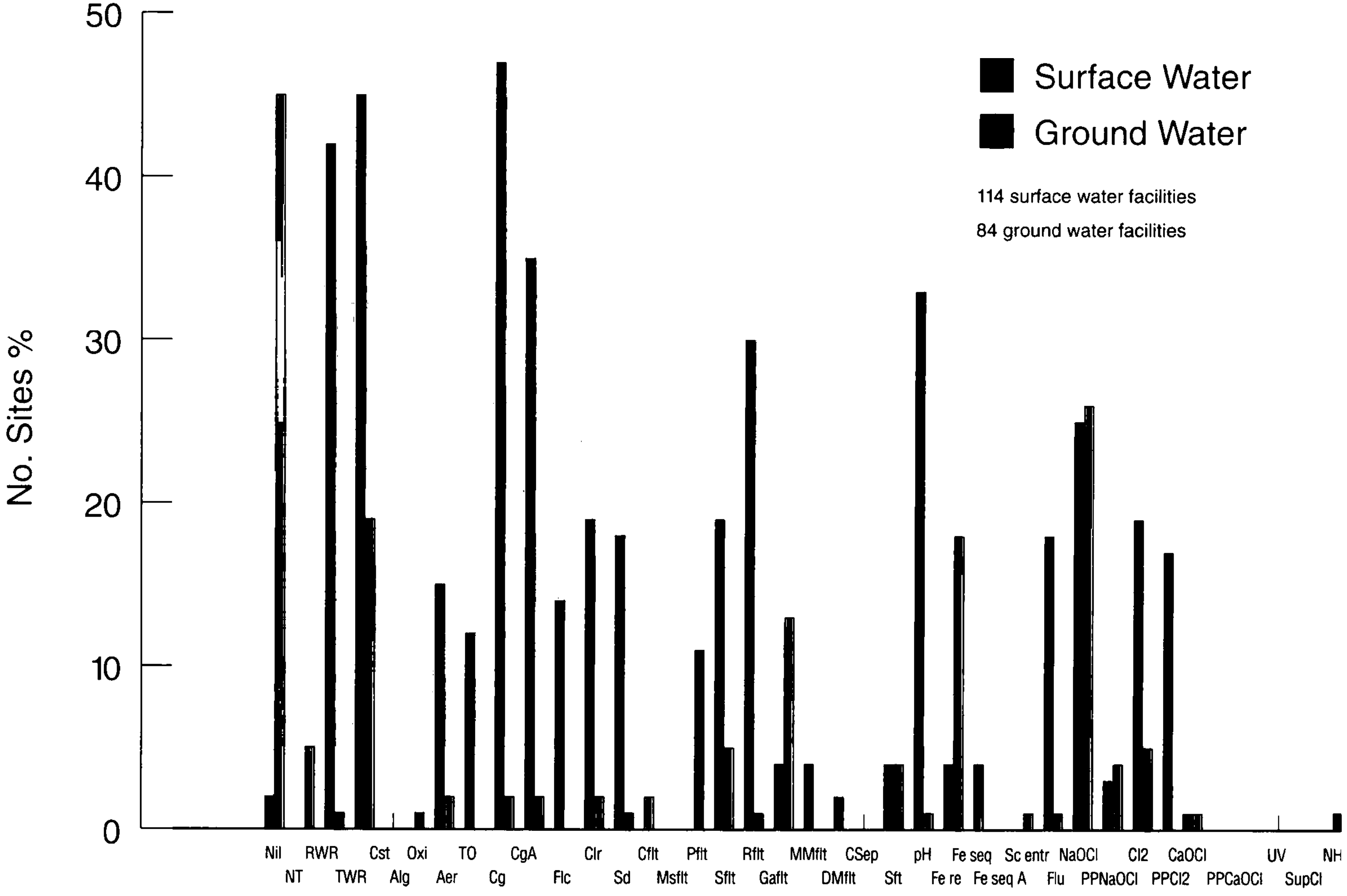
During the remote site visits in the NRBS area, one resident was interviewed who was further treating the water supplied to her home with a portable filter device. Therefore, a sample of the conventionally treated water influent and the point-of-use treated water effluent of water going through this device were sampled and interesting results were obtained. The conventional drinking water influent met all of the health related GCDWQ. However, the effluent sample had higher levels of yeasts, molds, general bacteria and also total coliform organisms. Therefore, all of these organisms had been contributed by the water treatment device itself. The consumer in this situation was using this device to get rid of the taste and odour of chlorine. From the results, it appears that this device is effective at removing both total and free chlorine. Free chlorine in the influent was 1 mg/L and in the effluent it was 0.05 mg/L. Based on the contribution of coliforms (suggesting bacterial colonization of the filter) and the reduction of chlorine, it is possible that the device contained activated carbon.

7.0 ASSESSMENT OF DRINKING WATER TREATMENT IN THE NORTHERN RIVER BASINS

7.1 CONVENTIONAL DRINKING WATER PLANTS

As is the case elsewhere, the standard conventional drinking water treatment plants differ for facilities using ground water and those using surface water sources. Figure 23 (Prince *et al.*,1995a) gives a summary of the treatment processes used in the NRBS area. The figure is not completely up to date but it shows that 15 % to 20 % of ground sites have processes for the removal of manganese and iron and the rest have no treatment except for chlorination (there are also several without chlorination). Most surface water facilities use a coagulation-sedimentation process followed by filtration and disinfection. These processes are combined in a variety of ways at the different plants. There are package plants, old and new, and individually designed and built plants as well. The dominant contrast amongst the surface water treatment plants is the difference between the large community and the small community and it is not just the size of the facilities but it is more importantly the amount of effort and care that can be afforded to run the facilities.

Figure 23. Summary of Treatment Processes Used in NRBS Conventional Facilities.



7.1.1 Small Systems

The performance problems at small drinking water treatment facilities is a well documented phenomenon. Prendergast (1993) describes the situation in Pennsylvania as follows; "of the approximately 2,400 community water systems in the state, 2,100 are small systems (population less than 3,300). They serve about 10 % of the population, but account for 90 % of regulatory violations." The results of the analysis of water quality in the previous section shows similar trends and identify the smallest communities as having the most difficulty meeting standards (Prince *et al.*, 1995b). The USEPA small systems coordinator commented that small system performance problems have been well documented as early as 1970 and that consistently, these performance problems can be traced to underlying weaknesses in the technical, financial, and managerial capabilities of these systems (Shanaghan, 1994). It is interesting that not only are small systems weaker technically and financially but small systems face poorer raw water quality than large systems because most are not on the larger river systems.

The results of a survey by the American Water Work Association indicated that most systems serving populations from 1000 to 3300 have the financial and technical expertise to manage their problems while systems from 500 to 1000 have more of a challenge and the rest below 500 are in trouble. "No group is reaching the smallest systems", says T. Lay, manager of AWWA small systems program (Prendergast, 1993). Many small systems are very well managed and operated, while others are in trouble because they are incidental parts of other undertakings (Shanaghan, 1994).

The solution to the problem of small systems performance is a complicated matter. The performance of a water system is inseparably linked with the viability of the system. Summarizing current discussions on system viability Shanaghan (1994) proposed a definition of water system viability as a system that has the technical, financial, and managerial capacity to consistently comply with current and prospective performance requirements. Cromwell *et al,*. (1992) warned that a piecemeal approach to addressing current problems and future regulations could become a trap for systems and that an assessment of system viability will give the systems confidence to proceed on their own or discover restructuring opportunities.

Small systems are struggling in the NRBS area and elsewhere. The situation is worsening with aging facilities and quality standards that continue to be tightened in these current times of fiscal restraint. The challenges facing small systems is formidable and innovative new ways of dealing with problems are required.

7.1.2 Medium Systems

While the larger communities showed better performance than the smaller ones there are still areas of concern with these. An important concern is the consistency of performance. The water quality reporting by AEP currently requires the analysis of one sample per day reported. Studies show that this may not be representative of the overall water quality (Prince *et al*, 1995b). Most plants start-up and shut-down as the need for water arises. The starting up of filters in this manner may result in turbidity spikes that may be serious.

The anticipated tightening of standards, particularly of turbidity, will challenge the current ability of these systems to perform. However, the larger communities are in a better situation to respond to any quality problems and future tightening standards. These systems can afford a full-time operator and give them the support necessary to be successful in providing good quality drinking water on a consistent basis.

7.2 NON-CONVENTIONAL DRINKING WATER TREATMENT

There are a variety of non-conventional drinking water treatment devices and processes that may be used to treat water at the point-of-use (POU). The treatment methodologies range from simple boiling procedures to multi-barrier treatment devices such as sophisticated package plants that mimic conventional drinking water treatment facility processes on a smaller scale.

The Other Uses Component survey asked both conventional drinking water consumers and non-conventional drinking water consumers whether or not they further treated their drinking water at the point-of-use, and if so, what sort of treatment was applied. The results showed that on average, 33.7 % of NRBS residents that consume non-conventional sources of drinking water practice some household treatment. Table 24 lists the type of treatment reported depending on the non-conventional source of drinking water consumed.

Table 24. Point of Use Treatment Practiced on Non-Conventional Drinking Water Supplies

Non-Conventional Water Source	Percent that further treat*	Filter	Chlorine	Distill	Boil	Minerals	Copper Sulphate	Reglone
Wells	29.5 %	25.5 %	15.0 %	29.0 %	5.4 %	23.0 %	0.0 %	0.0 %
Lake Water	56.8 %	31.3 %	19.2 %	37.1 %	17.4 %	0.0 %	0.0 %	0.0 %
River Water	41.7 %	55.3 %	0.0 %	0.0 %	44.7 %	0.0 %	0.0 %	0.0 %
Dugouts	40.4 %	33.2 %	21.8 %	8.1 %	0.0 %	0.0 %	28.8 %	8.1 %

(Adapted from Other Uses Component, 1995)

* The percent that further treat are listed for each water supply. Therefore, it is the weighted average of these figures that make up the 33.7 % of non-conventional consumers that further treat their drinking water.

Further treatment of non-conventional supplies was the least for well water consumers compared to the other non-conventional drinking water sources. The further treatment methods for well water consumers included: filtration, chlorination, distillation, boiling and treatment of minerals. 57 % of lake water consumers further treat their water. Filtration, chlorination, distillation, and boiling were all reported. River water consumers did not report treatment by chlorination or distillation. However, both filtration and boiling were practiced. 40 % of people consuming water from dugouts reported further treating their drinking water. Filtration, chlorination, distillation, and copper sulphate and reglone addition were practiced.

Twenty-eight percent of the people who consumed conventional drinking water reported additional treatment in their homes. The most common treatment method reported by conventional drinking water consumers was filtration (65 %). Boiling (16 %), distillation (16 %), and reverse osmosis

(3%) were also cited by NRBS residents as point-of-use treatment performed on conventional drinking water supplies. A summary of some of these POU treatment processes and devices is presented below in Section 7.2.1 and 7.2.2, respectively. In addition, more in-depth reviews on treatment methods for the removal of specific inorganic, organic and microbial contaminants were completed by the Drinking Water Component. Interested readers are referred to the documents by Liem *et al.*, (1995); Oke *et al.*, (1995); Zhou *et al.*, (1995) and Armstrong *et al.*, (1995).

7.2.1 Non-Conventional Drinking Water Treatment Processes

7.2.1.1 Boiling. "Heat is the oldest, safest, and most effective method of purifying water (Health and Welfare Canada and Environment Canada, 1991)." Boiling works on the principal that microorganisms cannot tolerate the high temperatures and bacterial cells rupture and proteins are denatured (AWWA, 1990). The amount of time that is recommended for boiling water so that the water is considered safe for consumption varies widely in the literature as illustrated in Table 25.

Table 25. Effective Boiling Times Cited in Literature

Reference	Boiling Instructions	Sufficient to:
Aukerman, 1989	Brought to a boil	Inactivate Giardia
Aukerman, 1989	55°C	Inactivate Giardia
Unknown (in Aukerman, 1989)	5 minutes at 64°C	Inactivate Giardia
Cerva, 1955 (in Aukerman, 1989)	Heated to 50°C	Inactivate Giardia
AWWA, 1994	Bring water to a rolling boil	Purify tap water
Dairy, Food and Environmental Sanitation Editors, 1993	Boil at 100°C for 1 minute	Kill any disease causing bacteria in the water
Fogel, 1982	Bring water to an instant boil	Kill Giardia lamblia cyst
Gabler, 1988	15 minutes at 121°C	Kill bacterial spores
Tobin, 1984	Boil for 1 minute	Kill almost all types of waterborne pathogens
Health and Welfare Canada, 1985 Dispatch	Boil for 1 minute	Kill most pathogens
Health and Welfare Canada, 1985Dispatch	Boil for at least 5 minutes	Ensure disinfection
Health and Welfare Canada, 1986	Boil for several minutes (when in doubt, 5 minutes)	Kill protozoan cysts
Health and Welfare Canada, and Environment Canada, 1991	At least 15 minutes and one extra minute for every 300m above sea level.	
Health Canada Boil Water Notice, 1995	At least 10 minutes	
US Department of Health Education and Welfare, 1965	Vigourous boiling for 1 full minute.	Kill any disease causing bacteria in the water.
USDA Forestry Service, 1989	1 minute boiling 3-5 minutes at high altitude	Inactivate Giardia
USEPA (Rice, E. and Johnson, C. 1994 in AWWA, 1994)	Full boil for 1 minute. Full boil for 3 minutes to compensate for lower temperatures at higher altitudes.	Kill cholera
WHO, 1993	Vigorous rolling boil for around 1 minute.	Inactivate viruses, bacteria and Giardia cysts.

(Source: Armstrong *et al.*, 1995)

Despite the low level of technology required for this treatment method, there are several drawbacks that limit its usefulness. The primary one is the requirement of fuel to heat the water. Also, boiling water is time consuming. Furthermore, the aesthetic quality of the water supply is not generally improved by boiling. Finally, the effectiveness of boiling is compromised by turbidity. However, in addition to the inactivation of microorganisms by heat treatment, boiling the water can also result in the removal of chlorine and volatile organics such as the trihalomethanes (Gabler *et al.*, 1988). Therefore, boiling is an effective method in the provision of a safe supply of drinking water.

7.2.1.2. Chemical Addition. Chlorine compounds are suitable disinfectants of raw water supplies. There are three chemically equivalent forms of chlorine that may be used as a disinfectant in drinking water treatment: (1) compressed gas; (2) sodium hypochlorite solution (bleach); and (3) solid calcium hypochlorite (AWWA, 1990). When chlorine is added to water, hypochlorous acid is formed which is the agent responsible for the inactivation of bacteria and viruses by disrupting normal cell functions such as respiration and DNA activity (AWWA, 1990). CT (concentration Σ time) values can be used to assess disinfection capability. Based on CT calculations in Armstrong *et al.*, (1995) it was found that to treat one litre of water for a 3 log reduction of *Giardia* using 0.1 mL of 5.25% household bleach (as recommended in the literature) would require 173 minutes or almost 3 hours for 0.5∞C waters and 45.5 minutes for 20∞C waters. Therefore, a strong correlation between temperature and disinfection capability is observed. The presence of ammonia and higher pH's also increase the reaction time required for disinfection by chlorine.

Iodine is another chemical that can be used to disinfect drinking water. Eight to ten drops of a 2 % tincture of iodine (commonly found in medicine cabinets) with a 30 minute contact time is sufficient to disinfect 1 L of water (Health and Welfare Canada and Environment Canada, 1991). Once again variation was found in the literature.

Ozone is an unstable form of oxygen that is an oxidizing agent that strips electrons from molecules and has been called the most powerful disinfection agent known (Burris, 1986; Pontius, 1994). Researchers have hypothesized that there are two primary oxidation pathways when ozone is dissolved in water: direct oxidation by molecular ozone and indirect oxidation by free radicals that are formed during decomposition of ozone in water (Zhou *et al.*, 1995). Typically, microbial inactivation occurs when ozone breaks molecular bonds on the cell wall, thereby lysing the cell (Zhou, 1995). Ozone is unstable and must be generated on site. Therefore, ozonators are actually POU devices such as some of the other devices that are discussed in the next section.

7.2.2 Non-Conventional Drinking Water Treatment Devices

The utilization of POU treatment devices for supplying a safe supply of drinking water has been gaining popularity. According to the Canadian Water Quality Association, the sale of point-of-use devices is a 700 million dollar a year industry in Canada (Robertson, 1995).

7.2.2.1 Disinfection Units. Chlorinators and ozonators are devices that administer a given dose of disinfectant that works by the mechanisms described above. Ultraviolet (UV) irradiators are also disinfection units that may be installed as a POU device. UV light is short wavelength radiation with a wavelength between 180 nm to 400 nm that inactivates microorganisms DNA (Gabler, 1988). Limitations with UV disinfection units are that turbidity limits their effectiveness, spores of *Giardia* and *Cryptosporidium* are not killed by UV radiation, and UV units require electricity and significant supervision and maintenance (Jacobsen, 1994; Culotta, 1989). Distillers can also be considered disinfection units because the distillation is a process whereby water is heated in a flask and the steam is collected and condensed back into liquid form (Gabler *et al.*, 1988). Distillation is an effective method for the reduction of dissolved solids, metals, minerals and particles (Culotta, 1989). Furthermore, boiling the water will effectively kill microorganisms. However, distillers have the potential to concentrate volatile organic chemicals with lower boiling points than water (such as pesticides, chloroform, benzene, toluene and xylene) because these chemicals will boil off with water and become concentrated in the treated water (Lester and Lipsett, 1988).

7.2.2.2 Mechanical Particle Removal Units. Adsorption units, ion exchange units, reverse osmosis systems and a variety of filters are all examples of POU treatment devices that physically remove particles from the water. Adsorption is the accumulation of a substance at the interface between two phases, such as a liquid and a solid (AWWA, 1990). Activated carbon is an effective adsorbent that has minuscule pores that increase the surface area for particle adsorption and entrapment (Geldreich and Reasoner, 1990). Activated carbon units are effective at removing organic chemicals, taste and odour causing compounds and chemical compounds produced by microorganisms (Lester and Lipsett, 1988). However, activated carbon is not effective at removing heavy metals, nitrates, dissolved iron or bacteria. In fact, using activated carbon devices may lead to the deterioration of the microbial quality of the treated water. Bacterial colonization of activated carbon POU devices has been well documented (Gabler *et al.*, 1988; Geldreich *et al.*, 1985; Reasoner *et al.*, 1987; Regunathan and Beauman, 1987). Furthermore, once the carbon is exhausted, there is the potential for collected contaminants (microbial and organic) to be sheared off and released from the filter beds leading to an increase in these contaminant levels in finished water (Lester and Lipsett, 1988). It is for this reason that Health and Welfare Canada (1991) insists that activated carbon units are only used "on municipally treated water or other supply known to be microbiologically safe."

Home water softeners are a common POU device that works on the principal of ion exchange. Ion exchange is a process in which ions in solution are exchanged with ions of like charge located on the surface of the solid being contacted (Montgomery, 1985). Water softeners typically remove "hard" calcium and magnesium ions for "soft" sodium ions attached to resin beads in the softener. Ion exchange units are also effective at removing other types of contaminants. For example, cationic softeners exchange sodium and potassium ions for calcium, magnesium, iron and manganese ions, while anionic softeners exchange hydroxyl ions for sulfates, nitrates, bicarbonates and chlorides (Culotta, 1989).

Reverse osmosis systems involves applying a pressure differential across a semi-permeable membrane so that dissolved ions, molecules and solids cannot pass through, but water can (Geldreich and Reasoner, 1990). While reverse osmosis units are very effective at removing heavy metals, total dissolved solids, nitrates, asbestos, and *Giardia* cysts, the membranes are not effective at removing small organic molecules. Furthermore, the membrane is susceptible to microbial degradation or breakage from excessive water pressure or chlorination (Geldreich and Reasoner, 1990).

Filtration is a water treatment process used to remove suspended particulate matter such as clay, silt, microorganisms and other organics (AWWA, 1990). Removal efficiency depends on the quality of the water supply as well as the type of filter being used. There are two classes of filters: depth filters and screen filters. Depth filters consist of an array of fibrous, granular or sintered material that is pressed, wound or bonded together and particles are trapped throughout the whole depth of the filter (Gabler *et al.*, 1988). Screen filters retain all particles larger than a given pore size on the upstream surface of the filter. The size of the mesh is the controlling factor in this method. Membrane filter papers exist with a pore size of 0.2 m. With this small size, the filters are capable of retaining bacteria. However, because of this small size, the filters clog rapidly and they are expensive (Gabler *et al.*, 1988).

There are a wide variety of portable POU drinking water treatment filters on the market that claim to be suitable for treating contaminated drinking water for wilderness camping and international traveling purposes. Since there are many residents in the study area that partake in traditional living off the land wilderness activities, as part of the assessment of non-conventional drinking water supplies, the Drinking Water Component tested a select group of portable filters. The filters were chosen to represent the larger industry as a whole. One of the most expensive ones on the market, the least expensive one, and a mid-price range filter were chosen. Each was from a different manufacturer and each had a different media. The media employed was silver impregnated ceramic (most expensive), granular activated carbon (mid-price range), and polyethylene matrix (least expensive).

An experimental protocol was set up based on the Protocols for Point-of-Use Devices Guide Standard and Protocol for Testing Microbiological Water Purifiers (USEPA, 1987). The filters were tested under worst case conditions that would be expected in the NRBS area. Challenge test water was developed that had an *E. coli* challenge of approximately 10^6 cfu/100mL; 20 mg/L TOC; 180 mg/L TDS; a turbidity of 30 NTU; pH 8; and particle challenges by particles ranging in size from 1m to 50m. The basic experimental design was a two way analysis of variance with the filter types as the *treatment* variable and microbial reduction, particle reduction and turbidity reduction as the *effect* variables. Both the treatment and effects were analyzed in triplicate so that variations between and within treatments could be established. The filters were manually pumped simultaneously and effluent samples were collected at pre-determined volume throughputs.

Essentially, it was found that only the performance of the silver impregnated ceramic unit was sufficient to meet the GCDWQ. All *E.coli* organisms were inactivated throughout the entire experiment and turbidity was removed to less than 1 NTU. Particle reduction in the *Cryptosporidium* and the *Giardia* range was 4 log. On the contrary, neither the plastic unit nor the activated carbon unit was effective at removing *E.coli*; even at the first litre filtered. In fact, there was evidence of bacterial colonization in the carbon filter. Particle reduction and turbidity reduction was also poor for the plastic and carbon filter. However, further tests are required on the ceramic unit before it can be recommended for use in the NRBS area. Interested readers are referred to Armstrong *et al.*, (1995) for more in-depth discussion of this experiment and for more information about the portable filters on the market available to NRBS residents.

8.0 CONCLUSIONS

8.1 DRINKING WATER QUALITY GUIDELINES AND PUBLIC HEALTH

Water is a basic human need and it is essential to sustain life. An adequate supply of *safe* drinking water is a prime requisite in the maintenance of good health. In Canada, the definition of *safety* in drinking water is based on whether or not the water quality parameters of a given water sample meets the limits outlined in the Guidelines for Canadian Drinking Water Quality. It is assumed that if the water supply in question meets all of the recommended levels set in these guidelines, that the quality is good and that the water is safe to drink.

Although the GCDWQ are intended to apply to all public and private drinking water supplies, in Canada, the regulation of drinking water supplies is under provincial jurisdiction. The province of Alberta is the only province in Canada that has adopted the Guidelines for Canadian Drinking Water Quality as legally enforceable standards. The legalities of drinking water quality control in Alberta are stated in Alberta Environmental Protection's (1988) Standards and Guidelines for Municipal Water Supply, Wastewater, and Storm Drainage Facilities as follows:

1. The water delivered to consumers shall meet the health related quality standards as outlined in the Health and Welfare Canada Guidelines for Canadian Drinking Water Quality. For those standards based on aesthetic considerations, less stringent requirements may be adopted by Alberta Environment;
2.. The water treatment system shall provide a basic level of protection against all possible sources and types of raw and treated water contamination; and,
3. Sufficient water must be available to meet the needs of the consumers, which may include fire protection.

In the GCDWQ, physical, chemical, microbial and radiological parameters are assigned Maximum Acceptable Concentrations (MACs) for substances that have known or suspected health threats. Interim Maxiumum Acceptable Concentrations (IMACs) are given to substances for which there is insufficient information to establish a MAC and Aesthetic Objectives (AO) are assigned to parameters that affect the acceptability of the water by consumers and so that treatment is not compromised. Although substances with assigned AOs do not have a direct adverse effect on health, if the concentration of a substance is well above the aesthetic objective, then there is a possibility of a health hazard. In the assessment of drinking water quality in the Northern River Basins Study area, the GCDWQ were used as the basis of evaluation of samples collected from the area as well as historical water quality databases.

Another indirect evaluation of drinking water quality in the NRBS area involved the assessment of health records. In addition to the direct comparison of drinking water sample parameters with guideline values, potential waterborne disease rates were determined for each health unit district in the study area. The results obtained in this assessment provided both an indirect indication of the microbial quality of the drinking water, as well as insight into the general level of public health in the study area, using waterborne disease rates as the indicator. Only giardiasis, salmonellosis, shigellosis and Hepatitis A had enough study area data for analysis. The cases of giardiasis appear to be higher in the NRBS area than the provincial average. The incidence of shigellosis, salmonellosis and Hepatitis A by this comparison was not significantly greater than the province as a whole. Therefore, it is possible that the water supply systems are inadequate in terms of removing protozoan cysts such as *Giardia*. The general level of public health in the study area compared to the rest of the province cannot be assessed with certainty based solely on the results from this assessment of waterborne disease statistics. This is because the definition of health there are many other influential factors to health. Also, there are several other factors that affect whether or not an illness is correctly identified and reported. Nonetheless, it is concluded that the risks of aquiring a waterborne disease in the study area is a concern and this risk is correlated with the quality of drinking water consumed.

8.2 SOURCES OF DRINKING WATER

The quality of a drinking water supply is strongly dependent on the source from which it was obtained. In the NRBS area, there are a variety of sources whereby water is obtained for consumption. Conventional drinking water supplies are those obtained from a community drinking water treatment facility. There are 214 conventional drinking water facilities in the NRBS area. Although there are numerous variations and types of processe used at these NRBS treatment plants, conventional treatment of surface water supplies *typcially consists of*: coagulation, flocculation, sedimentation, filtration, disinfection and distribution steps. However, depending on the source water quality, some of these steps may not be included or others may be added. A non-conventional drinking water supply is defined as any drinking water supply that has not been obtained directly (either piped delivery or distribution truck) from a conventional drinking water treatment facility. Examples of non-conventional drinking water supplies being consumed in the NRBS area include:

1. surface water supplies such as untreated lake water, river water, dugoutwater;
2. groundwater sources such as from a well or spring;
3. environmental sources of water such as rainwater, water from melted snow or ice, muskeg water and birch tree water;
4. bottled drinking water supplies; and
5. point-of-use treated water of any of the above listed supplies including the further treatment of a conventional drinking water supply.

There were several assessments of the ratio of conventional to non-conventional drinking water consumers in the NRBS area. The best estimate of this obtained by the Drinking Water Component was that about 75 % of the people in the NRBS area received drinking water from conventional drinking water facilities. Therefore, the remaining 25 % relied on non-conventional sources of drinking water. This estimate was based on Census population data and on the population served from Alberta Environmental Protection's Facility Inventory data on all of the conventional treatment plants. The Other Uses Component of the NRBS was involved in a thorough telephone survey of residents and responses in their study indicated that for the most part, 55 % of NRBS residents consume conventionally treated drinking water, while 45 % of the residents claim to consume non-conventional drinking water supplies. The non-conventional sources of water reported from the Other Uses results included: bottled water (4.4 %), well/spring water (31.0 %), lake water (2.0 %), river water (2.8 %), and dugouts (4.4 %). A final estimate of the percentage of conventional drinking water consumption by first and second generation aboriginal elders in the NRBS area was obtained by the Traditional Knowledge Component. In this study it was found that only 5 % of the respondents consumed drinking water from a conventional treatment facility. The remaining 95 % relied on non-conventional sources such as: surface water (63 %), wells or springs (4 %), dugouts (1 %), rain or melted snow (1 %) and various (26 %). Although definite conclusions based on the results obtained from the different study components cannot be made with certainty, the data does show that there are many people in the study area that do not receive their drinking water from a conventional drinking water treatment facility. The percent of the population that relies on non-conventional supplies is likely in the range between 25 % and 55 %. However, there are some segments of the population that may be more disposed to non-conventional drinking water consumption. These segments possibly includes elderly people, health conscious residents, people involved in traditional living off the land activities, cultural groups, or residents that live in remote areas not serviced by conventional distribution systems.

8.3 CHALLENGES TO WATER QUALITY

Challenges to providing good quality drinking water exist for both conventional and non-conventional potable water supplies in the NRBS area. For both types of supplies raw water quality is an important indicator of finished water quality. In the case of non-conventional supplies, sometimes raw water is the finished water. Physical, chemical, and microbial challenges to raw water occur as a result of both natural and anthropogenic activities. Both man-made and natural activities in a watershed have some effect on the physical parameters of NRBS waters, including temperature changes, dissolved solids concentrations, taste, colour, odour and appearance changes, and possibly ecosystem changes.

Chemical and microbial challenges to raw water quality as a result of natural factors are numerous. A wide range of microorganisms can be found in NRBS waters. Furthermore, wild and domestic animals are potential carriers of human pathogens, so even remote, pristine watersheds away from human activity may have significant pathogenic reservoirs. Inorganic chemicals such as metals occur naturally in water supplies as a result of contact with the earths crust via the underlying bedrock and sediments. Other inorganic chemicals may be present in a water supply depending on the ecosystem activity. For example, hydrogen sulphide is a by-product of anaerobic degradation by microorganisms. Most of the organic matter that occurs naturally in NRBS water systems is humic and fulvic substances which result from the breakdown of deposited organic material.

Significant man-made influences affecting raw water quality in the NRBS area include point-source discharges from 140 licensed municipal sewage treatment plants, 10 pulp and paper mill effluents, and 1 oil sands operation. Non-point source discharges into water in the study arearesult from surface municipal runoff, agricultural inputs and changes that occur as a result of the extensive forestry harvesting occuring in the area. Municipal sewage effluents and some farming practices can result in a significant release of microorganisms and input of inorganic nutrients that aid in the eutrophication process into Northern River Basins receiving streams. A variety of organic substances are contributed to raw water supplies in the NRBS area by agricultural pesticides, oil sands mining effluents, and pulp mill process streams. All of these anthropogenic influences present a challenge to the receiving water and also to the potential treatment of these sources. Therefore, it is vitally important to protect source waters from both bacterial and chemical pollutants for both health and economic reasons.

The actual treatment and distribution of conventional drinking water supplies are also challenges to drinking water quality in themselves. Tastes and odours contributed by treatment chemicals such as chlorine, or from leaching of construction materials and piping in the distribution system, are common physical challenges experienced by the water treatment industry. Inorganic chemical challenges also occur in treated drinking water as a result of the addition of chemicals in the treatment processes. For example, the common coagulant, alum, may contribute traces of aluminum to finished water supplies. Another process that is discussed as an inorganic challenge because of the mechanisms and associated ionic players, is corrosion. Corrosion of pipes in the treatment plant and the distribution system is a real problem. Leaks or infiltration that can occur as a result of corroded materials is a challenge to the supply of a good quality drinking water. Microbial challenges are also a concern for both treated and distributed drinking water. Recently, concern has mounted over the increased resistance that some viral and protozoan agents have to conventional disinfectants such as chlorine. This is a challenge to conventional treatment facilities to ensure microbiologically safe drinking water. Furthermore, the ability of microorganisms to attach to surfaces and grow in distribution systems as biofilms is a challenge to distributed water quality. Finally, there are also organic challenges associated with treated and distributed drinking water. Organic disinfection by-products associated with the utilization of chlorine in drinking water treatment has been receiving increased attention in recent years for their potential adverse effects on health. However, the World Health Organization (1993) clearly states that the risks associated with inadequate disinfection are great, and control of microbial contamination must be of paramount importance and not be compromised.

8.4 AESTHETICS

The aesthetic quality of water is the sensory perception of how water looks, tastes, smells and feels to the consumer. It is essentially this sensory evaluation of drinking water that is used as the basis by which consumers judge the quality of their drinking water. Therefore, the water industry must ensure that the water that they supply not only meets health related GCDWQ, but is also aesthetically pleasing to satisfy the consumer. The Drinking Water Component studied off-flavours (perceived "bad" taste or odour) in both raw and treated drinking water in the study area using both analytical (CLSA/GC-MS) and qualitative methods (sensory assessment by FPA), as well as a combination of the two (Olfactory GC).These three techniques all provide quite different information, and all three have certain limitations. GC/MS results give quantitative numbers for selected target compounds. The limitation with this is that the correct target compounds must be chosen and currently, pulp mill effluent off-flavours are not well characterized (Kenefick *et al.*, 1995). OGC analyses give semi-quantitative statements about the spatial distribution of odours in a sample and in some cases link odour with compound. However, as in GC/MS analyses, target compounds are required to be selected. Flavour Profile Analysis results give an overall odour and intensity of the whole sample based on human sensory perception, but individual components cannot be measured or quantified. However, this qualitative assessment is the most useful representation as to what would be perceived by the NRBS residents themselves.

The main body of work completed in regards to the aesthetic quality of water in the NRBS area focussed on the odour profile of the mainstem Athabasca River; tributaries that feed the Athabasca River; the municipal and industrial effluents that discharge into the Athabasca River; and the finished drinking water from sites adjacent to the Athabasca River. The study was carried out over a two year period and samples were collected and analyzed under low flow winter conditions both before (winter 1993) and after (winter 1994) the Alberta-Pacific Forestries pulp mill came on stream. The flavour profile results showed that the characteristic pulp mill odour (described as septic, resin, woody, pulp and paper and swampy) was detected 950 km downstream of Hinton in both 1993 and 1994, although the intensity was much less in 1994. This was a result of changes in the process so that more condensate was recovered and the bleaching process was changed from 45 % to 100 % chlorine dioxide substitution. The AlPac mill also had a characteristic odour similar to the Hinton effluent but less intense. The impact of the AlPac mill on the Athabasca River could not be determined with certainty because of the background bleached kraft effluent already in the river and because the baseline data collected in the 1993 sampling period could not be used for comparitive purposes because of the major process changes in the Hinton mill. The CTMP pulp mill effluents had low odour intensities and so did the sewage treatment plant effluents. The Suncor Inc. oil sands effluent had a strong chemical and hydrocarbon odour but the impact on the Athabasca River could not be determined. The odours of the tributary samples were minor and did not contribute greatly to the overall odour of the Athabasca mainstem. The off-odours detected in other samples were not detected in the treated drinking water at either Fort Chipewyan or Fort McMurray. However, this may be a result of the masking effect of chorine.

The target compounds assessed for in the CLSA/GC-MS and OGC analysis could not, by themselves, explain the odour character perceived by the odour panel. The main change observed between the 1993 and 1994 sampling session by these analytical instrumental assessments was that 246TC and 345TCV were not detected in the Winter 1994 samples (except for one 246TCA detection). The reasons for this can be explained by the process changes in the Hinton plant. In the Post-AlPac study, organosulphur compounds were added to the list of target compounds. The findings suggest a link between these odourous sulphur compounds and wastewater biological treatment processes.

Further anecdotal and individual flavour profile assessments were carried out with conventional and non-conventional drinking water samples. Chlorine was the most common descriptor for treated drinking water samples. Non-conventional drinking water samples were described differently depending on the source. Anecdotal taste and odour complaints based on discussions with drinking water treatment plant operators and informal interviews with study area residents, were categorized. The aesthetic concerns raised included several associated with the utilization of chlorine, seasonal turnover events, algae and other biotic growth and industrial effluent influences. Although some of these concerns may be benign in terms of health consequences, some of the concerns may represent a real threat to health. Therefore, the aesthetic quality of a water source is an important factor in the assessment of the overall quality of the supply.

8.5 ANALYSIS OF WATER QUALITY DATA FROM THE NRBS AREA WITH RESPECT TO THE PHYSICAL, CHEMICAL AND MICROBIAL PARAMETERS IN THE GUIDELINES FOR CANADIAN DRINKING WATER QUALITY

Three separate assessments of drinking water quality based on comparison with the MAC, IMAC and AO limits established in the GCDWQ were carried out by the Drinking Water Component. The first assessment involved the analysis of existing data. Existing drinking water quality data was obtained from Alberta Environmental Protection databases including the: (1) treated water survey data; (2) drinking water facility microbial sampling data; (3) Naquadat raw water data; and (4) Other AEP surface water quality data. The second assessment of conventional drinking water quality in the study area involved site visits to 38 facilities to collect samples of raw, treated and distributed drinking water. Each sample was analyzed for selected physical, chemical and microbial parameters which were then compared to the GCDWQ. The third assessment of drinking water quality in the study area was of non-conventional drinking water supplies. Information was collected based on the collection of surface water, groundwater, snow water, bottled water and point-of-use treated water during site visits to three areas in the Northen River Basins. Each sample was analyzed for selected physical, chemical and microbial parameters and compared to the limits established in the GCDWQ.

8.5.1 Physical Parameters

Historical water quality data of conventional drinking water in the study area for physical parameters included information on the colour, pH, temperature, total dissolved solids, and turbidity. Turbidity is the only one of these that is regulated in the GCDWQ. The MAC guideline value for turbidity in treated water is 1 NTU 95 % of the time. The historical water quality data obtained was for samples taken from the distribution system so the MAC guideline value does not apply. However, insight into the quality is still gained by an assessment of the results. The conclusion made from the data was that surface water facilities that serve a population greater than 500 have significantly lower turbidities (a= 0.02) than facilities with a population less than 500. No statistical difference was observed for the groundwater facilities.

Since the turbidity samples taken during the conventional drinking water facility site visits was a *single* grab sample, these also could not be assessed for compliance with the guidelines, but a turbidity greater than 1 NTU does indicate that the facility may have difficulty meeting the turbidity standard. A trend was observed that the average turbidity in small hamlets or watering points is higher than the turbidity observed in larger towns. This observation was statistically significant (95 % confidence interval) for the watering points in the NRBS area. None of the non-conventional surface water sources sampled during the site visits were below 1NTU. Based on this, it is concluded that turbidity is a challenge for non-conventional surface water supplies. Although the sampling of environmental sources of non-conventional drinking water was limited, turbidity from these sources is also expected to be high. The 1 NTU value was met for the bottled water samples, the point-of-use sample and for half of the groundwater samples. Therefore, these sources are more desirable than untreated surface water.

8.5.2 Inorganic Chemical Parameters

The health regulated inorganic chemical concentrations in the historical drinking water quality data for conventional drinking water showed that all samples taken were well within the MACs of the GCDWQ except for a community groundwater facility that exceeded the fluoride limit due to naturally occuring fluoride. Some aesthetic violations occurred with excesses of total dissolved solids, sodium, manganese and iron. However, based on historical data, it is concluded that conventional drinking water in the NRBS area, with the possible exception of fluoride, meets the health related inorganic parameters in GCDWQ, but some facilities exceed recommended inorganic chemical aesthetic objectives.

Non-conventional surface water supplies did not meet all of the health related guidelines established for inorganic chemicals. Mercury levels exceeded the MAC in surface and groundwater samples collected in the John D'Or Prairie area where high levels of naturally occuring mercury are found. Although nitrates were not assessed in the non-conventional samples, the high ammonia concentration in a groundwater sample suggests that nitrates may be a problem for some groundwater supplies in the study area. This was confirmed by some NRBS residents. Several aesthetic inorganic chemical constituents were exceeded in the non-conventional samples collected, particularly iron and manganese.

8.5.3 Organic Chemical Parameters

The evaluation of existing data on conventional drinking water indicated that historically, the only organic chemical to exceed MAC limits was THMs. This assessment is based on the guideline value of 100 mg/L for chloroform, rather than the old limit of 350 mg/L. It was found that the MAC for THMs was only exceeded in 32 % of the facilities that rely on surface water as their source. Only Less than 2 % of the groundwater facilities exceeded the THM guideline. There did appear to be a trend for smaller facilities to generate higher levels of THMs than larger facilities. This is likely the result of the poorer raw water quality of smaller centers.

The site visit data for THMs was consistent with the historical data. The samples showed that almost 60 % of the samples taken from surface water facilities were over the limit and none of the groundwater ones. In contrast to the trend observed in the historical data, there did not appear to be a significant difference between small facilities and larger facilities in the generation of THMs.

These results apply to non-conventional surface water supplies. There were two assessments of organic levels in the non-conventional samples of drinking water: total organic carbon and trihalomethanes. Although TOCs are not regulated in the GCDWQ, inferences about trihalomethane formation can be drawn from them. Typically, surface waters with higher TOCs have more potential to form trihalomethane upon addition of chlorine than do low TOC groundwaters. Organics may pose a problem for some bottled waters and for exhausted activated carbon point-of-use devices.

8.5.4 Microbial Parameters

Groundwater facilities with no disinfection have a high incidence of coliform positive samples. There was also a trend of higher coliform detection in smaller communities compared to larger communities that had a lower percent coliform positive samples. A more pronounced difference between the small and large facilities is noticed if the analyis of the data is such that all samples are used (including the "percent poor" which mean overgrown or confluent growth samples. Based on the historical data, it is concluded that small facilities produce poorer water quality in terms of microorganisms than larger facilities. Definitive conclusions could not be drawn based on the limited microbiological analysis of the site visit samples. However, coliforms were detected in some of the samples.

As a result of the limited microbial sampling of non-conventional samples, definite conclusions cannot be made. However, coliform organisms in untreated surface water were detected in all samples. Microbial challenges are also expected for other non-conventional sources as well.

8.6 DRINKING WATER TREATMENT

There are a variety of both conventional and non-conventional treatment processes utilized in the Northern River Basins. The effectiveness of a given process is dependent on the raw water quality, the treatment method, the finances required and the operation and maintenance of the system.

Small conventional drinking water facilities in the study area have weaker techological and financial bases than larger systems in the study area. Combined with poorer raw water quality faced by small facilities, it was found that the effectiveness of the overall treatment of water at these sites was poorer than for larger facilities. Based on the results from an AWWA survey, it is expected that drinking water treatment facilities in the NRBS area that serve more than 1000 have the financial and technical expertise to manage their problems. Communities that serve between 500 and 1000 have more of a challenge and those less than 500 are in trouble. In general, the situation for these small systems is not getting any better. Facilities are aging and the standards are tightening and finances are dwindling. The challenges facing small systems is formidable and innovative problem solving is necessary.

In terms of non-conventional drinking water treatment methods, when in doubt, water for consumption should be boiled.

9.0 SCIENTIFIC AND MANAGEMENT RECOMMENDATIONS

9.1 PUBLIC HEALTH

As has been stated, drinking water quality and public health are closely related. The assessment of public health should continue with special attention given to the correlation of public health with drinking water quality and drinking water supplies in the study area. This would require additional monitoring of health records in conjunction with water quality data if possible. Also, in terms of public health, the Drinking Water Component perceives that there is a need for some public health educational programs in the NRBS area, particularly in communities where there is a large objection to chlorination. This would be beneficial to those that turn to other supplies of drinking water as a result of their distaste for chlorine, to know why chlorine is used, and the risks and benefits associated with chlorinated versus unchlorinated water. Educational programs would also be beneficial for individuals who are involved in living off the land expeditions or other wilderness activities, so that they are provided with information with which they can make the best decisions regarding drinking water, sanitation and hygiene during activities such as these. Since all of these have an effect on health, good decisions in these regards would have a positive impact on public health protection.

9.2 AESTHETICS

Since the aesthetic quality of water is the generally the basis of evaluation by which consumers judge the safety of their drinking water, it is important that the aesthetic quality of the water in the northern river basins continues to be monitored and assessed. In this manner, a historical database with baseline information would be compiled. This type of historical data base would allow an assessment of changes in the aesthetic quality of water due to new industrial developments as well as changes in existing industrial developments. Furthermore, additional scientific studies are required to better characterize causes of taste and odour from industrial discharge, in particular pulp and paper wastewater discharges. This characterization may lead to the development of new methods to reduce the taste and odour associated with these discharges.

9.3 DRINKING WATER SUPPLIES

The main recommendation in terms of conventional drinking water facilities in the study area is that existing facilities in the study area need to optimize treatment performance so that the best quality drinking water possible is supplied to the consumer. This is especially true for small facilities which were found to produce poorer water quality than larger facilities. This will involve action at several levels.

1) Existing monitoring practices should be improved so that they are more representative of the plants performance. It must be recognized that monitoring is not only required for compliance with water quality guidelines but also needed for process control for operation of the facility. It is recommended that when possible finished water turbidity and chlorine

residual should be monitored continuously. This would not only help to ensure facilities meet set guidelines for these important parameters but also provide valuable information for the operation of the facilities.

2) Based on monitoring results proper remedial actions should be practiced for parameters that do not meet recommended guidelines. Results from this study indicate that many of the facilities which produced poorer quality drinking water had done so for long periods.

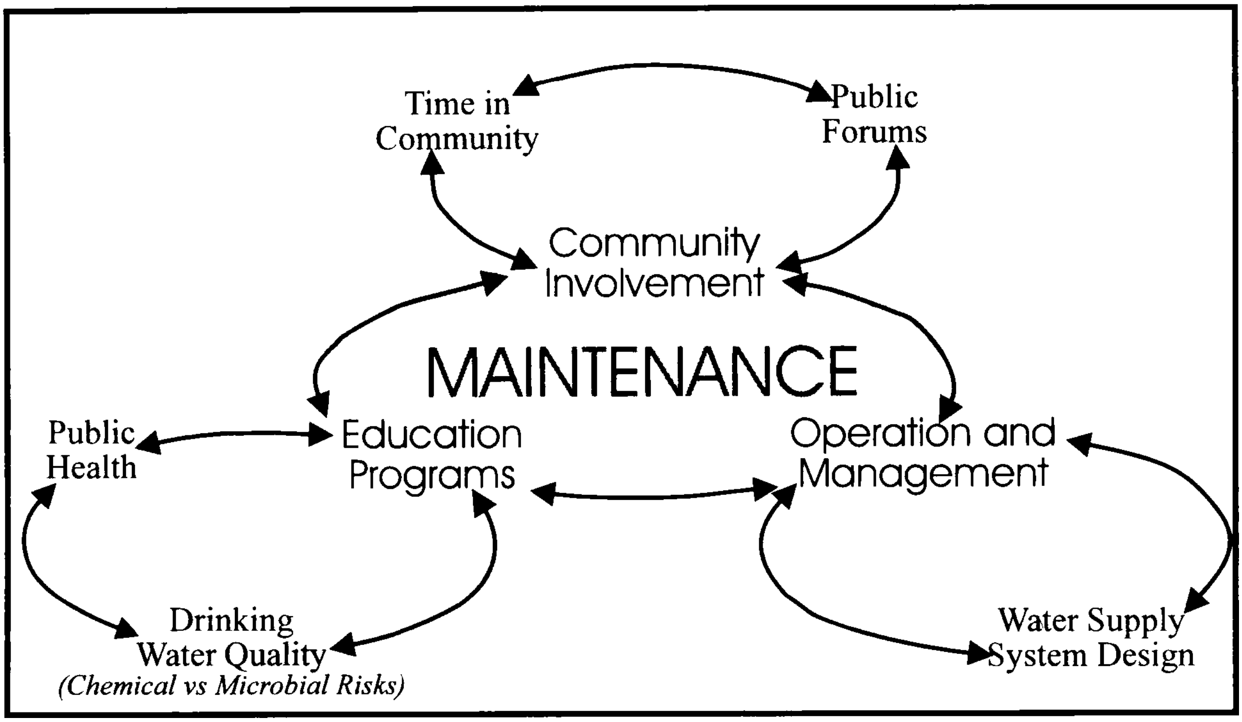
3) Based on site visits and similar results in other areas it was found that much of the difficulty that some facilities had in producing good quality drinking water can be related to operation and maintenance of the facilities. It is therefore recommended that continuing educational programs should be strengthened, especially for operations of small facilities.

4) It must be recognized that the quality of drinking water which the consumer receives is not only dependent on the treatment system but also the distribution system. Although piped distribution systems are ideal, they are not financially or technically feasible for many of the remote areas typical in the Northern River Basin Study area. Where trucked delivery of water is supplied, the water should be delivered to water cisterns rather than water barrels which are still in use by some NRBS residents. This is primarily due to concerns related to post contamination that are associated with water barrels. Furthermore the state of the distribution system, piped or trucked, should be monitored to ensure proper maintenance and operation.

An effective water supply system will involve the community in all aspects of decision making. Although this is especially important during the design stages, it is also important for the maintenance of an existing water supply system. Figure 24 illustrates a simple approach that can be used in communities in the NRBS area in the maintenance of a successful drinking water system.

According Figure 24, there are three main components involved in the maintenance of a community water supply system. Community involvement is of paramount importance to the success of any project in the community. If an outside *expert* is to be involved in the project, then that person should spend time in the community getting to know the residents. During this time in the community, public forums can be held where questions, concerns and ideas can be discussed. The forums would also be a good time to educate residents regarding drinking water quality and general public health. Educational programs such as these comprise the second important component in this model. The third main component in the maintenance of an effective water supply program is the proper operation and maintenance of the system implemented. This is done through appropriate selection of community members to operate the designed system and through continued community involvement in future decisions. If a model such as this is followed in the design of a water supply system in the study area, a safe and sustainable supply of potable water is possible.

Figure 24. Successful Drinking Water Supply System Implementation (Source: Armstrong, 1995)



Further scientific studies on non-conventional drinking water supplies in the study area and elsewhere are necessary. More drinking water quality data is needed, as well as the extent of consumption of non-conventional supplies. As part of the scientific investigation into non-conventional drinking water, an epidemiological study could be carried out which would look at waterborne disease rates in selected areas and potential links with non-conventional drinking water consumption and / or quality. If a significant relationship was found, the results could then be used for educational programs and determining possible solutions.

Remote access to good quality drinking water is a challenge. When possible, the best source of drinking water for people living in remote areas away from conventional facilities is from a protected groundwater well. If groundwater is unavailable, then other supplies should be tapped and treated appropriately. If the safety of a given water supply is unknown or questionable, then the water should be boiled.

Finally, it is vitally important that all present and future drinking water sources are protected from physical, chemical and bacterial contaminants. In doing so, additional precautions are taken in the maintenance of safe drinking water supplies in the Northern River Basins.

10. REFERENCES

Alberta Environmental Protection (AEP), 1993. *Licence to Operate or Use.* License Numbers Referred to: 91-WL-098E (Millar Western Pulp Ltd); 92-WL-234C (Weyerhaeuser Canada Ltd.); 93-WL-137A (Alberta Pacific Forest Industries Inc.); 93-WL-123A (Alberta Newsprint Company); 90-WL-159E (Slave Lake Pulp Corporation); 93-WL-080A(Daishowa-Marubeni International Ltd); 93-WL-014 (Weldwood of Canada Ltd.).

Alberta Environmental Protection (AEP), 1988. Standards and Guidelines for Municipal Water Supply, Wastewater, and Storm Drainage Facilities. Standards and Approvals Division, Edmonton, Alberta.

American Public Health Association (APHA), American Water Works Association and Water Environment Federation. 1992. Standard Methods for the Examination of Water and Wastewater, 18th ed. Greenberg, A.E., L.S. Clesceri, and A.D. Eaton. Editors. Washington, D.C.

American Water Works Association (AWWA). 1990. Water Quality and Treatment: A Handbook of Community Wate Supplies, 4th ed. McGraw Hill Inc., New York. 455pp.

Armstrong, T.F. 1995. An Assessment of Non-Conventional Drinking Water Supplies in Remote Northern Alberta Communities. M. Sc. Thesis. University of Alberta, Department of Civil Engineering. 198 pp.

Armstrong, T.F., S.J. Stanley, and D.W. Smith. 1995. Assessment of Non-Conventional Drinking Water in the Northern River Basins Study Area. NRBS Project 4423-D1.

Batik, O., G.F. Craun, and W.O. Pipes. 1984. Routine monitoring and waterborne disease outbreaks. *Journal of Environmental Health.* 45(5):227.

Bingham, Art. 1994. Personal Communication. Northwestern Health Unit. High Level, Alberta. November 3, 1994.

Brocklehurst C., G.W. Heinke, and H. Hodes. 1985. The Effect Of Water Supply And Sanitation On Health On Indian Reserves in Manitoba. University of Toronto. Department of Civil Engineering. 15pp.

Burris, A. 1986. Ozone. *Water Conditioning and Purification.* August 1986. 26-33.

Cairncross, S., and R. Feachem. 1993. Environmental Health Engineering in the Tropics: An Introductory Text. Second Edition. John Wiley and Sons. New York. 295 pp.

Chalifoux, Rosie. 1995. Personal Communication. Atikameg, Alberta. February 1995.Culotta, N.J. 1989. Home Water Treatment: What's the Use of Point-of-Use? *Health and Environment Digest.* 3(6): July 1989.

Costerton, J.W., K.J. Cheng, G.G. Geesey, T.I. Ladd, J.C. Nickel, M. Dasgupta, and T.J. Marrie. 1987. Bacterial Biofilms in Nature and Disease. *Ann. Rev. Microbiol.* 41: 435-464.

Cromwell, J.E., W.L. Harner, J.C. Africa, and J.S. Schmidt. 1992. Small water systems at a crossroads. *Journal AWWA*. 84(5): 40-48.

Culp, J.M. and R.W. Davies. 1983. In: G.F. Hartman (ed.) *Proceedings of the Carnation Creek Workshop: A Ten Year Review.* Pacific Biol. Station, Fisheries and Oceans, Nanaimo. pp 173-178.

Davenport, C.V., E.B. Sparrow, and R.C. Gordon. 1976. Fecal indicator bacteria persistence under natural conditions in an ice-covered river. *Appl. and Environ. Microbiology*. 32(4): 527-536. [Original not seen; information taken from Emde *et al.*, (1994)]

Ellehoj, Erik. 1995. Personal communication and map generation. Northern River Basins Study Office. Edmonton, Alberta. November, 1995.

Ellehoj, Erik. 1994. Personal communications and map generation. Northern River Basins Study Office. Edmonton, Alberta.

Emde, K.M.E. and D.W. Smith. 1992. Significance of Microbially Influenced Corrosion on Water Distribution Systems. Report for Alberta Environment, Edmonton, Alberta.

Emde, K.M.E., D.W. Smith, and S.J. Stanley. 1994. Health Records Study for the Northern River Basins Project. NRBS Project 4421-C1.

Environmental Health Directorate, 1993. Water Treatment Principals and Applications. Canadian Water and Wastewater Association. Ottawa. 365 pp.

Environmental Health Directorate Working Group. 1991. Reference Values for Canadian Populations. Draft. Health and Welfare Canada. Ottawa, Ontario. 36pp.

Epstein, R. 1982. Letters to the Editor. *Canadian Journal of Public Health.* 73: 433-434. [Original not seen; information taken from Fraser-Lee and Hessel, 1994]

Federal-Provincial Subcommittee on Drinking Water of the Federal-Provincial Advisory Committee on Environmental and Occupational Health. 1993. Guidelines for Canadian Drinking Water Quality, 5th ed. Ottawa, Ontario. 24pp.

Fraser-Lee, N.J. and P.A. Hessel. 1994. Acute Respiratory Infections in the Canadian Native Indian Population: A Review. *Canadian Journal of Public Health.* May-June 1994. 85(3): 197-200.

Gabler, R. and the Editors of Consumer Reports Books. 1988. Is Your Water Safe to Drink? Consumers Union, Mount Vernon. 390 pp.

Geldreich, E.E. 1990. Microbiological Quality of Source Waters for Water Supply. In : G.A. McFeters (ed). Drinking Water Microbiology. Springer-Verlag, New York, p 1-2.

Geldreich, E.E. 1972. Waterborne Pathogens. In R. Mitchell (ed). Water Pollution Microbiology. John Wiley, New York, pp 207-241.

Geldreich, E.E. and D.J. Reasoner. 1990. Home Water Treatment Devices and Water Quality in G. McFeters, editor. Drinking Water Microbiology. Springer-Verlag, New York. 502 pp.

Geldreich, E.E., R.H. Taylor, J.C. Blannon, and D.J. Reasoner. 1985. Bacterial Colonization of Point-of-Use Water Treatment Devices. *Journal AWWA*. February1985. 72-80.

Goodrich, A.G., J.Q. Adams, B.W. Jr. Lykins, and R.M. Clark. 1992. Safe drinking water from small systems: Treatment options. *Journal AWWA*. May 1992.

Gordon, R.C. 1972. Winter survival of fecal indicator bacteria in a subarctic Alaskan river. Report No. EPA-R2-72-013, USEPA, Washington, D.C. [Original not seen; information taken from Emde *et al.*, (1994)]

Hansmann E.W. and H.K. Phinney, 1973. Effects of logging on periphyton in coastal streams of Oregon. *Ecology.* Winter 1973. 54:194-199.

Hatfield, J.L. (1993). Sustainable Agriculture: Impacts on Nonpoint Pollution. *Water Science and Technology*. 28(3-5), pp 415-424.

Health and Welfare Canada. 1991. Water Treatment Devices for the Removal of Taste, Odour and Chemicals. *Health Protection Branch Issues*. 4pp.

Health and Welfare Canada. 1973. Sanitation Manual for Isolated Regions, 5th ed. Environmental Health Directorate. Health Protection Branch. 64 pp.

Health and Welfare Canada and Environment Canada. 1991. "Wilderness Water: A Guide to Wilderness Drinking Water." Pamphlet.

Huberman, Irwin. 1995. Personal Communication. Northern River Basins Study Office. Edmonton, Alberta. March 1995.

Jacobsen, N.A. 1994. Engineering to remove/inactivate parasite cysts. *Giardia/Cryptosporidium* seminar. Prince George, B.C. March 3, 1994.Kenefick, S.L. and S.E. Hrudey. 1994. Study of Water and Fish Tainting in Northern Alberta River Basins - A Review. NRBS Project 4412-C1.

Kenefick, S.L, B.G. Brownlee, T.R. Perley, and S.E. Hrudey. 1995. A chemical and sensory study of odour compounds in the Athabasca River, Alberta, Canada. *Water Science and Technology*. 31(11):15-21.

Kenefick, S.L., N.J. Low, and S.E. Hrudey. 1994a. Annotated Bibliography on Water and Fish Tainting in Northern Alberta River Basins. NRBS Project 4412-C1.

Kenefick, S.L., B.G. Brownlee, E.Hrudey, L. Gammie, and S.E. Hrudey. 1994b. Water Odour Athabasca River. February and March, 1993. NRBS Project 4411-B1.

Kenefick, S.L., B.G. Brownlee, E.Hrudey, G. MacInnis, and S.E. Hrudey. 1993. Water Taste and Odour Study, Athabasca River 1994 (Post Al-Pac). NRBS Project 4413-C1.

Lester, S.U. and B. Lipsett. 1988. Drinking Water Filters: What You Need to Know. *Citizens Clearing House for Hazardous Wastes*. Arlington, VA. 28 pp.

Letterman, R.D. 1994a. What turbidity measurements can tell us. *Opflow*. 20(8): 1-5. August 1994. Publication of AWWA.

Letterman, R.D. 1994b. Regs change use of turbidity measurements. *Opflow*. 20(8): 5-7. August 1994. Publication of AWWA.

Liem, E., D.W. Smith, and S.J. Stanley. 1995. Inorganic Contaminants Removal. NRBS Project.

Lin, S.D. 1976. Sources of tastes and odours in water. Part 1. *Water and Sewage Works*. 123(6): 101-104. [Original not seen; information taken from Kenefick and Hrudey, (1994)]

Lindsay, K. 1993. Factors Influencing Pulp Mill Effluent Treatment in Alberta. M. Sc. Thesis. Department of Civil Engineering. University of Alberta. 355 pp.

Manahan, S.E. 1991. Environmental Chemistry. Fifth Edition. Lewis Publishers, Chelsea.

Mayo, A.W. and D.A. Mashauri. 1991. Rainwater harvesting for domestic use in Tanzania. A Case Study: University of Dar Es Salaam Staff Houses. *Water International.* 16(1): 2-8.

McCabe, L.J. and Winton, E.F. 1990. Studies relating to water mineralization and health. *Journal AWWA,* 62(1):26-30.

McCubbin, N. and J. Folke, 1993. A Review of Literature on Pulp and Paper Mill Effluent Characteristics in the Peace and Athabasca River Basins. NRBS Project 2111-A1. 85 pp.

McFeters, G. A. 1990. Editor. Drinking Water Microbiology: Progress and Recent Developments. Springer-Verlag. New York. 502 pp.

McJunkin, F.E. 1982. Water and Human Health. U.S. Agency for International Development, AID/DSAN-C-0063. Washington, D.C. 134pp.

Metcalf and Eddy, Inc. 1991. Wastewater Engineering Treatment, Disposal, and Reuse. Third Edition. McGraw Hill Publishing Co. New York. 1334 pp.

Montgomery, J. 1985. Water Treatment Principals and Design. John Wiley and Sons. New York. 696 pp.

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on the aquatic ecosystems. *N. Amer. J. Fish Manag.* Winter 1991. 11(1): 72-83.

Noton, L.R. 1992. Water Quality in the Wapiti-Smoky River System Under Low-Flow Conditions 1987-1991. A Synopsis of Government Surveys and Monitoring, May 1992.

Noton, L.R. and K.A. Saffran. 1995. Water Quality in the Athabasca River System 1990-1993. Report prepared for Alberta Environmental Protection, July 1995.

Noton, L.R. and R.D, Shaw. 1992. Winter Water Quality in the Athabasca River System 1988-1989. Report prepared for Alberta Environment, August 1989.

Nystrom, A., A.Grimvall, C. Krantz-Rulcker, R. Savenhed, and K. Akerstrand. 1992. Drinking water off-flavour caused by 2,4,6-trichloroanisole. Water Science and Technology. 25(2): 241-249. [Original not seen; information taken from Kenefick *et al.*, (1994b)]

Oke, N.J., D.W. Smith, and S.J. Stanley. 1995. Literature Riview on the Removal of Organic Chemicals from Drinking Water. NRBS Project.

Paasivirta, J., J. Knuutinen, J. Tarhanen, T. Kuokkanen, K. Surma-Aho, R. Paukku, H. Kaariainen, M. Lahtipera, and A. Veijanen. 1983. Potential off-flavour compounds from chlorobleaching of pulp and chlorodisinfection of water. *Water Science and Technology.* 15: 97-104. [Original not seen; information taken from Kenefick *et al.*, (1994b)]

Panchapakasan, E. 1991. Process Modifications, End of Pipe Technologies Reduce Effluent Colour. *Pulp and Paper*, August 1991. 82. [Original not seen; information taken from McCubbin and Folke, 1993].

Payment P., L. Richardson, J. Siemiatycki, R. Dewar, M. Edwardes, and E. Franco. 1991. A randomized trial to evaluate the risk of gastrointestinal disease dur to consumption of drinking water meeting current microbiological standards. Amer. Jour. Public Health. 81(6):703-708.

Pontius, F.W. 1994. What you should know about *Cryptosporidium. Opflow.* 21(7): 5-6.

Postl, B., M. Moffat and P. Sarsfield. 1987. Epidemiology and interventions for native Canadians. *Canadian Journal of Public Health.* 78:219-220. [Original not seen; information taken from Fraser-Lee and Hessel, (1994)]

Prendergast, J. 1993. Fit To Drink. *Civil Engineering (New York).* 63(5):52-55.

Prepas, E. 1994. The Role of Buffer Strips for Maintenance of Terrestrial and Aquatic Communities in the Aspen Dominated Boreal Mixed Wood Forest. Submitted to NSERC for a Collaborative Special Projects Grant.

Prince, D.S., D.W. Smith, and S.J. Stanley. 1995a. Review and Synthesis of Existing Information on Consumptive Use of Drinking Water and Available Drinking Water Quality Data. NRBS Project 4401-C1.

Prince, D.S., D.W. Smith, and S.J. Stanley. 1995b. Independent Assessment of Drinking Water Quality in the Northern River Basins. NRBS Project 4422-D1.

Putz, G., D.W. Smith, and R. Gerard. 1984. Microorganism survival in an ice-covered river. Canadian J. of Civ. Engrg. 2(11):177-186. [Original not seen; information taken from Emde *et al.*, (1994)].

Reasoner, D.J., J.C. Blannon, and E.E. Geldreich. 1987. Microbiological characteristics of third faucet point-of-use devices. *Journal AWWA*. October 1987. 79(10): 60-66.

Regunathan, P. and W.H. Beauman. 1987. Microbiological characteristics of point-of-use precoat carbon filters. Journal AWWA. October 1987. 79(10): 67-75.

Reicher, P. and J.Thompson. 1995. Uses of Aquatic Resources in the Northern River Basins: Results of the Household and Stakeholders Surveys. NRBS Project 4121-E2.

Robertson, W. 1995. Personal Communication. Telephone Interview. Health Canada, Ottawa, Ontario. January and March, 1995.

Robinson, B.A. and G.W. Heinke. 1990. The Effect of Municipal Services on Public Health in the Northwest Territories. Department of Municipal and Community Affairs. Government of the Northwest Territories. 81 pp.

Rosen, A.A., R.T. Skeel, and M.B. Ettinger. 1963. Relationship of river water odour to specific organic contaminants. *J. Water Pollut. Control Fed.* 35(6): 777-782. [Original not seen; information taken from Kenefick *et al.*, (1994b)].

St. Arnault, L. 1994. Personal Communication. John D'Or Prairie, Alberta. November 1994.

SENTAR Consultants Ltd., 1995. Effluent Characterization for Municipal and Non-Pulp Mill Industrial Sources, Peace, Athabasca and Slave River Basins. NRBS Project 2112-B1-4. September 1995. 60 pp.

Shanaghan, P.E. 1994. Small Systems and SDWA Reauthorization. *Journal AWWA*. 86(5):52-62.

Shaw, R.D., L.R. Noton, A.M. Anderson, and G.W. Guenther. 1990. Water Quality of the Peace River in Alberta. Report prepared for Alberta Environment. June 1990.

Smith, V.H. 1983. Low nitrogen to phosporus ratios favour dominance by blue-green algae in lake phytoplankton. *Science.* 221(4611): 669-671.

Sobsey, M.D. 1989. Inactivation of health-related microorganisms in water by disinfection processes. *Water Sci. and Technol.* 21(3): 179.

Sobsey, M.D., A.P. Dufour, C.P. Gerba, M.W. LeChevallier, and P. Payment. Using a conceptual framework for assessing risks to health from microbes in drinking water. *Journal AWWA*. March, 1993. 85(3):44-48.

Stanley Associates Engineering Ltd. 1987. Water Use Study - Athabasca River Basin. Prepared for Alberta Environment, Planning Division. {Original not seen. Information taken from SENTAR, 1995]

Tate, C.H. and K.F. Arnold. 1990. Health and Aesthetic Aspects of Water Quality. Chapter 2 in Water Quality and Treatment A Handbook of Community Water Supplies. 4th ed. American Water Works Association. F. W. Pontius Editor. pp 63-156.

Thompson, J. 1995. Personal Communication. Telephone Conversation. Edmonton, Alberta. November, 1995.

Traditional Knowledge Component. 1995. Summary Results From the Document "How Our Knowledge Lives." Draft. Northern River Basins Study. 37pp.

United States Environmental Protection Agency (USEPA). 1994. National Primary Drinking Water Regulations: Enhanced Surface Water Treatment Requirements; Proposed Rule. 40 CFR Parts 141 and 142. EPA 811-Z-94-003. July 29, 1994.

United States Environmental Protection Agency (USEPA) 1987. Protocols for Point-of-Use Devices Guide Standard and Protocol for Testing Microbiological Water Purifiers.

United States Environmental Protection Agency (USEPA). 1974. Manual of Individual Water Supply Systems. Office of Water Programs Water Supply Division. EPA-430/9-74-007. 155 pp.

Water Pollution Control Federation (WPCF) 1983. Nutrient Control Manual of Practice FD-7 Facilities Design. Water Pollution Control Federation, Washington, D.C. [Original not seen. Information taken from SENTAR, 1995]

Weller, G.R. and P. Manga. 1987. The politics of health in the circumpolar north. *Arctic Medical Research.* 46(2):52-63.

World Health Organization. 1993. Guidelines for Drinking Water Quality. Volume 1: Recommendations, 2nd ed. Geneva. 188p.

World Health Organization. 1978. Primary Health Care: Report of the International Conference on Primary Health Care. Alma-Ata, USSR. September 6-12, 1978.

Zhou, H., D.W. Smith, and S.J. Stanley. 1995. Removal of Microbial Contaminants from Water Treatment Processes for the Northern River Basins Communities. NRBS Project.

APPENDIX A: REPORT SUMMARIES

REPORT SUMMARY 1

Kenefick, S.L. and S.E. Hrudey. 1994. Study of Water and Fish Tainting in Northern Alberta River Basins - A Review. NRBS Project 4412-C1 (Report No. 52).

The purpose of this review was to identify incidence of, or the potential for off-flavour tainting of fish and water by components discharged into the Peace, Athabasca, and Slave rivers. The main focus was the tainting effects of effluents released by pulp mills, but there is also a brief discussion of the role of other industrial discharges, municipal waste discharges, and non-point sources of run-off. There is a relatively weak literature base directly related to taste and odour problems attributable to pulp mills in the Northern Alberta river basins. However, discussions of other pulp mill related incidents of taste and odour problems throughout the world have been included.

There are a number of unique analytical methods used in the study of taste and odour problems and it is critical to have a basic understanding of these methods before interpreting reports of tainting incidents. To assist in the development of this understanding, a detailed review of analytical methods used for the investigation of water and fish tainting problems was included. There are a variety of chemical methods used for the isolation (extraction, adsorption and desorption, removal of interferences), fractionation, and instrumental separation and identification of the compounds responsible for taste and odour problems in water and fish. The problems and limitations associated with each of these methods were discussed. It is critical to select the most appropriate method for any specific taste and odour study in order to obtain meaningful results.

The sensory analytical techniques used for the study of taste and odour are even more unique and are subject to variabilities caused by differing human olfactory sensitivities. A detailed review of current sensory methods was completed. Sensory analysis is the only method of providing a qualitative description of the tastes or odours present in a sample. however, in order to confirm that specific chemicals are responsible for specific odours in a sample, a combination of sensory and instrumental techniques is required. Chromatographic sniffing (olfactory GC) is the current method of choice when integrating sensory and common instrumental techniques.

Fish tainting as a result of pulp mill discharges is well documented and there have been a number of comprehensive reviews on the subject. Reports of fish tainting indicated that often the tainting could not be linked to any specific compounds and off-flavours were often a result of the combined effects of different industrial discharges into the same water body. The current state of the fish tainting problem in Northern Alberta river basins is relatively undefined. There are 10 pulp / paper mills in the Athabasca and Peace River basins and other discharges are limited to five non-pulp mill industrial effluents, along with numerous small municipal sewage effluents. The combined tainting effects from multiple, diverse industrial effluents which arise in heavily industrialized regions is not a major concern in these rivers. We have therefore focused on the pulp mill discharges and non-industrial tainting substances (biogenic sources).

Although there is little definition of the specific compounds responsible for tainting problems downstream of pulp mill effluent discharges, water tainting problems in the Northern Alberta river basins have historically been attributed to kraft pulp mill effluents. There is significant discussion of the effects of chlorinated compounds formed as a result of the kraft bleaching process but the literature is not very helpful in elaborating the role of specific odour compounds produced prior to bleaching. Early work identified a number of process streams prior to bleaching as the most significant contributors to overall mill effluent odour. The importance of these odour sources is dependent upon in-plant spill control and wastewater treatment efficiency but is independent of recent improvements to the bleaching processes. Samples collected downstream from the pulp mill in Hinton have often exceeded odour compliance levels for up to half the length of the Athabasca River (under winter ice) since the mill was constructed. Occasional taste and odour problems at the town of Peace River have also been attributed to upstream pulp mills. Reports of the odour component of water quality studies for the Wapiti-Smoky River system indicate a noticeable increase in odour attributed to kraft mill effluents during low flows (under ice). Biological or natural sources of tastes and odours in water must also be considered as potential causes of off-flavours and the possibility of odour synergism when these natural compounds are combined with anthropogenic tainting compounds is likely.

Thorough (and costly) drinking water treatment processes can be effective in removing most taste and odour compounds, provided the nature of the odour problem is understood and the treatment processes can be optimized for the types of problems that are identified. Removal of many of the relatively volatile, chlorinated organics often thought to be responsible for tainting problems has been demonstrated in pulp mill wastewater treatment system studies. However, removal efficiencies vary and systems must be operated consistently under optimum conditions if tainting incidents are to be avoided. The preferred control method is prevention of the formation of these odourous chlorinated organics. Chlorine dioxide substitution significantly reduces the formation of such compounds, as does the use of hardwood. Where non-chlorine bleaching processes such as chemi-thermomechanical pulping (CTMP) are used there have been no documented taste and odour incidents.

Anecdotal, historical information obtained in discussions and correspondence with various regional fishery biologists in the Fish and Wildlife division of Alberta Environment repeatedly indicated that, in general, people do not eat the fish caught in the northern Alberta river basins. Similar avoidance by the First Nation's peoples was confirmed in communications with the NRBS Traditional Knowledge group leader. It is apparent that the concern surrounding tainting of water and fish by anthropogenic sources such as pulp mill discharges and accidental oil sands wastewater spills is not only based on documented problems but is also founded on expectations of tainting associated with the existence of industrial discharges.

REPORT SUMMARY 2

Kenefick, S.L., N. Low, and S.E. Hrudey. 1994. Annotated Bibliography on Water and Fish Tainting in Northern Alberta River Basins. NRBS Project 4412-C1 (Report No. 52).

Bleached kraft pulp mill effluent and discharges related to other industrial developments are known to contain odorous compounds that have the potential to cause off-flavours in water and fish in the receiving waters. The following is an annotated list of technical reports, government documents, books and periodical articles that document the current knowledge about water and fish tainting in the northern river basins of Alberta. The purpose of this work is to identify incidence of or the potential for off-flavour tainting effects of effluents released by pulp mills, but the role other industrial developments, municipal wastes and agricultural discharges may play in causing off-flavours is also briefly covered. A detailed annotated list of possible analytical and sensory methods for the investigation of water and fish taste and odour problems is also included.

The references are grouped into 7 categories. The categories and the references in each category are listed alphabetically and some references are listed in more than one section where applicable.

The division of references into categories can be summarized as follows:

1. Chemical Methods of Odorous Compound Analysis
2. Control or Treatment Options
3. Fish Tainting Relating to Non-Pulp Mill Sources
4. Fish Tainting Relating to Pulp Mill Effluents
5. Sensory Methods of Odorous Compound Analysis
6. Water Tainting Relating to Non-Pulp Mill Sources
7. Water Tainting Related to Pulp Mill Effluents

This list is by no means exhaustive but represents a very useful cross-section of literature that can be used to gain a thorough understanding of the problems associated with off-flavours in water and fish, especially as they relate to pulp mills in the Northern River Basins.

REPORT SUMMARY 3

Kenefick, S.L., B. Brownlee, E. Hrudey, L. Gammie, and S.E. Hrudey. 1994. Water Odour Athabasca River February and March, 1993. NRBS Project 4411-B1 (Report No. 42).

The purpose of this study was to determine the potential for off-flavour tainting of water and/or fish in the Athabasca River by compounds discharged by bleached kraft and chemi-thermomechanical pulp mills. The opportunity to determine in-stream occurrence of common tainting compounds prior to the startup of the Alberta-Pacific mill was exploited. This study combined three different analytical methods commonly used in monitoring for the presence of odorous compounds in water supplies. Two trained flavour profile panels were used to characterize the odour of the samples, two trained analysts evaluated the samples using olfactory GC and all samples were quantitatively analyzed for the presence of target odour compounds using GC/MS. These three techniques all provide quite different information and all have certain limitations.

The flavour profile panel work, involving two independent panels, clearly indicated an impact of Hinton combined effluent on the odour of the Athabasca River for substantial distances downstream. The odour contributions to the Athabasca River from tributaries were minor. The odour contributions from other effluent sources (sewage treatment plants and chemi-thermomechanical pulp mills) were less distinctive than the Hinton combined effluent and their role in affecting downstream odour is not as clear. Notwithstanding these observations, the observed impacts on raw water odour could not be detected in the treated drinking water at Ft. McMurray, possibly because of removal of odorous compounds in treatment and / or masking of the raw water odour with chlorinous odours. The raw water supply at Fort Chipewyan was not particularly odorous and the finished water exhibited a very strong chlorine odour that would have masked any subtle odours present. The CLSA-GC/MS for target compounds also suggests that there was limited contribution of odour compounds from the tributaries. None of the effluent samples, including the Hinton combined effluent, contributed substantial concentrations of the target odour compounds to the Athabasca River, with the possible exception of geosmin. Notwithstanding these findings, there was a very distinctive rise in 3,4,5-trichloroveratrole and a measurable, but less distinctive rise in 2,4,6-trichloroanisole in the Athabasca River downstream of Hinton. Because neither of these compounds were present in substantial concentration in the Hinton combined effluent, and their concentrations increased downstream of Hinton, there is not a simple explanation for a possible role of this effluent source in the observed Athabasca River system concentrations for these compounds. In any case, none of the target odour compounds, by themselves would explain the odour character that was perceived by the flavour panel in the Hinton combined effluent and affected downstream samples, The OGC should have provided a separate approach to account for non-target odorous compounds that might explain the odours perceived by the flavour panel. However, there were very few extra odour peaks detected by OGC with perhaps only a sulfury / septic odour and a sulfury / mercaptan / crude oil odour that were likely to have contributed in any substantial way to the pulp mill odour character. Identifying these compounds would likely assist the odour characterization process, but there are likely other contributing compounds that have not yet been detected by the methods employed in this survey. This possibility suggests the need for a better characterization of the compounds that are primarily responsible for creating the odour of pulp mill effluents.

REPORT SUMMARY 4

Kenefick, S.L., B.G. Brownlee, E. Hrudey, G. McInnis, and S.E. Hrudey. 1994. Water Taste and Odour Study, Athabasca River 1994 (Post AlPac). NRBS Project 4413-C1 (Report No. 114).

The purpose of this study was to determine the potential for off-flavour tainting of water and/or fish in the Athabasca River by compounds discharges from bleached kraft and chemi-thermomechanical pulp mills. This study combined three different analytical methods commonly used in monitoring for the presence of odorous compounds in water supplies.. A trained flavour profile panel was used to characterize the odour of the samples, two trained analysts evaluated the samples using olfactory GC and all samples were quantitatively analyzed for the presence of target odour compounds using GC/MS. These three techniques all provide quite different information and all have certain limitations.

The flavour profile panel method is most appropriate when monitoring for the presence of compounds that will lead to public complaints, relies on varying sensitivities to certain odours, and does not easily allow for reporting the presence of specific compounds. Consistency and specificity of the odour profile panel results require rigorous training in the recognition of target compounds and assignment of appropriate intensities.

The olfactory GC technique is useful when there are a number of odorous compounds present in a sample. The GC accomplishes the separation of each of the odour compounds and still allows for olfactory detection. The sensitivity of this method is limited by the dilution of odours by the inert carrier gas as well as the small volumes of sample that can be injected for capillary gas chromatography. The extraction of the samples using CLSA offers a ten thousand fold concentration of the sample so that these sensitivity problems are partially offset.

The analyses by gas chromatography with mass selective detection was the most quantitative analytical method, but also the least sensitive. To increase sensitivity of the instrument a selected ion monitoring program was set up to monitor the abundance of certain ions that are known to be present in the mass spectra of the target compounds. Sensitivity is increased because rather than slowly scanning for all possible ions, the detector scans many more times and much more rapidly for the small group of selected ions. However, the analyses are then limited to monitoring for the chosen target compounds. Any odorous non-target compounds, which may significantly contribute to the odour of a sample, will not be reported.

The flavour profile panel work, shows a decrease in the impact of Hinton combined effluent on the odour of the Athabasca River compared with the 1993 survey. The contribution from the Alberta Pacific discharge was even smaller than the Hinton contribution. The odour contributions to the Athabasca River from tributaries were minor. The odour contributions from other effluent sources (sewage treatment plants and chemi-thermomechanical pulp mills) are less distinctive than the Weldwood and AlPac mills and their role in affecting downstream odour is not as clear. Notwithstanding these observations, the observed impacts on raw water odour could not be identified for the treated drinking water at Fort McMurray, possibly because of removal of odorous compounds in treatment and/or masking of the raw water odour with chlorinous odours.

The raw water supply at Fort Chipewyan was not particularly odorous and the finished water also exhibited a strong chlorine odour that would have masked any subtle odour present.

The CLSA-GC/MS and OGC results suggest that there were very limited contributions to the odour of the samples by the target compounds. None of the target odour compounds, by themselves, can explain the odour character that was perceived by the odour panel in the Hinton combined and AlPac effluents and affected downstream samples.There are likely other contributing compounds that have not yet been detected by the methods employed in this survey. This suggests the need for a continued characterization of the compounds that are primarily responsible for creating the current odour of these pulp mil effluents.

REPORT SUMMARY 5

Emde, K.M.E., D.W. Smith, and S.J. Stanley. 1994. Health Records Study. NRBS Project 4421-C1 (Report No. 54).

This document was developed to determine the historical incidence of microbiological, viral and protozoan waterborne disease in the Northern River Basins area. An initial review of the literature pertaining to microbiological monitoring and quality of drinking water supplies as well as a discussion on waterborne disease transmission provides background information for the health records assessment. In the actual health record assessment, data was acquired primarily from health unit records from the study area and annual notifiable disease summaries provided by Alberta Health. No actual independent, microbiological testing was performed during the course of this study.

As a result of this research, it was concluded that:

- Potential risk from microbial contaminants can be high in comparison to potential risk from chemical contaminants.
- For many pathogenic microbes there are substantial non-human reservoirs. As a result even complete elimination of human discharges will not eliminate the source for many pathogens.
- Little data is available in the Northern River Basin Study area to assess the microbial water quality. There appears to be a need to increase the baseline microbiological data on surface water quality in the study area for microorganisms other than those currently required by the Alberta Environmental Protection.
- Analysis of health records showed that there appeared to be a trend towards higher incidence of giardiasis, salmonellosis, and shigellosis in some of the health units, but failed to indicate if this was due to foodborne, person to person or waterborne means of transmission.
- Results also indicated that although incidence of some disease were higher, in many cases the differences were not significant and residents generally do not appear to have substantially higher risk from waterborne disease in the study area compared to the rest of Alberta.

REPORT SUMMARY 6

Prince, D.S., D.W. Smith, and S.J. Stanley. 1994. Review and Synthesis of Existing Information on Consumptive Use of Drinking Water and Available Drinking Water Quality Data. NRBS Project 4401-C1 (Report No. 55).

The primary purpose of this report was to gather as much existing information about drinking water in the NRBS area as possible. Part of this task was to compile, synthesize and summarize information regarding: (1) applicable drinking water quality standards and regulations; (2) general drinking water quality data available for sites in the NRBS area; and (3) information on the drinking water treatment facilities in the study area. The results from this work is presented in a series of five appendices that include tables and figures of the summarized results.

Appendix 1 presents the results from the analysis of the *Treated Water Survey* drinking water quality data. There were 460 samples taken in the NRBS area in the *Treated Water Survey.* For the most part each site sampled was analyzed for 46 heavy metals and routine parameters, 58 volatile compounds, 65 semi-volatile compounds and 77 herbicides and pesticides. The data analysis involved the grouping of treatment sites and the subsequent calculation of means and standard deviations for each site sampled for which the parameters were above the method detection limit. Therefore, it is acknowledged that these results may be biased high as a result of not including values below the detection limit, but it was decided that this method was sufficient for this summary. Each site sampled is listed in this appendix along with: (1) the source and type of raw water; (2) the population served; (3) drinking water quality parameter in question; (4) the mean and standard deviation for each parameter; (5) the number of samples above the method detection limit (MDL); and, (6) the total number of samples taken.

Appendix 2 is an overall summary of the *Treated Water Survey* and relevant GCDWQ. The following lists the information included for each parameter: (1) the GCDWQ value; (2) the MDL; (3) number of samples taken in the NRBS area; (4) number of sites sampled; (5) number of samples greater than the MDL; and (6) number of sites whose average was greater than the MDL. This appendix also contains frequency distribution figures for regulated parameters.

Appendix 3 lists all the samples that have exceeded a GCDWQ guideline. The appendix lists the site for which the parameter has exceeded the guideline value, whether the raw water was from a groundwater or surface water source and the level of the parameter for which the GCDWQ has been exceeded. From this analysis it is apparent that by far most of the parameters that do not meet the values set in the GCDWQ are for aesthetic parameters. Chloroform and turbidity are the only health related parameters that exceed the GCDWQ regulations.

Appendix 4 is a summary of the conventional community drinking water treatment facilities in the Northern River Basins. This appendix lists information for each facility including: (1) the name of community served; (2) population and status of the community; (3) raw water source and type; (4) volume of treated water storage; (5) treatment processes used; (6) whether or not the site had been sampled in the Treated Water Survey. The main findings from this compilation was that the types and varieties of treatment processes utilized in the NRBS area is extremely variable.

Appendix 5 summarizes the differences between the raw and treated water data for all of the NRBS samples in which both a raw and treated water sample was taken. The differences obtained give information on the effect that the given water treatment process have on the finished water quality. Based on this analysis it was found that while conventional drinking water treatment processes are effective at removing or lowering the levels of some parameters (such as turbidity), the levels of other parameters (such as chloroform) can actually increase.

Based on the results presented in the Appendices it was concluded that, in general, drinking water quality in the NRBS area meets all applicable guidelines and regulations for the parameters examined in this assessment. However, a number of samples did exceed GCDWQ values of which turbidity and chloroform are the only ones that may present a risk to health. By far most of the samples which exceeded the GCDWQ were for parameters which have aesthetic objectives and most of these were due to the high dissolved solids associated with groundwater sources. It was also determined in this assessment that there were several directions for further study of drinking water in the NRBS area. First and foremost, it was determined that there was a need for microbial information. While drinking water treatment facilities are required to sample for total and fecal coliforms, independent microbial analysis on raw, treated and distributed water would provide important insights into the drinking water quality. Secondly, valuable information could be obtained from NRBS site visits. An audit of selected sites would include a sampling component and a process analysis component. To accomplish this, samples of the raw water, treated water and distributed water at each site would be taken. The samples should be assessed for various physical, chemical and microbial parameters. In addition, facility operators should be interviewed at each site which would give information about the protocol of operation versus the actual operation, as well as information on taste and odour complaints received by the operator. These and other facets of drinking water quality will be assessed in subsequent reports by the Drinking Water Component.

REPORT SUMMARY 7

Prince, D.S., S.J. Stanley, and D.W. Smith. 1995. Data Report for the Independent Assessment of Drinking Water Quality in the Northern River Basins.
NRBS Project 4422-D1 (Report No. 115).

The World Health Organization (WHO, 1993) states that: "water is essential to sustain life and a satisfactory supply must be made to achieve a drinking water quality as high as practicable." The primary purpose of drinking water treatment is the protection of public health. The quantity of drinking water and the efficiency of treatment can be assessed through comparison to guidelines. In Canada, the applicable document is the Guidelines for Canadian Drinking Water Quality (1993) which has been adopted as minimum drinking water quality for licensed facilities in the province of Alberta. Most other developed countries have similar guidelines or regulations. The World Health Organization has also developed "Guidelines for Drinking Water Quality" (WHO, 1993) with a primary aim of protecting public health.

To assess drinking water quality in the Northern River Basin Study area results obtained from existing information and that obtained during this study were compared to both sets of guidelines discussed above. Of the sites investigated many were licensed facilities by Alberta Environmental Protection (AEP) and are required to meet as a minimum the Guidelines for Canadian Drinking Water. Other sites although not licensed by AEP still supply water to consumers, who tend to assure the water is of potable quality. As stated in the guidelines for Canadian Drinking Water:

> "The guidelines and recommendations listed herein are intended to apply to all drinking water supplies, public and private. ... Judicious use of the guidelines will result in the provision of drinking water which is both wholesome and protective of public health."

As a result both licensed and unlicensed facilities were assessed based on comparison to guidelines.

Based on site visits to 38 facilities, water quality analyses completed for the site visit and analysis of existing water quality information a number of conclusions can be made on the drinking water quality in the Northern River Basin Study area.

1. Small facilities in the study area tend to produce poorer water quality than larger facilities. This was found to be the case in terms of microbiological quality, turbidity (a good overall measure of treatment performance), and historical THM data.

2. As stated by the World Health Organization (1993):

   > "Infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and wide spread health risk associated with drinking water."

As it is not possible or feasible to test for all pathogenic organisms, microbiological quality of drinking water is assessed based on indicator organisms. If these indicator organisms are present in the finished drinking water it then must be assumed that pathogens could also be present. The most common microbiological indicator used in drinking water is the coliform group of organisms. Due to difficulties in sampling, transporting and analysis a single coliform positive sample may not truly reflect the microbial quality of the drinking water. As a result the Guidelines for Canadian Drinking Water Quality (GCDWQ,1993) state that not more than 10% of samples taken should be coliform positive. The WHO (1993) uses a more stringent guideline of not more than 5% be coliform positive. As the number of samples in small facilities are not great the 10% value was used in this study to assess microbial water quality to avoid unwarranted concerns to be raised for a facility based on a couple of bad samples. Analysis of a large database obtained from AEP of coliform results from communities in the Northern River Basin Study area was completed. This database consisted of roughly 270,00 total and 270,000 fecal coliform analyzes taken over the last seven years. Of the smallest facilities, watering points, 30% of them exceeded the 10% coliform positive guideline. If one includes samples which are considered poor by the GCDWQ (1993) this increases to 45%. Of particular concern was the finding that a number of facilities had high coliform positive percentages for all of the seven years the data was analyzed.

The occurrence of fecal streptococci, another indicator of fecal contamination, in 6 of the 28 surface water sites visited adds additional concern on the microbiological quality of water in many communities in the NRBS area.

3. It was also found that small facilities in the study area tended to have higher turbidity than larger communities. Although turbidity is only a measure of the clarity of water, high turbidity has been shown to negatively impact the performance of disinfection. In addition the most effective method of removal of protozoan cysts such as Giardia and Cryptospordium is through physical-chemical treatment processes for which there performance can be related to turbidity removal. The importance of turbidity as a parameter to indicate microbial quality is evident in the USEPA using turbidity to justify pathogen removal credits in their most recent standard. In these standards, maximum credits are earned with turbidity of £ 0.5 NTU 95% of the time.

   Results from existing data indicated that surface water facilities serving populations less than 500 have a significantly higher turbidity than facilities serving populations greater than 500. Because these samples were obtained from the distribution system and the small number of samples collected, compliance with guidelines could not be assessed.

   During the site visits 6 of the 38 sites had turbidity greater than 1 NTU, which in included the two watering points visited. These grab samples cannot be compared to standards which specify the maximum average turbidity 95% of the time must be below 1 NTU but they indicate that there may be problems at these sites.

4. Chemical parameters associated with raw water quality were found to be below guideline values based both on existing data and site visit data. However, for disinfection by-products

(THMs) which are produced during treatment, the site visit data found, that 60% (12 Of 21) of the surface water sites exceeded the guideline value of 100ug/L for THM. Analysis of existing data for THMs was complicated by the fact that most samples taken occurred under the old value of 350ug/L. The analysis did show however, if levels remained unchanged, 20 of the 62 sites analyzed by AEP would have difficulty meeting the lower standard value that is now in place.

5. Observation from site visits tended to indicate that much of the difficulties associated with small facilities may be related to operation of the facilities. Generally this can be related to the allotted time the operator is given to operate the facility, with smaller facilities having less time than larger facilities. The attitude of the people in decision making positions related to water treatment may also be an important factor. Operation performance may also be related to training as in larger facilities the majority or sole duty of the operator is to run the facility. As a result the opportunity for these operators to receive training is much greater. In small facilities, the operation of the treatment facility may be one of numerous tasks the operator may have to do. As many other tasks may be part of their daily routine the opportunity and incentive for these operators for training tends to be less.

6. Based on results of this study, remedial action is required in many small communities in the Northern River Basin Study area to bring the drinking water into compliance with current standards which are based on the protection of public health. Many communities are currently drinking water that may not meet Guidelines for Canadian Drinking Water Quality. Areas of concern are both the microbiological quality of the water and high levels of disinfection by-products. Of these the microbiological quality of the drinking water is by far of greatest concern. Many of the small communities showed higher than acceptable levels of indicator organisms as well as high turbidity. The occurrence of both would indicate that if pathogenic organisms are present in the raw water source they probably will not be removed by the treatment system.

   In the time needed for remedial actions to rectify the problems it is of utmost importance that consumers of water be notified immediately as to the status of their drinking water with respect to standards along with recommendations of prudent courses of action available to them. In the case of microbiological problems that are not rectified consumers should be advised to boil their drinking water as recommended in Guidelines for Canadian Drinking Water Quality (1993) and World Health Organization (1993).

REPORT SUMMARY 8

Armstrong, T.F., S.J. Stanley, and D.W. Smith. 1995. An Assessment of Non-Conventional Drinking Water in the Northern River Basins Study Area. NRBS Project 4423-D1 (Report No. 116).

It is estimated that approximately 25 % of the residents of the Northern River Basins Study area do not receive their drinking water from conventional drinking water treatment facilities. Therefore, these people rely on alternative sources for their drinking water supply. This report assesses the utilization and quality of the different *non-conventional* sources of drinking water that are used by people that do not consume conventionally treated water. Some of the non-conventional drinking water supplies utilized in the NRBS area include: (1) self-hauled treated water; (2) untreated surface water; (3) dugout water; (4) groundwater; (5) environmental sources of water such as snow, rain, and birch tree water; (6) bottled water; and (7) water treated by a variety of point-of-use technologies. There were four main research components in the assessment of these non-conventional drinking water supplies.

First, the results of an in-depth review of the literature available on non-conventional drinking water sources, drinking water quality and the correlation of drinking water and health is presented in the first part of this report. Although the literature was limited on the actual consumption and quality of most of the non-conventional sources of drinking water consumed in the study area, substantial information exists on conventional drinking water quality as well as considerable information on several point-of-use treatment technologies. Essentially, the best type of point-of-use treatment depends on the raw water source. Perhaps the best point-of-use treatment method to use on water of unknown quality is to boil it. The recommended boiling time in the literature varies considerably from simply heating the water to 50°C to vigorous boiling for 15 minutes. However, the majority of the authors cited a full boil for 1 minute as being sufficient to inactivate most pathogens. Besides boiling, there are numerous other point-of-use treatment technologies that employ disinfection (ultraviolet disinfection, ozonation, chlorination, iodination) and mechanical particle removal processes (such as sedimentation and filtration). The best available technology depends on the raw water source and likely incorporates more than one process to provide multiple barriers to ensure adequate drinking water quality.

The second component of research regarding non-conventional drinking water in the Northern River Basins Study are was to visit selected NRBS communities and interview residents regarding their non-conventional drinking water practices. Remote areas around Fort Chipewyan, John D'Or Prairie, Fox Lake and Atikameg were visited and residents were asked about the sources and utilization on non-conventional drinking water supplies, as well as their overall drinking water quality concerns. It was through these informal interviews that most of the information was collected on the types of non-conventional drinking water used and how it was treated, if at all, prior to consumption. Many of the people interviewed discussed the deterioration of some of the surface water sources in the study area, but the majority of the concerns presented regarding drinking water quality in this study was in regards to the addition of chlorine in the conventional drinking water treatment process. Based on this, it was found that some people who do have conventionally treated water delivered to their home, collect a non-conventional supply of water for consumption such as from a nearby lake or river. This water has been called "special drinking water" by those consumers. It was also based on these findings that a series of population sub-groups that may be particularly pre-disposed to consuming non-conventional drinking water was postulated. First, those that live in remote areas not serviced by conventional drinking water facilities are obvious consumers of non-conventional drinking water supplies. Second, some NRBS residents may be traditional consumers of alternative drinking water supplies. Many elderly residents may be included in this second group. Third, NRBS residents may consume non-conventional drinking water as a result of cultural activities such as living off the land expeditions or other wilderness activities. And the final group includes those individuals that consume non-conventional drinking water supplies for health reasons. This may include people that drink bottled water for its perceived health benefits as well as those that consume *special drinking water* to avoid the taste and smell of chlorine in conventionally treated water.

Third, during these field trips, samples of non-conventional drinking water were collected and these samples were analyzed for various physical, chemical and microbiological parameters. The non-conventional samples collected included untreated lake, river and creek water, spring water, groundwater well water, snow water, bottled water, and one sample of water treated with a point-of-use filter. Although the number of samples collected was limited and does not allow for absolute conclusions, several trends can be hypothesized. It was found that untreated surface water did not meet many of the physical, chemical and microbial guidelines in the GCDWQ. Although the groundwater samples collected met the microbiological limits in the GCDWQ, some physical and chemical parameters may be exceeded. The bottled water samples were found to have a very high background bacterial count and the point of use device tested was found to have actually contributed coliforms to the influent water supply.

The fourth component in the assessment of non-conventional drinking water supplies in the Northern River Basins Study area was to pursue research on the effectiveness on some of the portable point-of-use drinking water treatment filters on the market. The reason for this was because there is a very limited body of literature regarding these devices, and the claims made by the manufacturers suggest that these units are suitable to provide a safe supply of drinking water for wilderness campers and travelers. For the rigorous laboratory testing of these units, three filters were chosen to represent the larger market. The filters were chosen based on the type of filter media (carbon media, plastic media and silver impregnated ceramic media were selected), the price range (least expensive to most expensive were tested), and each unit was from a different manufacturer. The filters were subjected to an influent test water with a high turbidity, high bacterial count and a high particle count. It was found that only the silver impregnated ceramic filter was capable of reducing the turbidity, bacterial count and particle levels to below recommended levels for supplying a safe drinking water. However, further microbiological tests on this unit are required before it can be recommended for utilization in the study area.

REPORT SUMMARY 9

Liem, E., D.W. Smith, and S.J. Stanley. 1995. Inorganic Contaminants Removal.
NRBS Project 4402-D2 (Report No. 88).

This review assesses the types of inorganic contaminants, the levels of inorganic contaminants and the potential treatment processes that may be utilized for the removal of inorganic contaminants in the Northern River Basins Study area.

The initial step in this assessment was to compile a list of the inorganic parameters regulated in both the Guidelines for Canadian Drinking Water Quality (GCDWQ) and the World Health Organization (WHO) Drinking Water Quality Guidelines. The list compiled included: antimony, arsenic, barium, boron, cadmium, chloride, chromium, copper, cyanide, fluoride, iron, lead, manganese, mercury, nickel, nitrate, nitrite, selenium, sodium, sulfate, sulfide, total dissolved solids, turbidity, uranium, and zinc.

In order to assess the importance of these inorganic contaminants with particular relevance to the Northern River Basins Study area, the next step in this review was to summarize the results of the inorganic data compiled by Prince *et al.*, (1994) in a prior study of drinking water quality in the study area. Average concentrations of inorganic contaminants in drinking water supplies in the Northern River Basins along with the upper and lower 95 % confidence limits were presented. By comparing the reported levels with the guideline values from the GCDWQ and the WHO, it can be seen that generally, in terms of inorganic contaminants, drinking water quality in the NRBS area is of good quality. Other than turbidity, which is not really an inorganic contaminant, the upper 95 % confidence level concentrations are all below the health related guidelines. However, there were a number of inorganic parameters with Aesthetic Objectives that were exceeded including iron, manganese, sodium and total dissolved solids. Nonetheless, most of these sites with high values are good water sources, and although they do not present any health concerns in terms of inorganic contaminants, they may have undesirable taste and odour, or other aesthetic problems associated with them.

The final aspect of analysis of inorganic contaminants in Northern River Basins Study area waters was to present possible treatment methods for the reduction of given contaminants. Each inorganic contaminant was listed with the recommended treatment options, as well as the effect that conventional treatment processes have on given inorganics. Although an individual treatment method may be successful for the reduction of one type of inorganic, it may contribute to the levels of other inorganics. Therefore, it is important that all types of contaminants are considered when making decisions on water treatment. Typically, a detailed analysis is required that considers site specific information before making significant changes in the treatment process. As is often the case in water treatment design and assessment, pilot and bench testing is required prior to implementing any significant changes.

REPORT SUMMARY 10

Oke, N.J., D.W. Smith, and S.J. Stanley. 1995. Literature Review on the Removal of Organic Chemicals from Drinking Water. NRBS Project 4402-D1 (Report No. 87).

Due to ever-increasing numbers and quantities of organic chemicals in our environment, and public concern as to the adverse health effects of these compounds, the treatment of water to remove organic contaminants has become important for the protection of public health. This literature review was compiled with the intent that it be used as a guide, outlining processes that might be implemented and the removal efficiencies that may be observed during water treatment for the removal of organic compounds. These unit processes are generally not intended to be used on their own, but rather as single elements in a series of processes. This concept is commonly known as the multiple barrier treatment approach, and is necessary to obtain high quality water.

It must be emphasized that while treatment processes can significantly improve water quality, there is no substitute for source water purity. The task of removing contaminants from a clean supply is far simpler and economical than for a heavily contaminated source. Thus, every effort should be made to draw water from as unpolluted a source as possible. Very few sources, however, will provide clean enough water that no treatment is necessary, and therefore, it is in every community's interests to investigate the characteristics of their water supplies and the technologies that are available to help remediate any problems encountered. This review should therefore provide a starting point, after which testing must be done to determine how individually selected processes and combinations will function to treat the water at a specific location.

This review is part of a series of studies by the Drinking Water Component of the Northern River Basins Study (NRBS), whose overall task is to assess the quality of drinking water in the NRBS area. Analysis of existing water quality has found that organic contaminants based on comparisons to the Guidelines for Canadian Drinking Water Quality (Prince *et al.*, 1994). The only health related organic contaminant which was found to exceed guideline values at some sites was trihalomethanes (THM). THMs are generally produced in the treatment process by the reaction of chlorine, used as a disinfectant, and certain organic material from the water. Concentrations of THMs in the finished water can generally be lowered to acceptable levels by ensuring effective removal of organic material from the water prior to the addition of chlorine.

The goal of water treatment is to reduce possible risk associated with drinking water to an acceptable level. Risk to public health may be posed by various organic and inorganic chemicals, microbiological contaminants and radiological contaminants. In addition, the aesthetic quality of the water can be very important to the consumer. This report makes up one of three literature reviews completed as part of the NRBS. The other two review removal of inorganic and microbiological contaminants. Although this report only considers organic contaminants, in making decisions on treatment requirements it is important to consider all types of contaminants as trying to minimize concentrations of one type of contaminant may actually negatively impact the removal of other contaminants. Therefore, bench and pilot plant testing is highly recommended where there is concern about the removal of an organic chemical. Effective processes must be matched with the chemical species present, and then optimized for the specific water to be treated.

REPORT SUMMARY 11

Zhou, H., D.W. Smith, and S.J. Stanley. 1995. Removal of Microbial Contaminants from Water Treatment Processes for the Northern River Basins Communities.
NRBS Project 4402-D3 (Report No. 139)

In 1992, the Northern River Basin Study (NRBS) was established to address a number of environmental concerns raised from the northern river basins communities. Under this umbrella, the drinking water component was commissioned to assess the drinking water quality in the region, identify problems to be solved and provide recommendations for improving the drinking water quality if necessary.

After extensively analyzing the existing information with respect to the physical, chemical, biological and aesthetic characteristics of water treatment facilities in the study area, Prince *et al.,*. (1995) found that a majority of water quality violations in the NRBS area,resulted from the microbial related contamination. Several sites violated or had poor bacterial quality more than 10% of the time. As a matter of fact, such a problem is not unique in the U.S. and worldwide (Goodrich *et al.*, 1992). The World Health Organization (WHO, 1993) concluded that the microbial quality continues to be the most important for safe drinking water in order to protect public health. Consequently, microbial control must always be of paramount importance and must never be compromised.

This report reviews the various water treatment technologies available to remove the microorganisms available to remove the microorganisms from raw water supplies. Discussion of each technology included the process overview, performance, design consideration, operating and maintenance aspects, costs and status of technology development. Specific considerations were taken to those technologies applicable for small community systems located in the Northern River Basins Study area. Also, the impacts of important microorganisms and relevant regulations were examined to highlight the significance and requirements of removing microorganisms from water treatment processes. The following conclusions were made:

1. Controlling microbial contaminants continue to be the most important considerations for safe drinking water in order to protect public health. Among various pathogens, particular attention should be directed to control newly recognized waterborne microorganisms such as *Giardia*, *Cryptosporidium* and viruses. These microorganisms are often widespread in nature, have a low infectious dose, cause high incidences of waterborne diseases, and are resistant to chlorination.
2. The use of coliforms as an indicator organism presently remains to the most sensitive and specific way to detect microbial contamination and assess treatment efficiency. However, one must realize their limitations in predicting the protozoa and virus contamination. It would be desirable to include the particle size distribution determination for performance monitoring.
3. To safeguard against the contamination of waterborne pathogens, the multiple barrier approach should be exercised whenever possible. With this approach, controlling of microbial contamination starts from the collection of all wastes for treatment at specified sites, followed by the use of natural self-purification capacity.In water treatment, the multiple barrier approach involves the use of multiple water treatment processes in ensure a safe public water supply.

4. The best available technologies for the removal of microorganisms in water treatment include the filtration and disinfection. The simple disinfection using chlorine and its derivatives as the only treatment for surface water is ineffective to prevent waterborne giardiasis and cryptosporidiosis. An adequate pretreatment and filtration in addition to disinfection should be implemented for all surface waters.
5. Pretreatment by coagulation and flocculation is necessary to obtain high microorganism removals in filtration. It can also remove a significant portion of organic materials that interfere with disinfection.
6. The filtration processes, combined with pretreatment, can remove *Giardia* cysts and *Cryptosporidium* oocysts 99 percent or more provided that an optimum dosage of chemical coagulant is used. The efficiency of removing viruses is over 90 percent, dependent on the type of filtration. However, the filter ripening and turbidity breakthrough can substantially deteriorate the effluent microbiological quality. The water treatment plants should keep the effluent turbidity as low as possible, preferably less than 0.2 NTU.
7. Provided that the raw water quality is adequate, the slow sand filters, diatomaceous earth filtration, membrane filtration and package plants are the most applicable filtration technologies to small community systems.
8. The Addition of filtration aids is essential for successful removal of microorganisms by the rapid rate filtration and direct filtration. The proper dosages should reflect the seasonal variations in filter influent quality. The mechanisms underlying the flocculation and filtration of microorganisms closely follows the same principles as the elimination of the colloidal and finely dispersed substances.
9. Different disinfectants exhibit wide variation in inactivation of microorganisms. In general, the their relative efficiency in descending order are ozone, chlorine dioxide, chlorine, and chloramines. Because it is a weak disinfectant, the chloramines can only be used as a secondary disinfectant. UV radiation is an excellent bactericide and virucide but a weak cysticide, consequently, it is unsuitable for the disinfection of surface water.
10. Different types of microorganisms have different resistance to the disinfectants. It appears that among the concerned pathogens, the *cryptosporidium* oocysts and *Giardia* cysts are the most resistant to disinfection, followed by viruses. The bacteria are usually the most sensitive to disinfection.
11. Disinfection efficiency are strongly affected by the turbidity, pH, temperature, disinfectant demand causing materials and initial mixing. To ensure the proper disinfection, it is critical to maintain the disinfectant residuals for a period of contact time.
12. Most disinfectants will react with various substances in water to form the disinfection by-products. The strategies for controlling the disinfection by-products include the source control, precursor removal, alternative disinfectant and air striping.
13. At present, none of disinfectants employed in practice could solve all the problems the water utilities are facing. The chlorination, in combination with the optimization of coagulation and filtration, remains the most technically effective and economically feasible approach for controlling the microorganisms from water treatment processes. When the disinfection by-products become concerned, the alternative disinfectants such as ozone should be considered.

APPENDIX B: Guidelines for Canadian Drinking Water Quality, 1993
Maximum Acceptable Concentrations

"Maximum Acceptable Concentrations have been established for certain substances that are known or suspected to cause adverse effects on health"(Health and Welfare Canada, 1993). MAC's are derived to protect health based on the assumption of lifelong consumption of the substance at the established guideline concentration.

Microbiological Parameters	**MAC**	**Chemical Parameters (con't)**	**MAC (mg/L)**
Total Coliforms[1]	0 cfu/100mL	1,4-dichlorobenzene	0.005
Turbidity[2]	1 NTU	DDT + metabolites	0.03
		dichloromethane	0.05
Radiological Parameters[3]	**MAC (Bq/L)**	2,4-dichlorophenol	0.9
Cesium-137	50	diclofop-methyl	0.009
Iodine-131	10	dinoseb	0.01
Radium-226	1	diquat	0.07
Strontium-90	10	diuron	0.15
Tritium	40 000	flouride	1.5
		heptachlor+heptachlor epoxide	0.003
Chemical Parameters	**MAC (mg/L)**	lead[4]	0.01
aldicarb	0.009	lindane	0.004
aldrin + dieldrin	0.0007	malathion	0.19
azinphos-methyl	0.02	mercury	0.001
barium	1.0	mehoxychlor	0.9
bendiocarb	0.04	metribuzin	0.08
benzene	0.005	monochlorobenzene	0.08
benzo(a)pyrene	0.00001	nitrate[5]	45.0
cadmium	0.005	nitrolotriacetic acid	0.4
carbaryl	0.09	parathion	0.05
carbofuran	0.09	pentachlorophenol	0.06
carbon tetrachloride	0.005	selenium	0.01
chlordane	0.007	2,3,4,6-tetrachlorophenol	0.1
chlorpyrifos	0.09	triallate	0.23
chromium	0.05	trichloroethylene	0.05
cyanide	0.2	2,4,6-trichlorophenol	0.005
diazinon	0.02	2,4,5-T	0.28
dicamba	0.12	trihalomethanes	0.1
1,2-diclorobenzene	0.2	uranium	0.1

---

[1] This MAC is considered in compliance if there is less than 10cfu/100mL (and none of these are fecal coliforms) and if no consecutive samples show the presence of total coliforms. Community systems must also not have more than one sample per day with the presence of coliforms and cannot have coliforms present more than 10% of the time. The water should be immediately resampled to confirm positive coliform counts if: (1) the MAC is exceeded, (2) the total coliform background plate count is greater than 200 cfu/100mL or (3) the heterotrophic plate count is greater than 500cfu/mL.

[2] 5 NTU is permitted if it can be shown that disinfection is not compromised.

[3] Radiological guidelines are currently under review.

[4] At the point of consumption.

[5] Equivalent to 10mg/L nitrate as nitrogen.

Guidelines for Canadian Drinking Water Quality, 1993
Interim Maximum Acceptable Concentrations

Interim Maximum Acceptable Concentrations (IMAC) are set for substances that are assumed to have an adverse effect on health but for which there is insufficient toxicological data to set an MAC with reasonable certainty. Larger safety factors have been employed to compensate for the uncertainties for these substances.

Chemical Parameters	**IMAC (mg/L)**	**Chemical Parameters (con't)**	**IMAC (mg/L)**
arsenic	0.025	metolachlor	0.05
atrazine	0.06	paraquat	0.01
boron	5.0	phorate	0.002
bromoxynil	0.005	picloram	0.19
cyanazine	0.01	simazine	0.01
1,2-dichloroethane	0.005	temephos	0.28
2,4-D	0.1	terbufos	0.001
dimethoate	0.02	trifluralin	0.045
glyphosate	0.28		

Guidelines for Canadian Drinking Water Quality, 1993
Aesthetic Objectives

Aesthetic Objectives are applied to parameters that affect the acceptablility of the water by consumers and so that a good quality of water can still be supplied. If the concentration is well above and aesthetic objective, there is a possibility of a health hazard. The AO parameters marked with an asterisk (*) also have assigned MAC guidelines.

Physical Parameters	**AO**	**Chemical Parameters (con't)**	**AO(mg/L)**
colour	≤15 TCU	ethylbenzene	≤0.0024
odour	inoffensive	iron	≤0.3
pH	6.5-8.5 units	manganese	≤0.05
taste	inoffensive	monochlorobenzene *	≤0.03
temperature	15°C	pentachlorophenol *	≤0.03
total dissolved solids (TDS)	≤500 mg/L	sodium	≤200
turbidity[1]	≤5NTU	sulphate	≤500
		sulphide (as H_2S)	≤0.05
Chemical Parameters	**AO(mg/L)**	2,3,4,6-tetrachlorophenol *	≤0.001
chloride	≤250	toluene	≤0.024
copper[1]	≤1.0	2,4,6-trichlorophenol *	≤0.002
1.2-dichlorobenzene *	≤0.003	2,4,5-T *	≤0.02
1,4-dichlorobenzene *	≤0.001	total xylenes	≤0.3
2,4-dichlorophenol *	≤0.0003	zinc[1]	≤5.0

[1] At the point of consumption

APPENDIX C: Characteristics of Selected Waterborne Pathogens

ORGANISM	Pathogenicity			Vectors		Infectious Dose		Range of Symptoms	Potential Risk Groups
	None (*)	Oppor-tunisitic	Direct	Water	Food	Normal	Compromised or Sensitive		
BACTERIA									
Acinetobacter species	+	+		+		U	N, ND	2, 4	E, H, IS
Aeromonas hydrophila		+		+		U	N, ND	3, 4, 5, 6, 7	CI, E, D, H, IC, ID, IS, S, O
Alcaligenes species	+	+		+		U	N, ND	2	IC, IS, ID
Bacillus cereus		+	+	+	+	≈10^5/g food or water	ND	5	CI, E, H, IC, IS, ID, O, S
Campylobacter jejuni		+	+	+	+	<500cfu to >5000cfu	ND	5, 9 (in special cases)	CI, E, H, IC, IS, ID, O, S
Campylobacter coli		+	+	+	+	<500cfu	ND	5, 9 (in special cases)	CI, E, H, IC, IS, ID, O, S
Citrobacter freundii		+	+	+	+	U	N, ND	3, 4, 5, 6	CI, E, H, IC, IS, ID, O, S
Clostridium perfringens		+	+	+	+	≈10/g food or water	N, ND	1(gas gangrene), 2, 5, 6	CI, E, H, IC, IS, ID, O, S
Enterobacter aerogenes	+	+		+	+	U	N, ND	3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Enterobacter agglomerans	+	+		+	+	U	N, ND	3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Enterobacter cloacae		+		+	+	U	N, ND	3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Escherichia coli		+	+	+	+	? to <10^8cfu by ingestion	N, ND	2, 3, 4, 5, 6, 7, 8	CI, E, H, IC, IS, ID, O, S
Flavobacterium species	+	+		+		U	N, ND	1, 2, 3, 4	CI, E, IC, IS, ID, S
Hafnia alvei	+	+		?	?	U	N, ND	3, 4, 5, 6, 7	CI, E, IC, IS, ID, S
Klebsiella oxytoca	+	+		+		U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Klebsiella ozonae	+	+		+		U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S

Klebsiella oxytoca	+	+		+		U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Klebsiella ozonae	+	+		+		U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Klebsiella pneumophila		+	+	+	+	U	N, ND	3, 4, 6	CI, E, IC, H, IS, ID, S
Legionella pneumophila		+	+	+		U	N, ND	4	CI, E, IC, H, IS, ID, S
Legionella species		+	+	+		U	N, ND	4	CI, E, IC, H, IS, ID, S
Mycobacterium avium-intracellulare		+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Mycobacterium chelonae	+	+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Mycobacterium fortuitum	+	+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Mycobacterium gordonae	+	+		+		U	N, ND	4, 8, 9	E, IC, IS, ID, S
Moraxella species	+	+		+		U	N, ND	2	CI, E, H, IC, ID, IS
Proteus species	+	+		+		U	N, ND	3, 6, 7	IC, ID, IS, S
Pasteurella multicida	+	+		+		U	N, ND	3, 4, 5, 6	IC, ID, IS, S
Pseudomonas aeruginosa		+	+	+	+	U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Pseudomonas cepecia	+	+		+		U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Pseudomonas fluorescens	+	+		+	+	U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Salmonella species		+	+	+	+	100 - 1000 by ingestion	N, ND	5, 8 (in special cases)	CI, E, H, IC, IS, ID, O, S
Serratia species	+	+		+		U	N, ND	1, 2, 3, 4, 7	CI, E, H, IC, IS, ID, O, S
Shigella species		+	+	+	+	180 by ingestion	N, ND	5	CI, E, H, IC, IS, ID, O, S

Staphylococcus aureus	+	+	+	+	+	U	N, ND	1, 2, 3, 4, 5, 6, 7	CI, E, H, IC, IS, ID, O, S
Staphylococcus epidermidis	+	+		+		U	N, ND	1, 2	IC, ID, IS
Streptococcus faecalis	+	+		+	+	U	N, ND	5, 6	CI, E, H, IC, IS, ID, S
Streptococcus fecium	+	+		+	+	U	N, ND	5, 6	CI, E, H, IC, IS, ID, S
Vibrio fluvalis		+				U	N, ND	2, 5, 7	CI, E, H, IC, IS, ID, S
Vibrio alginolyticus		+				U	N, ND	2	CI, E, H, IC, IS, ID, S
Yersinia enterocolitica		+	+	+	+	U	N, ND	5	CI, E, H, IC, ID, IS, S
AMOEBA									
Acanthamoeba species		+	+	+	?	U	N, ND	2, 8 (eg. meningitis)	CI, E, H, IC, ID, IS, S
Naegleria fowlerii		+	+	+	?	U	N, ND	8 (eg. meningitis)	CI, E, H, IC, ID, IS, S
FUNGI									
Aspergillus species	+	+		+	+	U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Cephalosporium species	+	+		+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Fusarium species	+	+		+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Penicillium species	+	+		+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S
Rhizopus species				+		U	N, ND	1, 4, 8, 9 (eg. allergic response)	CI, E, H, IC, ID, IS, S

VIRUSES									
Adenovirus		+		+		U	N, ND	2, 4, 5	CI, E, H, IC, ID, IS, S, O
Coxsackie virus		+		+		U	N, ND	2, 4, 5, 8, 9 (diabetes?)	CI, E, H, IC, ID, IS, S, O
Enterovirus		+		+		U	N, ND	2, 4, 5, 8	CI, E, H, IC, ID, IS, S, O
Hepatitis		+		+		U	N, ND	5, 8	CI, E, H, IC, ID, IS, S, O
Norwalk Virus		+		+		U	N, ND	5	CI, E, H, IC, ID, IS, S, O
Reovirus		+		+		U	N, ND	4, 5 (?)	CI, E, H, IC, ID, IS, S, O
Rotavirus		+		+		U	N, ND	5	CI, E, H, IC, ID, IS, S, O
PROTOZOA									
Cryptosporidium			+	+	?	1 cyst	1 cyst	5	CI, E, H, IC, ID, IS, S, O
Entamoeba histolytica			+	+	?	1 cyst	1 cyst	5	CI, E, H, IC, ID, IS, S, O
Giardia lamblia			+	+	?	1 cyst	1 cyst	5, 9 (eg. arthritis)	CI, E, H, IC, ID, IS, S, O

(Adapted from Emde et al., 1994)

1. * No documented pathogenicity for normally healthy persons

2. Risk Group Codes:

CI	Children and Infants	ID	Immunodeficient
E	Elderly	IS	Immumosuppressed
H	Healthy	S	Surgery
IC	Immunocompromised	O	Other (eg. previous illness, pregnancy etc)

3. Pathogenicity Codes:

U	Infectious dose for normally healthy persons unknown.
ND	Infectious dose for compromised persons not yet determined. n some cases the infectious dose may be as low as one organism .
N	Nosocomial infections documented.

4. Range of Symptoms Codes:

1	Skin/Hair infection	6.	Genitourinary infection
2	Eye/Ear infection	7.	Wound infections
3	Bacteremia/Septecemia	8.	Other types of infections (meningitis)
4	Pneumonia/Respiratory Illness	9	Chronic infection (asthma, arthritis etc)
5	Gastrointestinal infection		

APPENDIX D: Conventional Drinking Water Facility Inventory

Community Status Codes Used in Facility Inventory

C	City
T	Town
V	Village
H	Hamlet
SV	Summer Village
SD	Sub-division
PP	Provincial Park
MHP	Mobile Home Park
REG	Regional System
WCO	Water Cooperative
WP	Watering Point
IR	Indian Reserve
MS	Metis Settlement
S	School
O	Other

Type of Facility

G	Groundwater raw water supply
S	Surface water raw water supply

Treatment Codes Used in the Facility Inventory

NT (or Nil)	No Treatment
RWR	Raw Water Reservoir
CST	Cistern
Alg	Algae Control
Oxi	Oxidation
Aer	Aeration
TO	Taste and Odour Control
CG	Coagulation
CgA	Coagulation Aid
Flc	Flocculation
Clr	Clarification
Sd	Sedimentation
Cflt	Carbon Adsorption Filtration
Msflt	Micro Strainer Filtration
Pflt	Pressure Filtration
Sflt	Slow Sand Filtration
Rflt	Rapid Sand Filtration
Gsflt	Green Sand Filtration
Mmflt	Multi-Media Filtration

FACILITY	STATUS	POPULATION		% Pop. change	TYPE	SOURCE	RAW_STORAG m3	TREATED_ST m3	TREATMENT_
ANZAC	H	165	165		S				Cg/CgA/Flc/Sd/RSflt/NaOCl/TWR
ATHABASCA	T	1975	1975	-0.3%	S	Athabasca River		7092	Cg/CgA/pH/Sd/RSflt/AC/Flu/CL2/TWR
ATIKAMEG SCHOOL	S	0			S	Whitefish Band WTP			Prov for chlor/TWR
BARRHEAD	T	4014	4014	4.2%	S	Paddle River	363636	45454	RWR/Aer/Cg/Clr/Rflt/Flu/PPCl2/TWR
BEAR CANYON	WP	NA			S	Surface runoff	2700		Iron Removal,P. Filt.
BEAR CANYON SCHOOL	S	0			S	Bear Canyon WP			RWR/Gsflt/PPNaOCl
BEAVERLODGE	T	1808	1808	-1.6%	S	Beaverlodge River	690909	3405	RWR/TWR/Aer/Cg/pH/Clr/Rflt/Cl2
BERWYN	V	606	606	-12.1%	G			1091	Stor
BEZANSON	H	62	62		G			41	NT
BEZANSON	O				G				Nil
BEZANSON SCHOOL	S	0			G				Nil
BISHOP ROUTHIER(PEAVINE)	S	0			S	Hauled From Peavine WTP			
BLUE RIDGE	H	260	260		G			295	Nil
BLUESKY	H	165	165		S	Surface runoff	65000	332	RWR/Aer/Rflt/NaOCl/TWR
BONANZA	S	0			S	Dugout			Culligan Filters
BORGEL WHITELAW	WP	NA			G				Nil
BOYLE	V	704	704	-1.9%	S	Skeleton Lake(new pt.1992)		1899	T&O/Cg/CgA/Flc/Sed/pH/RSflt/PPCl2,CaOCl,NaOCl/TWR
BROWNVALE	H	134	134		G			45	Nil
BRULE	H	82	82		S	Supply Creek(GW 1992)		227	Pflt/NaOCl/TWR
BUFFALO HEAD PRAIRIE	WP	NA			S	surface runoff			P. Filt.
BUFFALO HEAD PRAIRIE SCH	S	0			G	Hauled From Lacrete WTP			Nil
CADOMIN	WP	114	114		G				Nil
CADOTTE LAKE	WP	241	241		G			450	Aer/PAC/Cg/CgA/pH/Clr/RSflt/PPNaOCl/TWR
CALLING LAKE	H	330	330		S	Calling Lake(upgraded 1992)		64	Flc/Sd/Flt/NaOCl
CALLING LAKE P.P.	PP				S	Calling Lake			I.Gal.
CANYON CREEK	H	367	367		S	Lesser Slave Lake	40000	818	RWR/Cg/CgA/Rflt/TO/pH/Cl2/TWR
CARCAJOU	WP	NA			G				
CHERHILL	H	79	79			Private			
CHIP LAKE	S	0			S				
CHIPEWYAN LAKE	H	157	157		S	Chipewyan Lake		45	Filt. W.P.
CHISHOLM	H	100	100		G				Nil,W.P.
CLAIRMONT	H	443	443		G			909	Nil
CLEARDALE	WP	25	25		S	Surface Runoff	35900	160	Comp.
COLINTON	H	126	126		G			115	Fe re/GSflt/NaOCl/TWR
CONKLIN	H					Private			
CONKLIN	S	133	133		G			45	P.Filt. KMnO4. W.P.
CROOKED CREEK	WP	NA			G				Nil
CYNTHIA	H	56	56		G			227	Nil
DAPP	S	0			G				
DEADWOOD SCHOOL	S	0			S	H from Manning or Loc. WTP			
DEADWOOD WP	WP	NA			S	Spring			I.Gal.
DEBOLT	H	106	106		G			45	NaOCl
DEER HILL	WP	NA			G				Nil
DESMARAIS	H	350	350		S	South Wabasca Lake	227000	1137	RWR/Cg/CgA/Clr/RSflt/TO/pH/PPCl2
DIXONVILLE 1	H	90	90		G			45	Nil
DIXONVILLE 2	WP	NA			G				Nil
DONNELLY	V	421	421	4.0%	S	Winagami Lake via canal	82500	530	RWR/Cg/Flc/RSflt/pH/NaOCl
DR. MARY JACKSON	S	0			G				Fe re/Gsflt/CaOCl/TWR
DUNVEGAN PROV.REC.PK.	O	0			G				Nil
EAGLESHAM	V	184	184	-6.6%	S	Surface runoff	86000	540	RWR/Cg/CgA/Clr/DMflt/Cl2
EAST GRIMSHAW WATER CO-OP	O				G				Nil
EAST MANNING	WP	NA			S	Surface runoff			I.Gal.
EAST PRAIRIE SETTLEMT	MS	260	260		G				Gsflt/NaOCl

FACILITY	STATUS	POPULATION		% Pop. change	TYPE	SOURCE	RAW_STORAG m3	TREATED_ST m3	TREATMENT_
EDSON	T	7323	7323	0.0%	G			7115	NaOCL2/TWR
ELMWORTH	S	0			G				Nil
ENILDA	H	128	128		S	High Prairie WTP		91	
ENTWISTLE	V	478	478	-3.8%	G			680	GSflt/Fe re/Sc cnt/PPNaOCl2/TWR
EUREKA RIVER	WP	4	4		G			5	Nil
EVANSBURG	V	750	750	-3.6%	G			2272	Corr Cnt/NaOCl/TWR
EVERGREEN PARK.AGR.SOC.	O	0			G				Nil
FAIRVIEW	T	3281	3281	0.8%	S	Peace River	636400	682	RWR/Ar/Cg&A/pH/Sflt/TO/Flu/PPCl2/TWR
FAIRVIEW REGIONAL WATER CO-OP	O				S	Fairview WTP			Nil
FALHER	T	1183	1183	0.4%	S	Winagami Lake via canal	86360	322	Aer/Cg/CgA/Sd/Sft/pH/T&O/Clr/RSflt/Flu/CL2/TWR
FAUST	H	344	344		S	Slave Lake	88200	1023	RWR/TO/Cg/CgA/pH/Flc/Sd/RSflt/PPCl2/TWR
FAWCETT	H	144	144		G			100	Fe re/GSflt/NaOCl/TWR
FOOTNER LAKE	H	60	60		S	High Level WTP			
FORT ASSINIBOINE	V	214	214	-16.4%	G			21	Mn re/GSflt/NaOCl/TWR
FORT CHIPEWYAN	H	1200	1200		S	Lake Athabasca	84000	865	RWR/Cg/CgA/pH//RSflt/Cl2/TWR
FORT MACKAY	H	267	267		S	Ells River		18	RWR/Fere/Aer/Cg/CgA/pH/Flt/PPNaOCl
FORT MCMURRAY	C	33698	33698	-0.7%	S	Athabasca River	45500	60000	Cg/CgA/TO/pH/Clr/DMflt/Flu/NH4/PPCl2/9TWR
FORT VERMILION	H	823	823		S	Peace River	100000	990	RWR/Cg/CgA/Clr/pH/Rflt/PPCL2/TWR
FOX CREEK	T	2068	2068	9.3%	G			4818	GW/(1:GSflt/NaOCl/TWR)(1:NT)(3:FeRe/Seq/Cl2/TWR)
GIFT LAKE	MS	424	424		S	Gift Lake		850	Cg/CgA/Flc/Clr/pH/RSflt/NaOCl/TWR
GIROUXVILLE	V	367	367	-4.9%	S	Winagami Lake via canal	45455	818	RWR/Cg/Sd/Rflt/Sft/Cl2/TWR
GOODWIN	WP	NA			G			10	
GRANDE CACHE	T	3842	3842	5.4%	S	Victor Lake		4545	Fe re/Pflt/CL2/TWR
GRANDE PRAIRIE	C	28350	28350	6.8%	S	Wapiti River	200000	26509	RWR/Cg/CgA/Flc/Sd/Rflt/Flu/PPCl2
GRANDE PRAIRIE	AP				G				Nil
GRASSLAND	H	66	66		S&G	Surface runoff	22727	82	RWS/Aer/KMnO4/Cg/CgA/pH/Clar/RSflt/AC/NaOCl/TWR
GREEN COURT	H	70	70			Private			
GRIFFIN CREEK	WP	NA			G				NT
GRIMSHAW	T	2812	2812	9.0%	G			5773	Flu/Cl2/TWR
GROUARD	H	352	352		S	Buffalo Bay/Lesser Slave	48500	705	Fe re-Aer.KMnO4/Cg/CgA/pH/Flc/Clr/Rflt/Cl2/TWR
GUY	H	54	54		S	Surface runoff	40900	22	RWR/Pflt/PPCL2/TWR
HARMON VALLEY	WP	NA			S	Surface runoff		14	I.Gal.
HAWK HILLS	WP	10	10		S	Surface runoff		5	I.Gal.
HIGH LEVEL	T	2921	2921	-5.2%	S	Footner Lake	500060	2845	Cg/CgA/Clr/pH/Rflt/T&O/Flu/Cl2/R&TWR
HIGH PRAIRIE	T	2932	2932	4.1%	S	West Prairie River	536428	4955	RWR/Aer/Cg/CgA/Clr/pH/Rflt/Flu/Cl2
HIGH PRAIRIE AIRPORT	AP	0				Bottled water			Nil
HIGH PRAIRIE NW CO-OP	O	0			S	High Prairie WTP			Nil
HILLIARD BAY PROV. PK	PP	0			G				GSflt/Fe re/NaOCL2
HILLTOP ESTATES	SD	23	23		G				Fe seq/NaOCl/TWR
HINES CREEK	V	513	513	-17.9%	S	Jack Creek	136000	727	RWS/Aer/Cg/CgA/pH/Sd/Sflt/PPNaOCl
HINTON	T	9893	9893	4.8%	S	Athabasca River		5228	Comp. (Weldwood)
HOTCHKISS	WP	NA			S	Surface runoff		5	1 Gal
HYTHE OFF/LIB	V	NA			G	Private			
JANVIER	H	435	435		S	Christina River	50000	31	RWR/Cg/Flc/RSflt/pH/NaOCl/TWR
JARVIE	H	102	102		G			68	Aer/Fe re/NaOCl
JASPER NATIONAL PARK	NP	4475	4475		S&G	Cabin Lake		1509	Nil
JEAN COTE	H	75	75		S	Surface runoff	45430	22	RWR/Pflt/PPCL2/TWR
JOUSSARD	H	269	269		S	Lesser Slave Lake	9090	454	Cg/RSflt/NaOCl/TWR
KEG RIVER	WP	NA			S	Surface Runoff		22	RWR/Cg/CgA/Flc/Clr/pH/MMFlt/NaOCl/TWR
KINUSO	V	154	154	-18.4%	S	Faust WTP		455	NA
LA CRETE	H	689	689		G			1136	Fe re/Pft/Sft/NaOCl
LA GLACE	H	169	169		G	Private			
LAC LA BICHE	T	2553	2553	0.2%	S	Lac La Biche		1134	RWR/Cg/Microflt/Pflt/TO/Flu/CL2/TWR

FACILITY	STATUS	POPULATION		% Pop. change	TYPE	SOURCE	RAW_STORAG m3	TREATED_ST m3	TREATMENT_
LITTLE BUFFALO	H	253	253		S	Hauled from Cadotte Lake		9	NA
LITTLE SMOKY	H	39	39			Private			
LODGEPOLE	H	161	161		G	Private			
LOON LAKE	H	218	218		S	Red Earth Creek WTP		23	Prov for Dis/TWR
MANNING	T	1144	1144	-0.4%	S	Notikiwin River	163640	1830	RWR/Aer/Cg/Sd/pH/Rflt/Flu/Cl2/TWR
MANOLA	H	71	71		S	From Barrhead		91	Nil
MARIE-REINE	WP	93	93		S	Surface runoff		14	RWR/Aer/Cg/Pflt/NaOCl/TWR
MAYERTHORPE	T	1692	1692	19.7%	G			3410	FeRe & Mnre/GSflt/Cl2
MCINNIS (WELL #1)	WP	NA			G				Nil
MCINNIS (WELL #2)	WP	NA			G				Nil
MCLENNAN	T	1026	1026	2.7%	S	Winagami Lake via canal	207500	1300	RWR/Cg/CgA/pH/Clr/RSflt/Flu/PPCl2/TWR
MILDRED LAKE/LOWER C.	I				S	Athabasca River	5910	36	Stdby Cl2
MILDRED LAKE/UPPER C.	I				S	Athabasca River	17728	932	P.Filt., Polymer
MITSUE IND. PARK	O	0			S	Lesser Slave River			P.Filt/Non-Potable
MOONSHINE LAKE PROV.PK.	PP	0			S	Moonshine Lake			P.Filt
NAMPA	WP	NA			S	Surface Runoff			I. Gal.
NAMPA	V	496	496	6.9%	S	North Heart River	113650	1137	RWR/Aer/Cg/CgA/pH/Sd/Clr/Rflt/PPCL2/TWR
NEERLANDIA	H	71	71		S	Baird Lake	22500	1360	RWR/Cg/CgA/Flc/Clr/pH/KMnO4/Flt/Cloram/TWR
NEW FISH CREEK	WP	NA			G			18	Nil
NITON JUNCTION	H	72	72			Private			
NORTH STAR	WP	NA			S	Surface runoff		11	I.Gal.
PADDLE PRAIRIE	MS	470	470		S	Boyer River	68000	255	RWR/Aer/Cg/CgA/Flc/Sd/Flt/NaOCl
PEACE RIVER	T	669	6696	6.8%	S	Peace River		14189	AC/Cg/CgA/Clr/Rflt/Flu/Cl2/TWR
PEACE RIVER AIRPORT	AP	0			G	East Grimshaw Co-op			Res/NaOCl
PEACE RIVER C.C.	O	0			S	Peace River	4546	1795	RWR/Cg/CgA/pH/Clr/Flr
PEACE RIVER PULP MILL	O								
PEAVINE	MS	363	363		S	South Heart River			RWS/Cg/CgA/MMflt/NaOCl
PEERLESS LAKE	WP	253	253		S	Peerless Lake		100	Comp.
PEERLESS LAKE	S	0			S&G				Soft.
PEERS	H	162	162		G	Private			
PEORIA	H	25	25		S	Surface runoff	16365	5	RWR/Pflt/NaOCL2/TWR
PIBROCH	H	100	100		G			100	Gsflt/Fe re/NaOCl/TWR
PICKARDVILLE	H	190	190		S	Pembina River (Westlock)		68	NaOCl/TWR
PINE SHADOW ESTATES	MHP	200	200		G				Nil
PLAMONDON	V	236	236	7.2%	S	Lac La Biche		714	Cg/RSflt/TO/pH/Cl2/TWR
PUSKWASKAU	WP	NA			G				Nil
QUEEN ELIZ.(LAC CARDINAL)	PP	0			G				
RAINBOW LAKE	T	817	817	21.0%	S	Surface runoff	318000	1576	RWR/Oxi/Aer/Cg/CgA/pH/RSflt/PPCl2/TWR
RED EARTH	WP	NA			S	Red Earth Creek WTP			
REINWOOD	WP	NA			S	Surface runoff			Nil
RENO	WP	20	20		S	Surface runoff	3182	14	I.Gal.
RIDGE VALLEY	H	52	52		G			46	Nil
RIDGE VALLEY	HC								
ROBB	WP	230	230		G	Private			Nil
ROCHESTER	H	87	87			Private			
ROCHFORT BRIDGE	H					Private			
ROCKY LANE	WP	NA			S	Surface Runoff			P. Filt.
ROCKY LANE SCHOOL	S	0			S	Hauled From Local WTP			Nil
ROYCE	WP	NA			S	Surface Runoff	6820	1	RWR/MMflt/NaOCl
RYCROFT	V	634	634	-5.7%	S	Spirit River	312000	1045	RWS/Aer/Cg/CgA/Clar/Sflt/PPCl2
SANDY LAKE	H	NA			S	Sandy Lake	3300	773	RWR/MMFlt/ACFlt/NaOCl
SANGUDO	V	368	368	3.6%	G			3	Fe seq/NaOCl/TWR
SASKATOON ISLAND PROV.PK.	PP	0			G				Gsflt/Fe re/NaOCl

FACILITY	STATUS	POPULATION		% Pop. change	TYPE	SOURCE	RAW_STORAG m3	TREATED_ST m3	TREATMENT_
SEXSMITH	T	1256	1256	0.3%	G			2728	TWR
SHELL-PEACE R. INSITU	I	0			S	Peace River			Flt/Sft/AC/Chlor
SIR WINSTON CHURCHILL PP	PP	0			S	Lac La Biche		45	Pflt/NaOCl/TWR
SLAVE LAKE	T	5607	5607	3.3%	S	Lesser Slave Lake		4786	Cg/CgA/Flc/Sd/pH/T&O/Rflt/Flu/Cl2/TWR
SMITH	H	323	323		S	Athabasca River	32731	454	RWR/Cg/Pflt/CL2/TWR
SPIRIT RIVER	T	1044	1044	-6.4%	S	Surface runoff	510556	1586	RWR/Cg/CgA/Flc/Sd/Clr/TO/pH/2RSflr/Flu/PPCl2
ST. ISIDORE	H	90	90		S	Surface runoff	38600	185	2RWR/Aer/Cg/CgA/Flc/Clr/pH/RSflt/AC/NaOCl/TWR
STRONG CREEK	WP	NA			G			11	Nil
STURGEON HEIGHT COM.	H					Private			
SUNSET HOUSE	WP	NA			G				Nil
SUNSET HOUSE	S				G				Nil
SWAN HILLS	T	2407	2407	-2.3%	S	Freeman Lake		4546	Cg/Sed/Sft/pH/AC/Rflt/Flu/PPCl2/NaOCl/TWR
SWEATHOUSE	WP	NA			G			18	Nil
T&E TRAILER PARK	MHP	150	150		G				Nil
TANGENT	H	60	60		S	Surface runoff	25000	13	RWR/Pflt/NaOCl/TWR
TEEPEE CREEK	S	18	18		G				Iron Removal
THREE CREEKS	WP	NA			S	Surface Runoff		14	I.Gal.
THUNDER LAKE PROV.PK.	PP	0			G				NaOCl (Apr 1 to Oct 31 each year)
TOMKINS LANDING	WP	NA			S	Surface Runoff			P. Filt.
TOMPKINS LANDING SCHOOL	S	0			S	Hauled From Local WP			
TRIPLE L T.P.	MHP	300	300		G			55	Nil
TROUT LAKE	WP	290	290		G			33	Cg/CgA/Sd/Sft/Clr/Rflt/Fe re/NaOCl/TWR
TROUT LAKE (KATERI)	S	100	100		S	Trout Lake			P.Filt.
VALHALLA	S	0			G				Nil
VALLEYVIEW	T	2039	2039	-0.4%	S	Sturgeon Creek	194000	3000	RWR/Cg/CgA/pH/Fe re/Sd/AC/RSflt/Flu/PPCl2/TWR
VALLEYVIEW	HC				G				
WABASCA	H	501	501		S	North Wabasca Lake	15000	1050	RWR/Cg/CgA/Sd/pH/Pflt/ACflt/CL2/TWR
WAGNER	WP	76	76		S	Canyon Creek WTP			NA
WANDERING RIVER	H	43	43		S	Wandering River	27000	573	RWR/Cg/CgA/RSflt/pH/TO/NaOCl/TWR
WANHAM	V	216	216	-7.3%	S	Surface Runoff	50000	68	RWR/Cg/Sd/Rflt/CL2
WARRENSVILLE	WP	NA			G				Nil
WATINO	WP	66	66		G				Nil
WEBERVILLE (#1)	WP	NA			G				Nil
WEBERVILLE (#2)	WP	NA			G				Nil
WEMBLEY	T	1382	1382	11.5%	G			682	TWR
WESTLOCK	T	4463	4463	4.1%	S	Pembina River	256849	4546	RWR/Cg/CgA/AC/Sd/Rflt/Flu/PPCl2/TWR
WEYERHAEUSER GRANDE CACHE OP.	I								
WEYERHAEUSER GRANDE PRAIRIE OP.	I				S	Wapiti River			Complete
WHITE GULL	SV	0			G				NT (operated Apr 1 - Nov 1)
WHITECOURT	T	6692	6692	20.9%	S	Macleod River		10433	TO/Cg/CgA/Rflt/pH/Clr/Flu/Cl2/TWR
WHITELAW	H	139	139		S	Spring		114	NaOCl/TWR
WHITELAW SPRING	WP	NA			S	Spring			NaOCL2/CLOSED Dec 5, 1991
WIDEWATER	H	130	130		S	Canyon Creek WTP			
WILDWOOD	V	353	353		G			1318	Fe Seq/Cl2
WILLIAMSON PROV.PK.	PP	0			G				GSflt/NaOCl
WILLOW GROVE T.P.(HYTHE)	SD	0			G				Iron Removal
WINAGAMI LAKE P.P.	PP	0			S	Hauled From High Prairie			
WOKING	H	77	77		S	Surface Runoff	34060	78	RWR/Aer/Cg/CgA/Sd/Flt/NaOCl/TWR
WORSLEY	H	51	51		S	Eureka River	73640	418	RWR/Cg/CgA/Flc/flt/NaOCl
YOUNG'S POINT PROV.PK.	PP	0			G				
ZAMA	WP	NA			G				Nil
ZAMA	H	178	178		G			472	Sft/Fe re/PPNaOCl

The Northern River Basins Study was established to examine the relationship between industrial, municipal, agricultural and other development and the Peace, Athabasca and Slave river basins.

Over four and one half years, about 150 projects, or "mini studies" were contracted by the Study under eight component categories including contaminants, drinking water, nutrients, traditional knowledge, hydrology/hydraulics, synthesis and modelling, food chain and other river uses. The results of these projects, and other work and analyses conducted by the Study are provided in a series of synthesis reports.

This Synthesis Report documents the scientific findings and scientific recommendations of one of these components groups. This Synthesis Report is one of a series of documents which make up the North River Basins Study's final report. A separate document, the Final Report, provides further discussion on a number of scientific and river management issues, and outlines the Study Board's recommendations to the Ministers. Project reports, synthesis reports, the Final Report and other NRBS documents are available to the public and to other interested parties.

Synthesi
Report