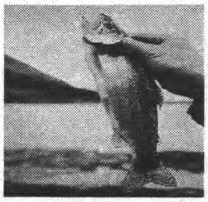
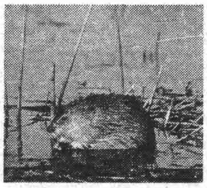
Canada Alberta Northwest Territories

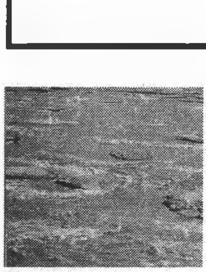
Northern River Basins Study

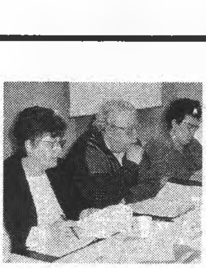




NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 88

A REVIEW OF LITERATURE ON THE REMOVAL OF INORGANIC CONTAMINANTS FROM DRINKING WATER





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by

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

(Dr. Fred J. Wrona, Science Director)

14 Feb 96
(Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

(Dr. P. A. Larkin, Ph.D., Chair)

14 Feb 1996
(Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington
(Lucille Partington, Co-chair)

14/02/96
(Date)

Robert McLeod
(Robert McLeod, Co-chair)

14/02/96
(Date)

A REVIEW OF LITERATURE ON THE REMOVAL OF INORGANIC CONTAMINANTS FROM DRINKING WATER

STUDY PERSPECTIVE

Water is essential to life and it can be an important vector for conveying contaminants into humans. To assist the Northern River Basins Study (NRBS) Board in making recommendations about the safety of drinking water supplies, the Drinking Water component designed a five-step program of studies. The steps included:

1. synthesis of existing data on water use and water quality;
2. investigation of odour in water and tainting in fish;
3. review of health records for water borne diseases;
4. assessment of conventionally treated and non-conventional water; and
5. preparation of a synthesis report.

Related Study Questions

2) What is the current state of water quality in the Peace, Athabasca and Slave River basins, including the Peace-Athabasca Delta?

8) 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?

This report deals with step four and provides a literature review of the current state of knowledge in the area of inorganic chemical removal from drinking water. The review considered inorganic contaminant parameters that include arsenic, barium, boron, cadmium, chloride, chromium, copper, cyanide, fluoride, iron, lead, manganese, mercury, nitrate, selenium, sodium, sulphide, total dissolved solids, uranium and zinc. Sources of inorganic chemicals include industrial and municipal effluent, agricultural runoff, and natural sources. The effects of high concentrations of inorganic chemicals range from aesthetic problems to toxic effects. Some inorganic chemicals are required for good health although in high doses they can be toxic. Also they can exist in a relatively safe form that is not toxic and then change into a toxic form due to a chemical reaction that may be natural or due to industrial processes or other human intervention. The review revealed that conventional water treatment processes such as coagulation/flocculation, water softening and filtration, can effectively remove many of the inorganic contaminants. Advanced processes such as ion exchange and membrane exchange processes were found to be very effective at removing inorganics" but are also very expensive to apply.

A previous report "Independent Assessment of Drinking Water Quality in the Northern River Basins" (NRBS Report Number 115) determined that, in general, the raw water sources of drinking water in the Northern River Basins had low concentrations of inorganic chemicals and that microbiological contamination was more of a concern. In general, the main effect that inorganic chemicals have is related to the aesthetics of the drinking water.

The information from this report and its companions surveys, "A Review of Literature on the removal of Organic Chemicals from Drinking Water", and "A Review of Literature on the Removal of Microbial Contaminants from Drinking" (NRBS Report Numbers 87 and 132) provide an overview of the current state of knowledge in drinking water treatment. These and other drinking water projects will form the basis for the Drinking Water Synthesis report. This report will also support a companion study, "Human Health Monitoring Program" that will be examining human health issues in Northern Alberta.

REPORT SUMMARY

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 Basin Study (NRBS) 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 inorganics in concern include arsenic, barium, boron, cadmium, chloride, chromium, copper, cyanide, fluoride, iron, lead, manganese, mercury, nitrate, selenium, sodium, sulphate, sulphide, total dissolved solids, uranium, and zinc. In the case of GCDWQ, three criteria have been set for contaminant limits: MAC (maximum acceptable concentration), IMAC (interim maximum acceptable concentration), and AO (aesthetic objective).

In order to assess the importance of these inorganic contaminants with particular relevance to the NRBS area, the next step in this review was to summarize the results of the inorganic data compiled by Prince et al (1995) in a prior study of drinking water quality in the study area. By comparing the reported levels with the guideline values from the CGDWQ and the WHO, it can be seen that in terms of inorganic contaminants, drinking water quality in the NRBS area is generally of good quality. With the exception of turbidity, the upper 95% confidence level concentrations were all below the health related guidelines. However, the aesthetic parameters were exceeded for total dissolved solids, iron, manganese, and sodium that might cause some taste / odor problems.

The final aspect of analysis of inorganic contaminants in NRBS area 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 effects that conventional and advanced treatment processes have on given inorganics. It was found that not all inorganics could effectively be removed using conventional treatment processes. Cost factors should be considered when using advanced treatment processes. It is also important to note that an individual treatment method may be successful for the reduction of a certain type of inorganic, but 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 to consider site specific information. As is often the case in water treatment design and assessment, pilot and bench testing is required prior to implementing any significant changes.

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LIST OF ABBREVIATIONS

Ag	silver
Al	aluminum
$Al_2(SO_4)_3.14.3H_2O$	alum
AO	aesthetic objective
As	arsenic
Ba	barium
CCREM	Canadian Council of Resource and Environmental Ministers
Cd	cadmium
Cr	chromium
Cu	copper
$Cu(OH)_2$	copper hydroxide
Fe	iron
$FeCl_3.6H_2O$	ferric chloride
GAC	granular activated carbon
GCDWQ	Guidelines for Canadian Drinking Water Quality
H	hydrogen
Hg	mercury
IMAC	interim maximum acceptable concentration
JTU	jackson turbidity unit
MAC	maximum acceptable concentration
MDL	method detection limit
Mn	manganese
N	nitrogen
NAS	National Academy of Sciences
NO_2	nitrite
NO_3	nitrate
NRBS	Northern River Basin Study
NTU	nephelometric turbidity unit
O	oxygen
PAC	powder activated carbon
Pb	lead
pH	$-\log[H^+]$
S	sulphur
Se	selenium
SO_4	sulphate
TDS	total dissolved solids
USEPA	United States Environmental Protection Agency
USNRC	United States National Research Council
VOC	volatile organic contaminant
WHO	World Health Organization

1.0 INTRODUCTION

As part of the Drinking Water Component of the Northern River Basin Study (NRBS), three literature reviews have been produced to assess treatment removals for organic and inorganic chemical contaminants and microbiological contaminants. This review assesses the occurrence and removal processes of inorganic contaminants.

The Guidelines for Canadian Drinking Water Quality (GCDWQ) 1993 provide a list of inorganic contaminants of concern as presented in Table 1. The guidelines have set maximum acceptable concentrations (MACs) for the protection of public health. Concentration of a certain contaminant that exceeds the MAC value will expose individuals to possible health risks which have been deemed to be unacceptable. The interim maximum acceptable concentrations (IMACs) have also been set for a similar purpose in the cases where there is insufficient information of the chemical to set MACs. Aesthetic objectives (AOs) are used for any contaminants that can cause aesthetic problems such as taste and odor (Federal - Provincial Subcommittee on Drinking Water of the Federal - Provincial Advisory Committee on Environmental and Occupational Health, 1993). As with any guidelines, values may change as additional information on possible impacts of the contaminant become available. The World Health Organization (WHO) also provides guidelines for various inorganic contaminants. For comparative purposes, these guidelines are presented in Table 2.

To assess the importance of inorganic contaminants in drinking water supplies in the NRBS area, results from a previous study by Prince et al (1995) are summarized in Table 3. Average inorganic concentrations in drinking water supplies in the NRBS and the upper and lower 95% confidence limits are presented. It should be noted that these results are skewed high because only values above the method detection limit were used in the calculation of the averages. By comparing results in Table 3 with results in Tables 1 and 2, it can be seen that generally, in terms of inorganic contaminants, drinking water quality in the NRBS is of good quality. Other than turbidity which is not really an inorganic contaminant, the upper 95% confidence level concentration are below MAC values, which are set based on health related concerns. A number of AO values are exceeded such as iron, manganese, sodium, and total dissolved solids. Most of these sites with high values are good water sources, and although they present no health concerns in terms of inorganic contaminants, they may have undesirable taste and odor or other aesthetic problems associated with them.

Table 1. Guidelines for Canadian Drinking Water Quality (Inorganic Limits)

Inorganics	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
arsenic		0.025	
barium	1.0		
boron		5.0	
cadmium	0.005		
chloride			250
chromium	0.05		
copper			1.0
cyanide	0.2		
fluoride	1.5		
iron			0.3
lead	0.01		
manganese			0.05
mercury	0.001		
nitrate	45.0		
selenium	0.01		
sodium			200
sulphate			500
sulphide			0.05
TDS			500
turbidity	1 NTU		5 NTU
uranium	0.1		
zinc			5

Table 2. WHO Guidelines for Drinking Water Quality (Inorganic Limits)

Inorganics	Guideline Values (mg/L) Year 1984 (1)	Guideline Values (mg/L) Year 1993(2)
antimony		0.005
arsenic	0.05	0.01
barium		0.7
cadmium	0.005	0.003
chromium	0.05	0.05
cyanide	0.1	0.07
fluoride	1.5	1.5
lead	0.05	0.01
manganese		0.5
mercury	0.001	0.001
nickel		0.02
nitrate	10	50
nitrite	—	3
selenium	0.01	0.01

(1) WHO as cited by Cotruvo and Vogt (1990)
(2) WHO (1993)

Table 3. Inorganic Contaminant Levels in Drinking Water Supplies in the NRBS Area

Inorganics	GCDWQ (mg/L)	MDL (mg/L)	AVERAGE VALUES >MDL (mg/L)	UPPER 95% limit > MDL	LOWER 95% limit > MDL
aluminum		≤ 0.002	0.1	1.37	0.007
arsenic	IMAC = 0.025	0.0001	0.00046	0.018	0.00001
barium	MAC = 1.0	0.001	0.05	0.18	0.014
beryllium		0.001	0.001		
boron	IMAC = 5.0	≤ 0.002	0.05	0.51	0.01
cadmium	MAC = 0.005	0.001	0.0017	0.0041	0.0007
calcium		1.0	35.73	168.4	7.58
chloride	AO = 250.0	≤ 1.0	7.47	36.5	1.53
chromium	MAC = 0.05	0.001	0.0029	0.0069	0.0012
cobalt		0.001	0.0015	0.0037	0.0006
copper	AO = 1.0	0.001	0.02	0.19	0.0028
cyanide	MAC = 0.2	0.001	0.0023	0.0053	0.001
fluoride	MAC = 1.5	≤ 0.05	0.2	1.62	0.02
iron	AO = 0.3	≤ 0.05	0.06	0.38	0.01
lead	MAC = 0.01	0.002	0.003	0.0062	0.0015
magnesium		1.0	12.86	50.6	3.27
manganese	AO = 0.05	≤ 0.08	0.02	0.19	0.0
mercury	MAC = 0.001	0.0001	0.00016	0.00039	0.00007
molybdenum		0.001	0.0024	0.006	0.001
nickel		0.001	0.0036	0.0095	0.0013
NO_2 and NO_3	MAC = 45.0 (Nitrate)	≤ 0.02	0.05	0.53	0.005
potassium		0.2	2.95	17.91	0.49
selenium	MAC = 0.01	0.0001	0.00012	0.00022	0.00006
silica		≤ 0.5	3.61	21.92	0.59
sodium	AO = 200.0	1.0	27.39	307.90	2.44
sulphate	AO = 500.0	≤ 5.0	53.88	439.46	6.61
TDS	AO = 500.0		293.20	951.00	90.40
turbidity (NTU)	AO = 5.0 MAC = 1.0	≤ 0.1	0.63	4.70	0.08
vanadium		0.002	0.0034	0.0072	0.0016
zinc	AO = 5.0	0.001	0.008	0.064	0.001

Note: MDL = method detection limit

2.0 OVERVIEW OF INORGANIC REMOVAL PROCESSES

2.1 CONVENTIONAL TREATMENT PROCESSES

There are three conventional treatment processes for removing inorganic contaminants. These include coagulation / flocculation, softening, and filtration. In general, these processes are considered to be effective and do not have any serious concerns with regards to costs. Therefore, these processes are commonly found in many water treatment practices and are suitable for utilization in the NRBS area.

2.1.1 Coagulation / Flocculation

Coagulation / flocculation is a process utilized to agglomerate fine dispersed particles (colloids) in water so that they can be removed in sedimentation and filtration processes. This usually can be achieved by adding certain chemicals (coagulants) and or coagulant aids. Rapid mixing is needed in the early stage to allow the coagulant to interact with the particles. This is followed by a slow mixing stage to allow the particles to agglomerate. Alum ($Al_2(SO_4)_3.14.3H_2O$) and ferric chloride ($FeCl_3.6H_2O$) are the most common coagulants used in water treatment practices (Environmental Health Directorate, 1993).

In order to make the particles agglomerate, they must first be destabilized. Destabilization can occur by two distinct processes. The first process is the neutralization of the particle charge (usually negatively charged) so that electrostatic repulsive forces are removed and particles can agglomerate when brought in contact with each other. pH is a very important factor as the coagulants behave differently when the pH changes. The best coagulation / flocculation performance for alum can be achieved at certain pH values as shown in Figure 1. A pH value slightly less that 5.5 allows the maximum formation of precipitates while ensuring that the dominant species is positively charged. Since the colloids are usually negatively charged, this seems to be the best option. Figure 2 shows that in the case of ferric chloride, the best pH value is about 8.

The second process for destabilization involves the enmeshment or adsorption of particles to the coagulant precipitant and is known as the "sweep flocculation" process. In this process, pH is not an important factor as basically the particles are enmeshed by the coagulant precipitants, swept down, and removed. Figure 3 illustrates the effect of applying alum coagulant in both the charge neutralization and the sweep flocculation region. The figure indicates that at a relatively low dose, particles are destabilized by charge neutralization. When more dose is added, the excess coagulant causes the particles to be restabilized (thereby carrying a positive charge). At higher doses, a great deal of precipitates is formed and sweep flocculation occurs. Due to the narrow range of charge neutralization, sweep flocculation is often used for river waters as the area of charge neutralization is hard to determine with changing water quality conditions. Charge neutralization is used in direct filtration, where the raw water normally comes from a large lake and has constant water quality.

Inorganic polymers (such as polyaluminum chloride and activated silica) and organic polymers are often used to improve coagulation / flocculation performances. They basically work the same as other types of coagulants or coagulant aids by strengthening the floc already formed in the coagulation process.

In the case of low turbidity water, adding more particles such as bentonite or powder activated carbon (PAC) is sometimes necessary. It was reported that ferric chloride performed better than alum for water that was slightly alkaline. Iron salt is also denser and settles better than alum. However, other factors like cost and practicability problems should be taken into account. In

Figure 1. Alum Coagulation (Amirtharajah and O'Melia, 1990)

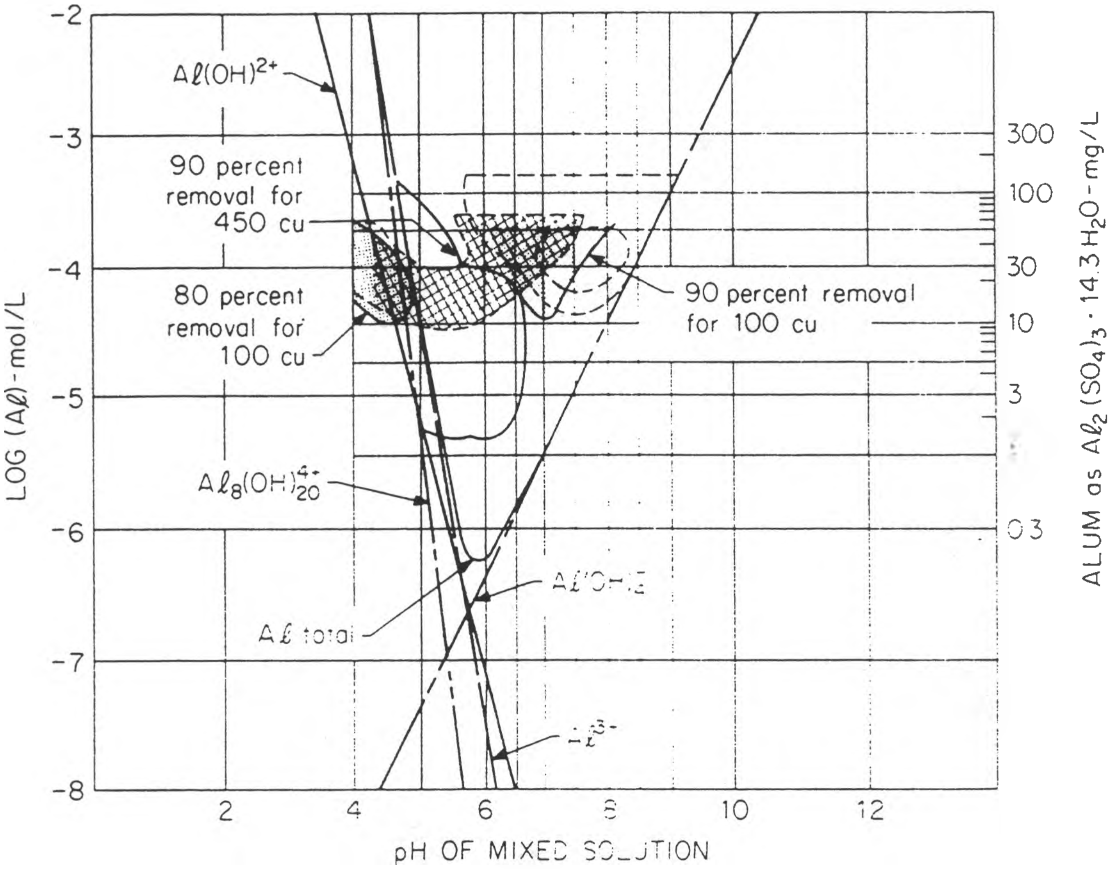


Figure 2. Ferric Coagulation (Amirtharajah and O'Melia, 1990)

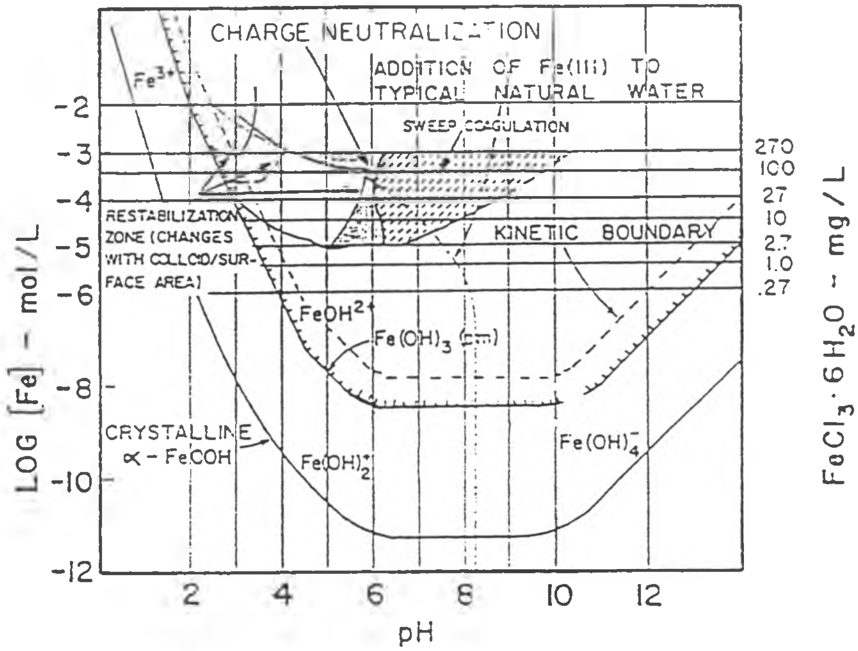
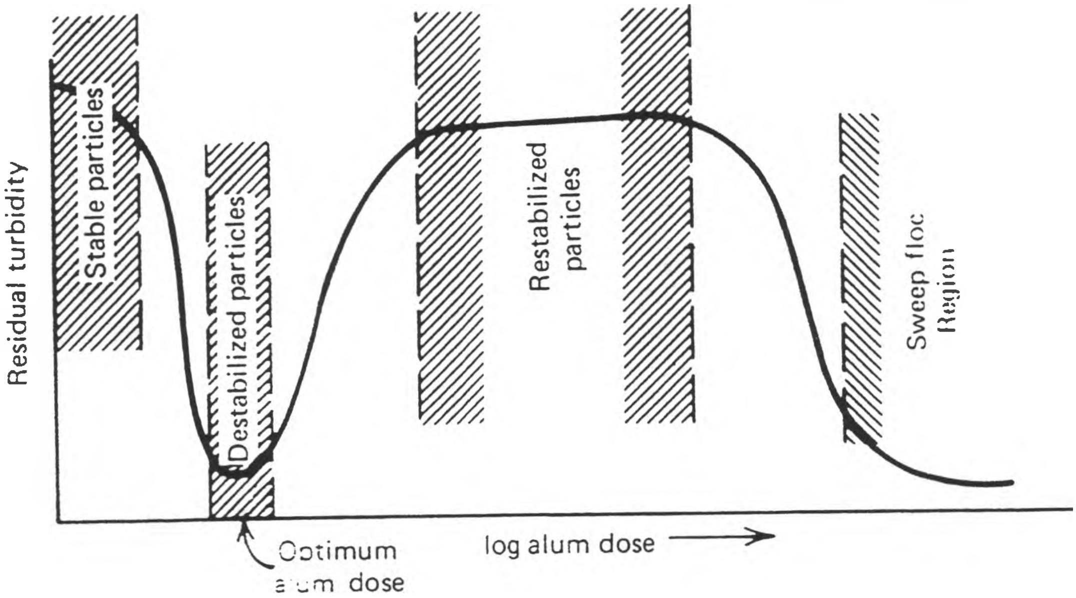


Figure 3. Alum Sweep Floc Process (Snoeyink and Jenkins, 1980)



general, alum is more commonly used in waterwork practices (Environmental Health Directorate, 1993).

USEPA (1977) provides general information for inorganic removals using iron and alum coagulation processes for specific inorganic contaminants. The inorganic percent removals vs. pH are presented in Figures 4 and 5.

Better monitoring and control programs are also necessary in order to improve the overall performance of the process. Bench and pilot scale experiments are also very important. They basically provide abundant information about the optimum pH, chemical dose, mixing speed, temperature, and other factors. Cost and practical problems can be assessed from these studies.

2.1.2 Softening

Softening typically removes magnesium and calcium hardness in water. The main mechanism is based on chemical reactions that make soluble compounds precipitate. Depending on the constituents that need to be removed, either lime or soda ash may be used for inorganic reduction. Lime precipitates both calcium bicarbonate and magnesium bicarbonate effectively, while soda ash is more effective for the removal of non - carbonated calcium and magnesium salts. The use of sodium hydroxide has also been reported to have some softening capabilities (Environmental Health Directorate, 1993).

Lime can also remove inorganics through the "sweep flocculation" process by creating calcium carbonate precipitate that sweeps all the particles down. The optimum pH to achieve the maximum calcium carbonate precipitate varies, however it was reported that pH values ≥ 12 were usually adequate. The general performance of lime softening in removing inorganics can be seen in Figure 6. The figure indicates that for most inorganic contaminants, the higher the pH the better the removals.

Again, monitoring and control programs are two important factors to achieve the best lime softening process performance. Bench and pilot scale studies similar to those for flocculation / coagulation are also necessary to give the most complete information about the optimum conditions.

2.1.3 Filtration

Filtration occurs in two steps: first the particle must contact the media and second the particle must be retained by the media. There are two main types of filters commonly used in the water treatment practices: rapid filters and slow sand filters. Rapid filters can consist of one or more materials such as sand, crushed anthracite coal, granular activated carbon (GAC), and garnet or ilmenite. GAC is used in filter adsorbers replacing sand and anthracite. Sand and dual media filters are commonly found, however a substantial number of triple media filters are also exist. Unstratified coarse sand and anthracite coal can also be used as filter medium. However, it requires a deeper bed to achieve the same particulate removals. The upflow filter is another variation of a rapid filter in term of flow direction that is utilized in a few water treatment plants in other countries. It may consist of a retaining grid to resist the water uplift. Figure 7 shows the schematic diagrams of filter configuration for rapid filtration (Cleasby, 1990).

In regards to filter operation, there are several filter characteristics that must be considered to optimize its performance. First, filter headloss is the primary problem that must be overcome. The

Figure 4. Inorganic Removals using Iron Coagulation (USEPA, 1977)

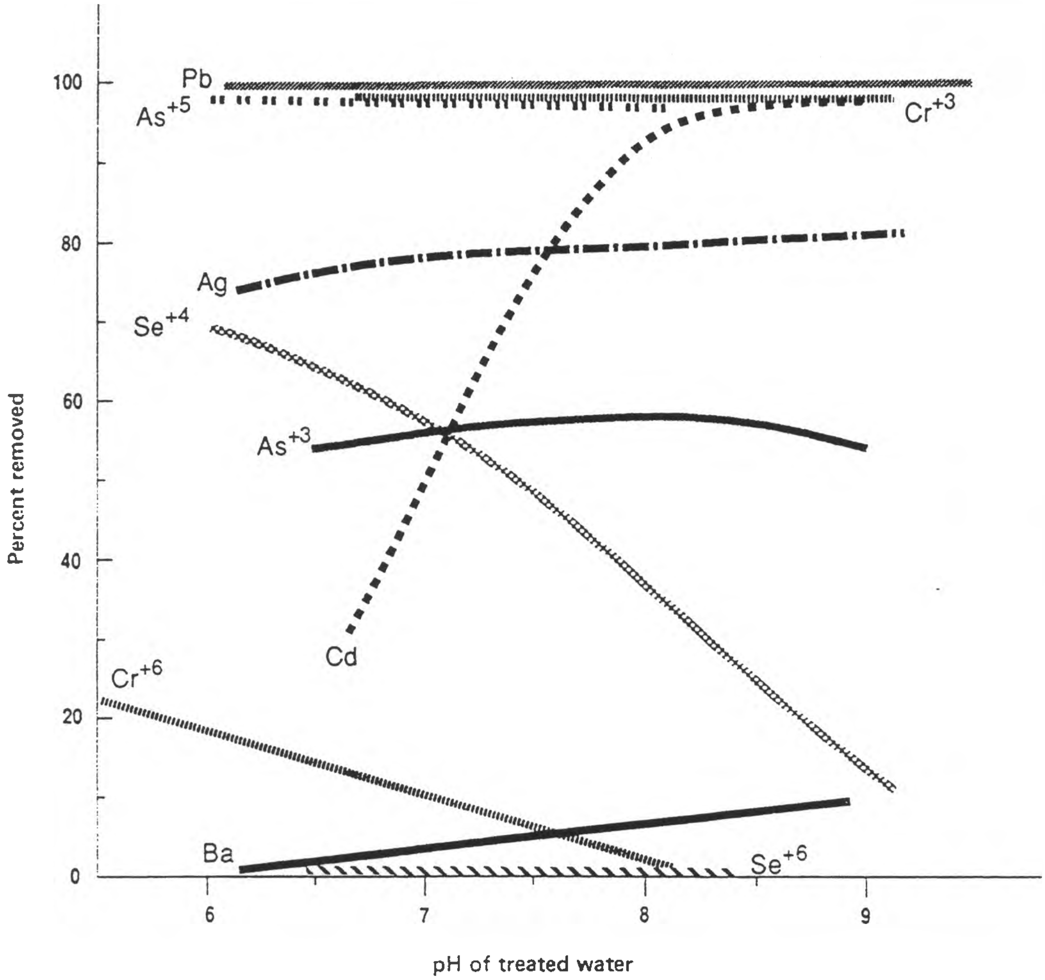


Figure 5. Inorganic Removals using Alum Coagulation (USEPA, 1977)

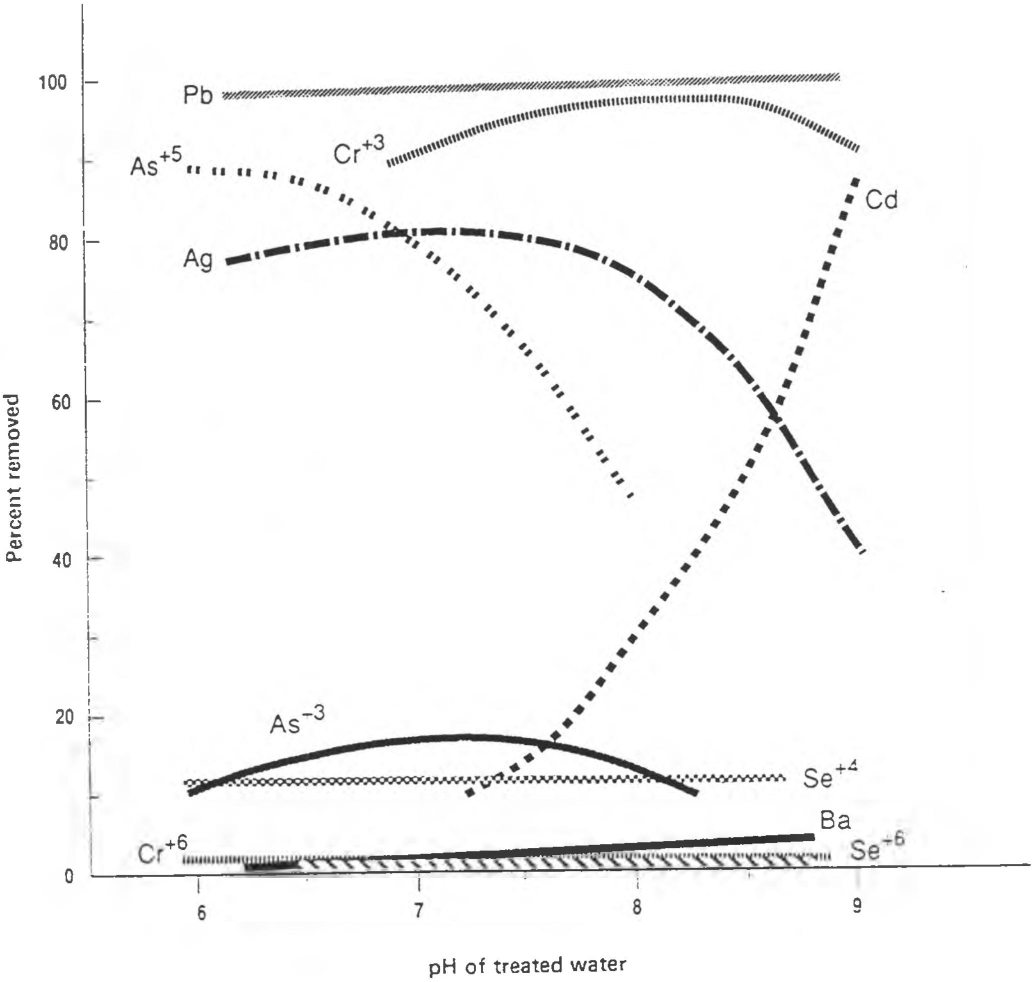


Figure 6. Inorganic Removals using Lime Softening (USEPA, 1977)

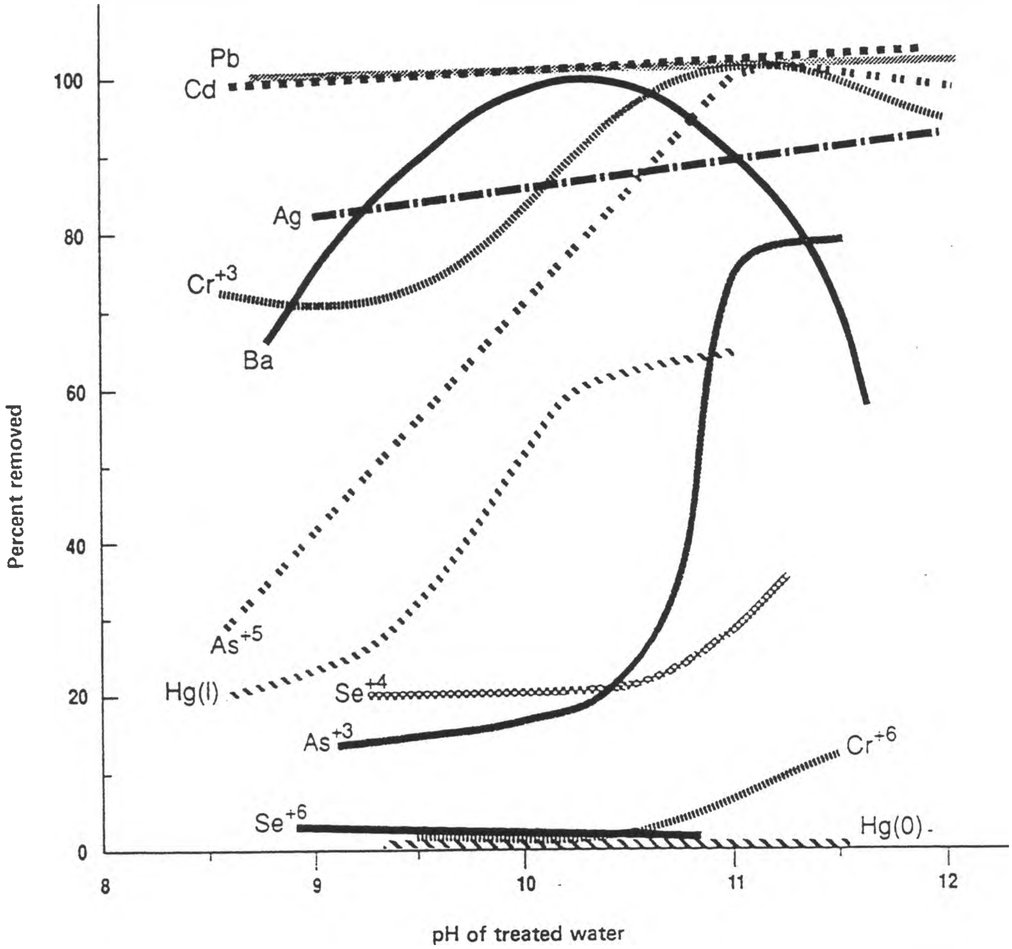
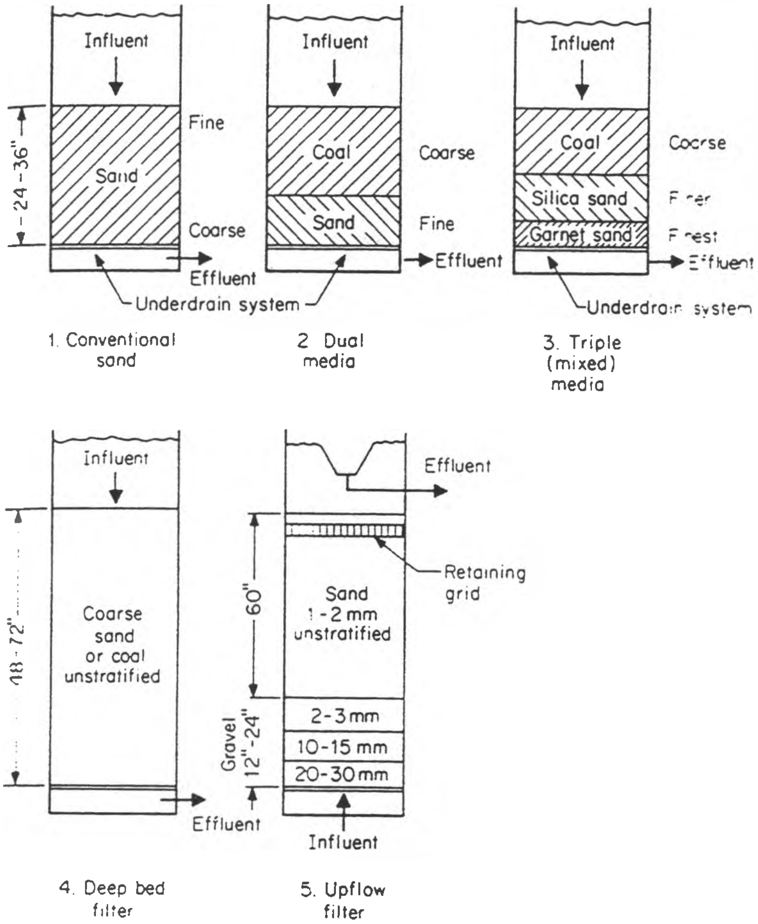


Figure 7. Rapid Filtration (Cleasby, 1990)



1. Conventional sand

2. Dual media

3. Triple (mixed) media

4. Deep bed filter

5. Upflow filter

flow is either kept constant by controlling the valve (constant rate operation) or by allowing the flow to decline (declining rate operation). Second, backwashing is necessary to remove particles which are captured in the filter media. It is known that immediately after backwashing events, water quality deteriorates. Therefore, the water must be discarded to allow the filter to "ripen" before the water is sent to the distribution system. Adding polymer and coagulant in the backwash water decreases the time and peak of turbidity during the filter ripening stage. The use of multilayer (coarse and fine) media also improves the media cleaning process (Environmental Health Directorate, 1993). Finally, operational control is another way to improve the filter performance. Examples include continuous monitoring and particle counts. Conducting filter column tests is also very important to achieve the optimum treatment performance.

The slow sand filter is a sand filter operated at very low rates without the use of coagulant in pretreatment. The removal mechanisms are both physical and biological. Microorganisms living in the filter cause the reduction of organic constituents. The removals occur mainly in the "dirty skin" that develops on the surface. Because the slow sand filter is partially a biological process, prechlorination might be required (Cleasby, 1990). However as reported by Lettermen (1987), the filter removes only a little portion of submicrometer particles like clay, viruses, and humic substances. The operating cost is also high since the medium needs to be periodically cleaned by removing the top part of the filter.

2.2 ADVANCED TREATMENT PROCESSES

Advanced treatment processes are other options when the conventional treatment processes do not work well in removing a certain contaminant. These processes might not be economical and therefore are not commonly found in many public water treatment plants. Some of the main advanced treatment processes that may be applicable for the NRBS area are discussed briefly below.

Aeration can be defined as a process of bringing water into contact with air in order to expedite the transfer of gas between the two phases. Aeration has traditionally been used to remove hydrogen sulfide due to taste / odor problems and carbon dioxide to reduce the use of lime in softening processes. Recently, this process is also used to remove trace volatile organic contaminants (VOCs) from water. Another application of this process is the addition of oxygen to oxidize certain types of ions such as iron to the insoluble form which is easier to remove using other processes. Ozone and potassium permanganate are other alternatives as the oxidation agents. Several types of unit operations can be used including packed towers, diffused aeration, spray nozzles, and tray aerators (Cornwell, 1990).

Adsorption is a process where a specific substance known as the adsorbate is accumulated at the interface between two phases (a solid and a liquid or a gas and a solid). The solid on which adsorption occurs is called the adsorbent. The transport processes include bulk solution transport, film diffusion transport, pore transport, and adsorption. Adsorption can be used to remove constituents that cause health concerns as well as taste / odor and color problems. GAC (granular activated carbon) is an adsorbate that is commonly used in columns or beds. The influent is passed through an adsorbent bed until the adsorbent reaches its break through (exhausted) stage, evidenced by the appearance of the unwanted ion. Regeneration is therefore required for the exhausted bed. PAC (powder activated carbon) is another adsorbent that can be used to reduce taste / odor problems by mixing it in water (Snoeyink, 1990).

Ion exchange is a process in that an unwanted ion is exchanged with another ion. Ion exchange can be applied to remove contaminant cations such as barium, strontium, radium, and others. Certain types of anions such as fulvates, arsenate, and others can also be removed using this process.

Similar to the adsorption process, the regeneration process is required when the bed has been exhausted. These ions can be in the form of strong acid cations, weak acid cations, strong base anions, and weak base anions (Clifford, 1990).

Membrane processes can be applied to remove particles which are to small to remove using ordinary filtration processes. This process has been expanded so that it is capable of providing superior drinking water quality with competitive capital, operation, and maintenance costs. Various types of membranes processes exist. Reverse Osmosis is a pressure driven process that passes water through a thin membrane but retains virtually all ions. The pressure must exceed the osmotic pressure, therefore forcing the water through and leaving the ion behind. Electrodialysis is a process in which ions are transferred through membranes from a less to a more concentrated solution as a result of the passage of direct electric current. Ultra and nanofiltrations are pressure driven processes using filters with very fine pores for fractionating and concentrating solutions containing colloids and other fine particles (Conlon, 1990).

Distillation is a process whereby water is heated and the hot water vapor passes into a collection chamber where the steam condenses and changes back to the liquid form (Gabler et al, 1988). Distillation is an effective method of removing dissolved solids, metals, and minerals (Culotta, 1989).

Sequestering is another process of binding a certain type of ion into a complex form that is acceptable aesthetically. This complex will eventually degrade with time. Sodium hexametaphosphate is very commonly used as the sequestering agent (Environmental Health Directorate, 1993).

3.0 SPECIFIC CONTAMINANT REMOVAL PROCESSES

All inorganics listed in Table 1 above will be discussed in this chapter. Introductory explanations for each inorganic basically cover some the chemical properties, natural and human - made sources, concentration levels in many waters (such as surface water, groundwater, and stormwater), and some health concerns.

This is followed by discussions about the application of conventional treatment processes for removing the inorganic in water. The emphasis is given to the use of coagulation / flocculation, softening, and filtration which are the standard treatment processes in most water treatment practices.

The advanced treatment is then briefly discussed as the last option when the conventional treatment process does not seem to work well. These processes include the application of activated carbon, ion exchange, oxidation, aeration, specific membrane filter, and others.

As it will be shown, the removal efficiency is greatly influenced by the pH, temperature, properties and concentration levels of the inorganic and other chemicals in water, and many others. The percent removal is presented for each treatment process whenever the data are available. This can be used as a parameter to choose which treatment method is the most suitable for removing a certain inorganic in water.

3.1 ARSENIC

Arsenic is found in the aquatic environment in the trivalent (arsenite) and pentavalent (arsenate) forms. Arsenite is found in anaerobic groundwater, while arsenate in aerobic surface water (Sorg and Logsdon, 1978). Arsenic is very mobile with cycles through water, biota, and sediment (USEPA, 1979). The occurrence of arsenic in the earth's crust is about 0.0005% by weight (Merck, 1989). Erosion of arsenic - containing surface rocks seems to be the most dominant natural source of arsenic in water supplies (USNRC, 1977). Arsenic is used in metallurgy for copper, lead, and alloy processing (Merck, 1989). Arsenic is also found in industrial emissions, fossil fuel combustion, smelting, some pesticides, preservatives, and others (CCREM, 1987). Dannecker et al (1990) recorded arsenic concentrations of 0.024 to 0.21 mg/L in stormwater. Department of National Health and Welfare (1980) reported that Canadian surface waters contained arsenic with concentrations less than 0.05 mg/L. It was reported that only 4% of drinking water in the United States contained more than 0.01 mg/L of arsenic. Arsenic concentrations in groundwater seldomly exceed 0.005 mg/L (Tate and Arnold, 1990). Acute effects due to arsenic ingestion include shock and death, while chronic effects can be in the forms of kidney / liver degeneration, cardiac damage, and others (Merck, 1989).

Arsenic can be removed during coagulation / flocculation and lime softening processes. These processes depend on the oxidation stage of arsenic, type and dose of coagulant, pH, and initial arsenic concentration (Gulledge and O'Connor, 1973). In a laboratory experiment, it was reported that 30 mg/L of ferric sulphate coagulant was able to remove more than 90% of arsenate in water. The optimum pH values were reported to be less than 8.5. Alum at 30 mg/L was also reported to perform very well when the pH was less than 7.5 (Gulledge and O'Connor, 1973). Lime softening was also capable of removing more than 90% of arsenate in water at pH values greater than 10.5 (Logsdon et al as cited by USEPA, 1977).

Arsenite can be converted to arsenate through oxidation processes to enhance its removal. As shown by Gulledge and O'Connor (1973) and USEPA (1977), chlorinated arsenite was very well removed using ferric sulphate / alum coagulation and lime softening processes. However, removals using the same processes were relatively poor in the case of non - chlorinated arsenite.

Advanced treatments such as membrane and ion exchange processes also offer good options for arsenic removals. Reverse osmosis used in a small system was reported to have capability in reducing some of the arsenate concentration in water (Sorg et al, 1980). Several anionoic exchange resins were able to remove 55 to 100% of arsenic in water (Calmon, 1973). However, Hathaway and Rubel (1987) noted that a high sulphate concentration had an negative impact on the arsenate removal. Activated alumina was found to be able to reduce low arsenate concentrations in groundwater at pH values less than 6 (Bellack, 1971 and Sorg and Logsdon, 1978). However, the presence of sulphate and iron was found to decrease the removal (Fox, 1989).

3.2 BARIUM

Barium is usually present in natural water in the forms of barium salts. The acetate, halide, and nitrate salts are soluble in water, but not the phosphate, sulphate, carbonate, and some other types of salts (Department of National Health Directorate and Welfare, 1980). The occurrence of barium in the earth's crust is about 0.05% by weight (Merck, 1989). Barium is also found in printing, dyeing, paint, synthetic rubber, lubricating oil manufactures, and other sources (CCREM, 1987). Makepeace et al (1995) reported that barium concentrations in stormwater run off were in the range of 0.066 to 0.087 mg/L. Less than 0.1 mg/L of barium concentrations were reported in Canadian surface waters (Department of National Health and Welfare, 1980). While, a barium mean concentration of 28.6 µg/L was found in finished drinking water (NAS, 1982). In general, all water and acid soluble barium compounds are toxic (Merck, 1989). Tate and Arnold (1990) mention that the acute effects of barium include prolonged stimulation of the cardiac, gastrointestinal, and neuromuscular systems.

Laboratory studies on barium removal found that both ferric sulphate and alum coagulants at 20 to 30 mg/L only removed up to 30% of 7 to 8 mg/L barium in water. While, lime softening was reported to remove 90% to almost 100% of the same barium concentrations in water when pH values were in the range of 9.5 to 11 (Logsdon et al as cited by USEPA, 1977). The use of anionic polymer and calcium sulphate with direct filtration was reported to be capable of reducing 6 mg/L of barium in water to 0.5 mg/L (Krause and Stover, 1982).

Strong acid cation exchange resins were capable of achieving up to 99% reductions of 10 to 19 mg/L barium. In a laboratory study, reverse osmosis was also found to have more than 95% removals of 7 to 89 mg/L barium in water. On the other hand, GAC and PAC were not reported to have good removals (Sorg and Logsdon, 1980).

3.3 BORON

Boron is usually found in water in the form of undissociated boric acid. This ion can be adsorbed by clay and other types of soil (Choi and Chen, 1979b). Median values less than 0.5 mg/L were found in Canadian surface waters (Department of National Health and Welfare, 1980).

No complete reports are available for conventional treatment processes. However, since boron can be adsorbed in clay and other types of soil, the removal of suspended materials through coagulation / flocculation is supposed to be able to remove some of this inorganic (Environmental Health Directorate, 1993).

The advanced treatment using synthetic ion exchange resins was reported to be effective in removing boron in water. While, activated carbon was also found to be capable of removing up to 90% of 5 mg/L of boron in water (Choi and Chen, 1979b).

3.4 CADMIUM

Cadmium is found in natural water in the forms of divalent cations. This soluble form is especially found at pH greater than 9 (USEPA, 1979). Cadmium can also be adsorbed by sediments. However, the adsorption was reported to be greatly reduced at pH 6.5 (Wiley and Nelson, 1984). Cadmium is naturally found in the earth's crust with concentrations of 0.1 to 0.2 ppm (Merck, 1989). Cadmium is also found in such processes as combustion, metal finishing industrial effluents, fertilizers, pesticides, corrosion of galvanized metals, and others (Merck, 1989 and CCREM, 1987). Cadmium concentrations in surface water were found to be less than 0.001 mg/L (Guidelines for Canadian Drinking Water 1978, 1980). While, a concentration up to 13.73 mg/L was recorded for stormwater run off (Makepeace et al, 1995). A cadmium mean concentration of 3 μg/L was reported in the United States groundwaters (Tate and Arnold, 1990). Symptoms such as anemia, renal dysfunction, and others are related to the cadmium ingestion (Merck, 1989).

In the case of 0.03 mg/L cadmium in water, more than 90% removals were achieved using ferric sulphate coagulant when the pH was greater than 8.5. But, at the same cadmium concentration, alum coagulant did not perform well with its best removal of 50% at pH 8.5. While, an almost 100% cadmium removal was reported using lime softening at pH greater than 9 (USEPA, 1977).

A very large dose of PAC was reported to remove up to 90% of cadmium. GAC did not seem to work well with a maximum removal of 50% of 0.02 to 0.03 mg/L cadmium in water. While, reverse osmosis was predicted to remove up to 70% of cadmium (Sorg et al, 1978).

3.5 CHLORIDE

Chloride is not a dominant ion in surface water with the exception of arid or semi - arid regions and sea water. This ion is unreactive and highly soluble in water that cannot be removed from water easily. In some areas, chloride is present in water from the weathering and leaching of sedimentary rocks and soils. Chloride can be found in groundwater depending on the geological formation (CCREM, 1987). Other sources include deicing streets, tire road ballast, wastewater treatments, chemical industries, fertilizers, and insecticides (Makepeace et al, 1995). Makepeace et al (1995) also reported chloride concentrations of 0.3 to 25,000 mg/L in stormwater. Less than 10 mg/L of chloride concentrations were recorded for Canadian surface waters (CCREM, 1987).

Little to no information is available regarding to the utilization of conventional treatment processes to remove chloride from water. Advanced treatment processes such as membrane processes, ion exchange, and adsorption are supposed to be capable of removing chloride. The combination of granular activated carbon and reserve osmosis was reported to reduce 87% of chloride in water (Regumathan et al, 1983). Mixing with a low concentration of chloride - containing water is another method to decrease the concentration (Environmental Health Directorate, 1993).

3.6 CHROMIUM

Besides many other forms, only the trivalent and hexavalent forms of chromium are significantly considered in aqueous system. The Cr(VI) is very soluble and mobile, not adsorbed by clay and other types of soil, but may have some affinity for organics in water. Cr(VI) is a strong oxidizing agent that reacts with reducing chemicals to form Cr(III) (USEPA, 1979). Up to 300 ppm of chromium is found in the earth's crust (Merck, 1989). Sources of chromium include corrosion of welded metal plating, paints, paper, heating / cooling coils, pesticides, fertilizers, and others (Merck, 1989 and CCREM, 1987). Concentrations up to 0.023 mg/L were reported for Canadian surface waters (Department of National Health and Welfare, 1980). A median value of 2 µg/L was recorded for drinking water supplies (Meranger et al, 1979). Stormwater runoff was reported to have 0.001 to 2.3 mg/L of chromium (Makepeace et al, 1995). While, the U.S. surface and groundwaters had mean values of 10 and 16 µg/L of chromium, respectively (Tate and Arnold, 1990). Even though Cr(III) is not considered very poisonous, other types of chromium such as chromium acid and salt are toxic. They can cause irritation to the gastrointestinal tract and renal damage (Merck, 1989).

Since Cr(VI) is very soluble, the best removal of chromium will be achieved in the form of Cr(III). A Cr(III) concentration of 0.15 mg/L in water can almost be 100% and about 90% removed at pH 7 to 9 using 30 mg/L alum and ferric sulphate coagulants, respectively. The same concentration of Cr(VI) can be more than 90% removed using ferric sulphate coagulant. Lime softening removed 80% to 90% Cr(III) at high pH values. While, the Cr(VI) removal using lime softening was reported to be poor (Sorg, 1979).

Cr(III) and Cr(VI) can be removed during ion exchange processes using cation and anion resins, respectively. Reverse osmosis is probably good for Cr(III) and Cr (VI) removals, while GAC and PAC do not seem to perform well (Sorg, 1979).

3.7 COPPER

Copper can be found as a common metallic element of rocks and minerals (70 ppm found in the earth's crust) and sea water (up to 0.02 ppm) (Merck, 1989). Copper can present in the forms of cupric ions or complexed with inorganics and organics. Copper is more soluble at low pH and will precipitate as $Cu(OH)_2$ at pH values greater than 6.5 (CCREM, 1987). Anthropogenic sources of copper include metallurgical and other industrial emissions, agricultural uses of fungicides / pesticides, and others (CCREM, 1987 and Dannecker et al, 1990). Natural copper concentrations in Canadian surface waters were found to be less than 5 µg/L (CCREM, 1987). A concentration up to 1.41 mg/L was reported in stormwater runoff with mean values of 0.0065 to 0.15 mg/L (Makepeace et al, 1995). The United States finished waters were reported to have less than 200 µg/L of copper (Tate and Arnold, 1990). The soluble copper salt, i.e. copper sulphate is strong irritant to skin and mucous membranes (Merck, 1989).

Both alum and ferric salt coagulants were predicted to remove 99.8% and 98.7% of copper in water at pH 8 (Singer et al, 1988). However, one study reported that only 49% of copper was removed in several conventional water treatment plants with 26% and 37% reductions in the clarifiers and filters, respectively (Zemansky, 1974). A bench - scale lime softening study was reported to reduce copper in a contaminated groundwater from 0.1 mg/L to less than 0.001 mg/L at pH 9.1 and 9.9 (Stover and Kincannon, 1983).

A good corrosion control including water conditioning is necessary as dissolution of copper from plumbing materials is an important source of copper in drinking water (Schock and Chester, 1988). Reverse osmosis can be used to remove up to 90% of copper in water (Furukawa as cited by Environmental Health Directorate, 1993). Activated carbon can also be used even though the result will not be very satisfactory (Sigworth and Smith, 1972).

3.8 CYANIDE

Cyanide is usually found in several forms, such as hydrogen cyanide, cyanide salts, and metallocyanide complexes. Cyanide in the forms of sodium and potassium salts are soluble, while halogenated compounds are volatile, and some heavy metal complexes are insoluble. Free cyanide enters aquatic system via biodegradation and volatilation processes (Department of National Health and Welfare, 1980). Cyanide sources include industrial effluents, chemical and biological laboratories, decomposition or metabolism of certain types of plants and microorganisms (blue - green algae), and others. Cyanide was found in stormwater runoff in a concentration range of 0.002 to 0.033 mg/L (Makepeace et al, 1995). In the case of groundwater, most cyanide concentration levels were reported to be less than 0.01 mg/L (Department of National Health Directorate and Welfare, 1980). A cyanide mean concentration of 0.09 μg/L with a maximum concentration of 8 μg/L were found in the United States finished water supplies. Cyanide is readily adsorbed from the lungs, gastrointestinal tract, and skin. Cyanide is extremely toxic in that it prevents oxygen transport in the human body (Tate and Arnold, 1990).

Oxidation using chlorine or other chemicals can remove cyanide effectively from water. For chlorine gas, alkaline pH values of 8.5 to 9.5 are necessary to avoid cyanogen chloride formation or complete oxidation of the cynate ion. A chlorine concentration of 7 mg/L is required for treating 1 mg/L of cyanide ion (White, 1992). Ozonation can also be used for the same purpose (Environmental Health Directorate, 1993)

3.9 FLUORIDE

Fluoride contributes 0.065% by weight of the earth's crust formation (Merck 1989). Sources of fluoride include metallurgical effluents, chemical manufacturing, agricultural activities, and addition of fluoride in drinking water (Makepeace et al, 1995). In the case of artificial fluoridation, the chemicals are in the forms of sodium fluoride, sodium silicofluoride, and fluorisilic acid (Environmental Health Directorate, 1993). Fluoride in stormwater run off was found to be in the range of 0.1 to 0.2 mg/L (Makepeace et al, 1995). Natural Canadian water supplies have fluoride concentration levels of 0.01 to 4.5 mg/L (Department of National Health and Welfare, 1980), while American rivers and groundwaters have about 6.5 and 35.1 mg/L, respectively (NAS, 1980). Fluoride is added in drinking water to reduce dental caries. However, when its concentration exceeds 1.5 mg/L, fluoride increases the occurrence of mottling (Reeves, 1990). Neurophysiological effects are also mentioned due to fluoride ingestion (Merck, 1989).

It was reported that conventional treatment processes were generally not effective in removing fluoride. However, alum coagulation / flocculation and lime softening were reported to remove fluoride slightly, but the removals were not satisfactory and needed high chemical doses (Sorg, 1978).

A full - scale activated alumina was reported to reduce 8 mg/L of fluoride in water to 1 mg/L (Sorg, 1978). While, a laboratory - scale study of activated alumina including fluidized beds was reported to remove up to 95% at pH 4.9 to 8 (Choi and Chen, 1979a). Reverse osmosis also performed well by reducing fluoride concentrations from 2 and 2.2 mg/L to 0.4 and 0.8 mg/L, respectively (Sorg et al, 1980). However, activated carbon was reported to be ineffective in removing fluoride (Choi and Chen, 1979a).

3.10 IRON

Iron is commonly found in water in the forms of Fe^{2+} (ferrous) and Fe^{3+} (ferric). Ferrous iron is oxidized to the insoluble ferric iron in the presence of oxygen. It is therefore, aerobic water is usually low in iron due to its insolubility (CCREM, 1987). Iron contributes 5% of the earth's crust. Iron is easily released to water system from rocks and ores (Merck, 1989). Other sources of iron include the corrosion of steel, burning of coke and coal, and steel industry emissions. Iron is also used in the production of plastics, paint pigments, polishing agents, and electrical materials. Iron concentrations of less than 0.5 mg/L are usually found in aerobic surface water. However, a concentration as high as 100 mg/L can be found in groundwater and thermal hot springs (CCREM, 1987). Iron was also found in stormwater runoff in a concentration range of 0.08 to 440.0 mg/L (Makepeace et al, 1995). Iron might cause some color and taste problems. This ion can also promote the growth of iron - tolerant bacteria (AWWA, 1990)

Removal of iron from groundwater can be done by oxidizing the soluble Fe^{2+} to insoluble Fe^{3+} using chlorine, potassium permanganate, or ozone at pH greater than 7.5 (CCREM, 1987). Theoretically, 0.62 mg of chlorine oxidizes 1 mg of iron. Either 0.91 of potassium permanganate or 0.14 mg of ozone can also be used to oxidize 1 mg of iron (Sung and Forbes, 1984). Sedimentation followed by filtration processes are required for solid - liquid separation. Lime / soda ash softening is also capable of removing iron (Environmental Health Directorate, 1993).

Reverse osmosis using high - selectivity cellulose acetate, GAC, and electrodialysis processes were also reported to have good iron removals (James M. Montgomery Consulting Engineers, Inc., 1985)

3.11 LEAD

Two important lead compounds are lead carbonate (at pH 5 to 8) and lead hydroxide (at pH greater than 8) (Sorg et al, 1978). Both can be considered as water insoluble compounds (Department of National Health and Welfare, 1980). Sorption is the most important and dominant fate process of lead. Lead complexes with organics that increases its adsorptive affinity for clay and other mineral surfaces (USEPA, 1979). Its occurrence in the earth's crust is 0.002% (Merck, 1989). Gasoline powered vehicles and gasoline additives are the main human - made sources of lead (CCREM, 1987). Lead is also used in tank linings, pipings, metal manufacturing, and others (Merck, 1989). Canadian surface waters were reported to have less than 0.05 mg/L of lead, while an average concentration of 0.0076 mg/L was found in tap water samples (Department of National Health and Welfare, 1980). In the case of the United States surface waters, a mean concentration of 14 µg/L was reported. While, a mean concentration of 13 µg/L was recorded for the United States groundwaters (Tate and Arnold, 1990). A permanent brain damage especially for young children, weight losses, and anemia are the main health concerns associated with lead exposures (Merck, 1989).

It was reported that lead was 85% to 90% removed from river water with 9 to 40 JTU in turbidity using a simple settling process without adding any coagulants (USEPA, 1977). Hem and Durum (1973) basically made the same statement. It was found that 30 mg/L of alum coagulant at pH 6 to 10 removed almost 100% of 0.15 mg/L lead in river water. Iron coagulant also had the same performance (USEPA, 1977). Ferric sulphate was found to be more effective than alum at low turbidity (Sorg et al, 1978). It was reported that lime softening with pH values greater than 8.5 was able to remove almost 100% of 0.15 mg/L lead concentration in well water (USEPA, 1977).

Ion exchange was reported to have some potential in removing lead from water even though the pH range might be critical (Sorg et al, 1978). Activated carbon was also considered as another good alternative by Sigworth and Smith (1972).

3.12 MANGANESE

Manganese is usually found in natural water as manganous (Mn^{2+}) and manganic (Mn^{+4}) forms. The manganous form will be oxidized to the other form in the presence of oxygen. Manganese has similar properties as those of iron. Manganese can be released from sediments, ores, and rocks (CCREM, 1987). Manganese contributes about 0.085% by weight to the earth's crust (Merck, 1989). Human made sources include steel manufacturing, chemical manufacturing, fertilizers, and others (Makepeace et al, 1995). Makepeace et al (1995) also reported manganese concentrations of 0.007 to 3.80 mg/L in stormwater runoff. Several symptoms due to manganese include sleepiness, weakness, paralyses, and others (Merck, 1989).

Theoretically, 1.92 mg of chlorine and 1.3 mg of potassium dichromate at pH greater than 9.5 are needed to oxidize 1 mg of the soluble Mn^{2+} to insoluble Mn^{4+}, respectively (Wong, 1987). Subsequently, sedimentation and filtration processes can be applied to separate the insoluble form of manganese from water. Lime / soda ash softening and zeolite softeners were also found to be effective in removing manganese (Clark et al, 1977).

The injection of oxygenated water can also be conducted to remove manganese (James M. Montgomery Consulting Engineers, Inc., 1985). Sequestering of manganese is a another different method. Other processes using reverse osmosis, electrodialysis, and distillation methods can effectively be applied to remove manganese in water as well (Environmental Health Directorate, 1993).

3.13 MERCURY

Mercury is found in aquatic system in the forms of uni and divalent ions (Department of National Health Directorate and Welfare, 1980). Chemical speciation, sorption, and bioaccumulation / transformation are the fates of mercury in water (USEPA, 1979). Sources of mercury can be from chemical industries, coal combustion, paint industries, and dental almagam. Even though mercury is sometimes found naturally in soil, generally concentration levels of mercury in natural water are very low, i. e. less than 0.001 mg/L for Canadian surface waters (Department of National Health Directorate and Welfare, 1980). However, higher concentrations of mercury were found in stormwater runoff (up to 0.067 mg/L) (Makepeace et al, 1995). Inorganic mercury is poorly adsorbed in the gastrointestinal tract and is not as toxic as organic mercury. However, kidney injury might occur due to the ingestion of inorganic mercury (Tate and Arnold, 1990).

Bench - scale studies showed that 20 to 30 mg/L of alum and ferric sulphate coagulants did not work very well in removing inorganic mercury with only 60% reduction even when the turbidity was high (greater than 100 JTU). Lime softening was also reported to have 60% of mercury removal at pH 10.5 (Logsdon and Symons, 1973).

Advanced treatment processes seem to be the best option to remove mercury in water. It was suggested that GAC would adsorb 80% to 100% of mercury with at least 3.5 minutes contact time. PAC was also mentioned to be able to enhance the adsorption quality (Sorg, 1979).

3.14 NITRATE

Nitrate is highly soluble in water. However, its level in water is not excessive because of natural biological uptake (Environmental Health Directorate, 1993). Nitrate concentrations in surface water depend on the season, plant growth, oxygen regime, and nitrogen sources. A typical concentration of 1 or 2 mg/L was reported for surface waters. Groundwater can also contain nitrate, while shallow groundwater may have more problems with nitrate due to anthropogenic sources. A survey in the United States showed that in the case of 1,000 wells, 60% of them had greater than 10 mg/L of NO_3 - N (Tate and Arnold, 1990). For stormwater runoff, nitrate concentrations of 0.01 to 12.0 mg/L were reported (Makepeace et al, 1995). As mentioned by Tate and Arnold (1990), nitrate in drinking water causes two adverse health effects. One is the induction of methemoglobinemia especially for infants, and second the potential formation of carcinogenic nitrosamines.

Since conventional treatment processes do not seem to work well, alternative sources and mixing with low - nitrate concentration sources are the most common methods to remove nitrate in water (Environmental Health Directorate, 1993). Biological denitrification, in expanded and fluidized beds, was reported to remove about 10 mg/L of NO_3 - N in water (Gauntlett and Zabel, 1982). Some strong and weak base ion exchange resins were reported to reduce 50 mg/L of nitrate concentration as N in water to 0.5 mg/L (Gregg, 1973). Reverse osmosis may also be effective. It was reported that in the case of single stage system, a nitrate removal up to 73% was achieved (Sorg, 1978).

3.15 SELENIUM

There are two forms of selenium usually found in water: Se^{+4} (selenite) and Se^{+6} (selenate). Both of them are soluble in water with the increasing concentration at high pH values (Department of National Health and Welfare, 1980). Selenium contributes about 0.09 ppm of the earth's crust, occurs naturally in the forms of sulfide ores of heavy metals, and is also found in other minerals (Merck, 1989). Burning coal and lead refineries are other sources of selenium (Makepeace et al, 1995). Average selenium concentrations in Canadian and United States surface waters were found to be in the range of 0.1 to 0.2 µg/L (CCREM, 1987). In the case of groundwater, only few locations had concentrations of selenium greater than 10 µg/L (Tate and Arnold, 1990). A concentration range of 0.0005 to 0.077 mg/L was found in stormwater runoff (Makepeace et al, 1995). Several health effects due to selenium include depression, nervousness, liver injury, and others (Merck, 1989).

Coagulation / flocculation removed selenium in water even though the results were not very good. Alum of 25 mg/L was reported to remove 20% to 25% of 0.03 mg/L Se(IV) in river water at pH 6.5 to 9.5. Ferric sulphate had a better performance by removing 80% of selenium in water at pH 6. However, the removal was reduced when the pH increased, i. e. only 15% at pH 9.5. Lime softening for the same condition had 20% to 40% removals at pH 9.5 to 11.5 (Sorg and Logsdon as cited by USEPA, 1977). While Se(VI) reductions were less than 10% at pH 9 to 11.5 (Sorg and Logsdon, 1978).

Activated alumina adsorption has been used to reduce Se(IV) concentrations in groundwater. The higher the pH the less effective the removal. Se(VI) was well removed at low pH (Hornung et al as cited by Environmental Health Directorate, 1993). Reverse osmosis, ion exchange, and adsorption were also reported to have some potential (Environmental Health Directorate, 1993).

3.16 SODIUM

Sodium is one of the main inorganic constituents of natural water. Its occurrence in the earth's crust is about 2.83% by weight (Merck, 1989). Sodium enters natural aquatic system through water contact with igneous rocks, intrusion of sea water, weathering of salt deposits, and from human activities such as deicing, food processing, water softening, chemical manufacturing, and pulp / paper industries (Makepeace et al, 1995). In some natural waters, the sodium concentration can be as high as 10,000 mg/L. In the case of North American rivers, a sodium mean value of 9 mg/L was obtained (CCREM, 1987). In the case of stormwater runoff, 0.18 to 660 mg/L sodium concentrations were reported (Makepeace et al, 1995). A survey for finished water in the United States showed that 42% of the water contained more than 20 mg/L of sodium and 5% of the water had more than 250 mg/L of sodium. A sodium concentration range of 0.4 to 1,900 mg/L was reported. High blood pressure and heart diseases are usually correlated with sodium (Tate and Arnold, 1990). Another health concern of sodium is mentioned by Merck (1989) as "very caustic to all tissues".

No conventional treatment processes were reported to remove sodium effectively. Prevention strategies such as reducing the amount of sodium-containing chemicals in a treatment process are necessary. Mixing with a low sodium containing water is also another alternative to reduce the concentration in water (Lauch and Sorg, 1981).

A reverse osmosis process with cellulose acetate was reported to have a good performance in the removal of sodium (Hindin and Bennett, 1969). Other options that should be considered including distillation, ion exchange, and electrodialysis processes (Environmental Health Directorate, 1993).

3.17 SULPHATE

Sulphate (SO_4^{2-}) is a stable oxidized form of sulphur. The main natural sources of sulphate are the leaching from sedimentary rocks and by the oxidation of organics. Human made sources include the emission of fossil fuels, fertilizers, and chemical manufacturing effluents (Makepeace et al, 1995). Sulphate is very abundant in natural water. Concentrations in the range of 10 to 80 mg/L were reported for surface water (CCREM, 1987). Sulphate concentrations in stormwater runoff were reported in the range of 0.06 to 1,252 mg/L (Makepeace et al, 1995). A median value of 4.6 mg/L was found in the United States water supplies. A high concentration of sulphate in drinking water can result in transitory diarrhea as mentioned by Tate and Arnold (1990).

Conventional treatment processes are not effective in removing sulphate due to its high solubility in water. Reducing or avoiding the use of sulphate - containing chemicals in a treatment process is therefore necessary (USNRC, 1977).

Reverse osmosis, electrodialysis, ion exchange, and distillation processes are probably effective even though they might not be economical. It was reported that the use of a gel - type weakly basic anion exchange resin in a batch - scale continuous flow experiment for a groundwater case was able to reduce sulphate from 1,050 to 250 mg/L. However, the exchange capacity was reported to decrease at higher pH values (Johnson and Musterman, 1979).

3.18 SULPHIDE

Hydrogen sulphide is the most dominant form of sulphide in natural water when the pH is less than 7. Hydrogen sulphide is formed by the bacterial reduction of sulphate and organic sulphur in anaerobic conditions. This compound is volatile and therefore can cause serious odor problems

(Environmental Health Directorate, 1993). Natural sources include geochemical weathering and atmospheric decompositions. Hydrogen sulphide can be found in coal pits, gas wells, sulfur springs, and decaying organic matter - containing sulphur (Merck index, 1989). Anthropogenic sources include manufacturing processes such as dye, tanning, chemical processing, cosmetics, and others. In the bottom part of surface water known as the sludge region, it was found that the sulphide concentration was up to 0.7 mg/L. While, concentration levels of 0.02 to 0.1 mg/L were found above that region (CCREM, 1987). Serious toxicity effects of hydrogen sulphide were reported such as collapse and death due to respiratory failure. At low concentrations, symptoms such as headache and nausea might occur (Merck, 1989).

In general, aeration at pH less than 6 is able to remove hydrogen sulphide to a concentration less than 0.05 mg/L. Still, detailed configurations of the aeration devices and process systems are necessary to ensure the adequate removal. Post chlorination is also necessary to oxidize the trace residuals (Howe and Lawler, 1989). Oxidation can also be practiced using different oxidants like potassium permanganate, ozone, hydrogen peroxide, and ferrate (CCREM, 1987).

No advanced treatment processes are necessary as sulphide can be effectively removed using conventional treatment processes (Environmental Health Directorate, 1993).

3.19 TOTAL DISSOLVED SOLIDS

Total dissolved solids (TDS) is a measure of total ions that are present as true solution in water. TDS concentrations tend to be very high in arid regions or in water subjected to pollution run off. Rock and soil interactions are the most dominant sources of TDS in groundwater. TDS can be transported to surface water through atmospheric precipitation, evaporation - transpiration, and rock interaction processes. In the case of North American streams, an estimate concentration of 142 mg/L was reported (James M. Montgomery Consulting Engineers, Inc., 1985).

TDS in treated water usually increases due to the addition of chemicals in the treatment processes. The use advanced treatment processes such as membrane processes, electrodialysis, and distillation processes are required for TDS removal (Environmental Health Directorate, 1993).

3.20 URANIUM

Uranium is usually found in the form of the uranyl ion. This ion can form stable carbonate and bicarbonate complexes. Uranium is sorbed on natural colloidal materials at pH about 6 (White and Bondietti, 1983). Its occurrence in the earth's crust is about $2x10^{-5}$ %. Uranium and its salts are very toxic and can cause dermatitis, renal damage, and may pose long term carcinogenic hazards, (Merck, 1989).

It was reported that municipal water treatment plants with conventional treatment processes were not able to remove uranium in water with concentrations of 0.1 to 16 μg/L effectively (White and Bondietti, 1983). However, a bench study reported that alum and ferric sulphate coagulants, and lime softening processes were able to remove up to 85% of 83 μg/L dissolved uranium at pH 6 and 10 for coagulation processes, and 10.6 to 11.4 for lime softening. It was reported that the presence of magnesium improved the softening process (Lee and Bondietti, 1983).

Activated carbon was not reported to have any removal capability. On the other hand, a bench - scale study using a strong base anion exchange was able to remove up to 99% of these carbonate complexes in water (Lee and Bondietti, 1983).

3.21 ZINC

Zinc is usually found in natural water in divalent forms. However, this ion can also be found in other forms depending on the pH and the presence of other ions or compounds (Environmental Health Directorate, 1993). In nature, zinc sorbs with hydrous metal oxides, clay, and organics. Its occurrence in the earth's crust is about 0.02% by weight. Other sources of zinc include combustion of oils, building material and metal corrosions, and wear from tires (Merck, 1989). A concentration range of less than 0.001 to 0.1 mg/L in Canadian surface waters was reported. A mean concentration of 120 mg/L was found in aquatic sediment (Environmental Health Directorate, 1993). A concentration range of 0.0007 to 22.0 mg/L was reported for stormwater runoff (Makepeace et al, 1995). While, concentrations of 3 to 2,010 µg/L were reported for finished water in the United States (Tate and Arnold, 1990). Toxicity effects include skin irritation, injury to mucous membranes, weakness, and others (Merck, 1989).

Zemansky (1974) reported that 40% of zinc was removed from several conventional full - scale water treatment plants. It was also reported that alum coagulant removed only less than 30% of zinc in water at pH 6.5 to 7. Lime softening was found to have better performances by removing 60% to 90% of zinc at pH 9.5 to 10 (USNRC, 1977). It was theoretically predicted that ferric sulphate and alum coagulant would remove more than 90% of zinc in water at pH 8 (Singer et al, 1988).

The use of GAC had also been studied in terms of zinc removals for years. However, it was concluded that GAC was not effective for that purpose (Sigworth and Smith, 1972).

4.0 CONCLUSIONS

In general, drinking water quality in the Northern River Basin Study (NRBS) in term of inorganic contaminants is of good quality even though there may be some concerns with aesthetic problems. Both conventional and advanced treatment processes were presented to give some idea how each contaminant could be removed from water. The conventional processes included coagulation / flocculation, softening, and filtration. The advanced processes were oxidation, adsorption, ion exchange, membrane processes, distillation, sequestering, aeration, and dilution.

According to the literature review, these following inorganics could effectively be removed using conventional treatment processes: arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, and zinc. A certain chemical process, such as oxidation, could be used to change the water soluble into non soluble form that could then be removed effectively using conventional treatment processes. In the case of coagulation / flocculation, pH was found to be important although a certain type of inorganic (such as lead) could effectively be removed at any pH values. Lime softening was reported to perform well at high pH values. Filtration was reported to be able to remove barium, iron, and manganese effectively.

Ion exchange and especially membrane processes removed most inorganics effectively. While, activated carbon might be effective in removing certain inorganics only, such as iron, lead, mercury, and selenium. Dilution using water with low inorganic concentration was suggested for chloride, nitrate, and sodium. Sequestering could be used for manganese and iron removals. Distillation was mentioned to remove manganese, sodium, sulphate, and total dissolved solids. Aeration could be applied for sulphide removal, while oxidation was used for cyanide removal. However, high costs might prevent the use of advanced treatment processes in water treatment practices.

It should be noted that the overall goal of water treatment is to reduce concentrations of contaminants such that possible health risk to the consumer is reduced. It is therefore important that all types of contaminants are considered when making decisions on water treatment. It may be possible in an attempt to reduce the concentration of one contaminant, the removal efficiency of another contaminant is negatively impacted. This may not result in a reduction of overall health risks to the consumer. In addition, information presented in this report is general in nature. It gives merely an indication of processes and process operating conditions which will result in increased removals of various inorganic contaminants. However, site specific water quality characteristics may impact the actual treatment performance. Typically, a more detailed analysis is required that considers site specific information before making any significant changes in the treatment process. As is often the case in water treatment design and assessment, pilot and bench testing may be required.

5.0 REFERENCES

Amirtharajah, A. and O'Melia, C. R. 1990. Coagulation Processes: Destabilization, Mixing, and Flocculation. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 269 - 366.

AWWA. 1990. Water Treatment Design. McGraw - Hill, New York, NY.

Bellack, E. 1971. Arsenic Removal from Potable Water. Journal AWWA. **63** (7): 454 - 458.

Calmon, C. 1973. Notes and Comments. Journal AWWA. **65** (8): 586 - 589.

CCREM. 1987. Canadian Water Quality Guidelines. Prepared by the Task Force on Water Quality Guidelines of CCREM.

Choi, W. W. and Chen, K. Y. 1979a. The Removal of Fluoride from Waters by Adsorption. Journal AWWA. **71** (10): 562 - 569.

Choi, W. W. and Chen, K. Y. 1979b. Evaluation of Boron Removal by Adsorption on Solids. Environmental Science and Technology. **13** (2): 189 - 196.

Clark, J. W., Viessman, W. Jr., and Hammer, M. J. 1977. Water Supply and Pollution Control, 3rd edition. Harper and Row, New York, NY.

Cleasby, J. L. 1990. Filtration. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 455 - 560.

Clifford, D. A. 1990. Ion Exchange and Inorganic Adsorption. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 561 - 640.

Conlon, W. J. 1990. Membrane Processes. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 709 - 746.

Cornwell, D. A. 1990. Air Stripping and Aeration. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 229 - 268.

Cotruvo, J. A. and Vogt, C. D. 1990. Rationale for Water Quality Standards and Goals. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 1 - 62.

Culotta, N. J. 1989. Home Water Treatment: What's the Use of Point - of Use? Health and Environment Digest. **3** (6): July 1989.

Dannecker, W., Au, M., and Stechmann, H. 1990. Substance Load in Rainwater Runoff from Different Streets in Hamburg. Science of the Total Environment. **93**: 385 - 392.

Department of National Health and Welfare. 1980. Guidelines for Canadian Drinking Water Quality 1978. Supply and Services Canada, Ottawa, ON.

Environmental Health Directorate. 1993. Water Treatment Principles and Applications. Canadian Water and Wastewater Association, Ottawa, ON.

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 edition. Minister of Supply and Services , Ottawa, ON.

Fox, K. R. 1989. Field Experience with Point - of - Use Treatment Systems for Arsenic Removal. Journal AWWA. **81** (2): 94 - 101.

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

Gauntlett, R. and Zabel, T. F. 1982. Biological Denitrification for Potable Water Treatment. Water Services. **86** (1): 17 - 18.

Gregg, J. C. 1973. Nitrate Removal at Water Treatment Plant. Civil Engineering. **43** (4): 45 - 47.

Gulledge, J. H. and O'Connor, J. T. 1973. Removal of Arsenic (V) from Water by Adsorption on Aluminum and Ferric Hydroxides. Journal AWWA. **65** (8): 548 - 552.

Hathaway, S. W. and Rubel, F. 1987. Removing Arsenic from Drinking Water. Journal AWWA. **79** (8): 61 - 65.

Hem, J. D. and Durum, W. H. 1973. Solubility and Occurrence of Lead in Surface Water. Journal AWWA. **65** (8): 562 - 568.

Hindin, E. and Bennett, P. J. 1969. Water Reclamation by Reverse Osmosis. Water Sewage Works. **116** (2): 65 - 73.

Howe, K. J. and Lawler, D. F. 1989. Acid Base Reactions in Gas Transfer: A Mathematical Approach. Journal AWWA. **81** (1): 61 - 66.

James M. Montgomery Consulting Engineers, Inc. 1985. Water Treatment Principles and Design. John Wiley and Sons, New York, NY.

Johnson, M. S. and Musterman, J. L. 1979. Removal of Sulphate by Ion Exchange. Journal AWWA. **71** (6): 343 - 348.

Krause, T. L. and Stover, E. L. 1982. Evaluating Water Treatment Techniques for Barium Removal. Journal AWWA. **74** (9): 478 - 485.

Lauch, R. P. and Sorg, T. J. 1981. The Occurrence and Reduction of Sodium in Drinking Water. Journal AWWA. **73** (5): 256 - 264.

Lee, S. Y. and Bondietti, E. A. 1983. Removing Uranium from Drinking Water by Metal Hydroxides and Anion - Exchange Resin. Journal AWWA. **75** (10): 536 - 540.

Letterman, R. D. 1987. An Overview of Filtration. Journal AWWA. **79** (12): 26 - 32.

Logsdon, G. S. and Symons, J. M. 1973. Mercury Removal by Conventional Water - Treatment Techniques. Journal AWWA. **65** (8): 554 - 562.

Makepeace, D. K., Smith, D. W., and Stanley, S. J. 1995. Urban Stormwater Quality: Summary of Contaminants Data. Submitted for Publication.

Meranger, J. C., Subramaniam, K. S., and Chalifoux, C. 1979. A National Survey for Cadmium, Chromium, Copper, Lead, Zinc, Calcium, and Magnesium in Canadian Drinking Water Supplies. Environmental Science and Technology. **13** (6): 707 - 711.

Merck. 1989. The Merck Index: an Encyclopedia of Chemicals, Drugs, and Biologicals, 11th edition. S. Budaravi, editor. Rahway, NJ.

NAS. 1980. Drinking Water and Health. Vol 3. National Academy Press, Washington, DC.

NAS. 1982. Drinking Water and Health. Vol 4. National Academic Press, Washington, DC.

Prince, D. S., Smith, D. W., and Stanley, S. J. 1995. Review and Synthesis of Existing Information on Consumptive Use of Drinking Water and Availability Drinking Water Data: for Northern River Basin Study. Appendix C - 1. NRBS Project Report.

Reeves, T. G. 1990. Water Fluoridation. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 933 - 654.

Regumathan, P., Beauman, W. H., and Kreusch, E. G. 1983. Efficiency of Point of Use Treatment Devices. Journal AWWA. **75** (1): 42 - 50.

Schock, M. R. and Chester, H. N. 1988. Trace Metal Contamination from Brass Fittings. Journal AWWA. **80** (11): 47 - 56.

Sigworth, E. A. and Smith, S. B. 1972. Adsorption of Inorganic Compounds by Activated Carbon. Journal AWWA. **64** (6): 386 - 391.

Singer, P. C., Dempsey, B. A., Davis, J. A. Pisarzyk, K., Cornwell, D. A., Dart, D. J., Hoffman, M. R., Huang, C. P., Minear, R. A., Robinson, B., Sung, W., and Theis, T. L. 1988. A Review of Solid - Solution Interactions and Implications for the Control of Trace Organic Materials in Water Treatment. Journal AWWA. **80** (10): 56 - 64.

Snoeyink, V. L. 1990. Adsorption on Organic Compounds. (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 781 - 876.

Snoeyink, V. L. and Jenkins, D. 1980. Water Chemistry. John Wiley and Sons, New York, NY.

Sorg, T. J. 1978. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics. Journal AWWA. **70** (2): 105 - 112.

Sorg, T. J. 1979. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 4. Journal AWWA. **71** (8): 454 - 466.

Sorg, T. J. and Logsdon, G. S. 1978. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 2. Journal AWWA. **70** (7): 379 - 393.

Sorg, T. J. and Logsdon, G. S. 1980. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 5. Journal AWWA. **72** (7): 411 - 422.

Sorg, T. J., Csanady, M., and Logsdon, G. S. 1978. Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 3. Journal AWWA. **70** (12): 680 - 691.

Sorg, T. J., Forbes, R. W. and Chambers, D. S. 1980. Removal of Radium - 226 from Sarasota County, Fla., Drinking Water by Reverse Osmosis. Journal AWWA. **74** (4): 230 - 237.

Stover, E. L. and Kincannon, D. F. 1983. Contaminated Groundwater Treatability - A Case Study. Journal AWWA. **75** (6): 292 - 297.

Sung, W. and Forbes, E. J. 1984. Some Consideration on Iron Removal. Journal of Environmental Engineering. **110** (6): 1048 - 1061.

Tate, C. H. and Arnold, K. F. 1990. Health and Aesthetic Aspects of Water Quality (In) Water Quality and Treatment. F. W. Pontius, editor. McGraw - Hill, New York, NY. pp. 63 - 156.

USEPA. 1977. Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations. Office of Research and Development, Municipal Environmental Research Laboratory, Water Supply Research Division, Cincinnati, OH.

USEPA. 1979. Water Related Environmental Fate of 129 Priority Pollutants. Vol 1: Introduction, Technical, Background, Metal and Inorganics, Pesticides, Polychlorinated Biphenyls. Report No. EPA - 440 / 4 - 79 - 029a. Office of Water Planning and Standards, Washington, DC.

USNRC. 1977. Drinking Water and Health. Vol 1. Safe Drinking Water Committee, National Academic Press, Washington, DC.

White, G. C. 1992. The Handbook of Chlorination, 3rd edition. Van Nostrand Reinhold, New York, NY.

White, S. K. and Bondietti, E. A. 1983. Removing Uranium by Current Municipal Water Treatment Processes. Journal AWWA. **75** (7): 374 - 379.

WHO. 1993. Guidelines for Drinking Water Quality, 2nd edition. Vol 1: Recommendations, Geneva.

Wiley, J. O. and Nelson, P. O. 1984. Cadmium Adsorption by Aerobic Lake Sediments. Journal of Environmental Engineering. **110** (1): 226 - 243.

Wong, J. M. 1984. Chlorination - Filtration for Iron and Manganese Removal. Journal AWWA. **76** (1): 76 - 79.

Zemansky, G. M. 1974. Removal of Trace Metals during Conventional Water Treatment. Journal AWWA. **66** (10): 606 - 609.

NORTHERN RIVER BASINS STUDY

APPENDIX A - TERMS OF REFERENCE

4402-D1: Literature Reviews on Treatment Efficiencies

I. BACKGROUND & OBJECTIVES

The quality of drinking water is based both on the quality of the source water and the treatment processes used. The methods used and proposed for the treatment of drinking water are many and varied. A great deal of information is available in the literature on the performance, advantages and disadvantages of the various processes. A detailed critical review of this information will be performed in this proposed project. The reviews will concentrate on processes that are appropriate for use and contaminants that are of special concern in the study area. This information will be used for a general assessment on drinking water quality in the basins. This will be completed by assessing the raw water quality and treatment systems that various communities use (Project 4422-D1). In addition the reviews will be valuable information for communities in the study area for selection and assessment of treatment processes that are in use or are proposed.

Objectives

1. Review and assess existing water quality data for raw and treated water in the study area.

2. Critically review the available literature on the performance, advantages, disadvantages and appropriateness of drinking water treatment processes for organic and inorganic chemical and bacterial contaminant removal applicable to the study area.

II. REQUIREMENTS

The completion of three literature reviews on the efficiency of drinking water treatment processes is proposed for 1994/95. The reviews will include: assessment of inorganic chemical removal efficiencies; assessment of organic chemical removal efficiencies; and assessment of microbial contaminants removal efficiencies. Each review will involve:

1. Assessment of existing water quality data for the study area (inorganic, organic and microbial). Most of this information will be obtained from provincial, federal and NRBS studies (4401-C1, 4421-C1).

2. Thorough review of pertinent literature. Extensive use will be made of the University of Alberta Library that is the second largest library in Canada. Information obtained from various suppliers, past unpublished research projects, and personal contacts will also be incorporated in the review. The following will be completed as part of the review:

- A literature search carried out using facilities at the U of A Library.
- Review of literature found.
- Review of information from suppliers, personal contacts and other unpublished research reports.
- Summarizing available information in a concise form.

3. Evaluation of process alternatives. Treatment methods found in (II.2) will be evaluated for use in the study area. Evaluation will include factors such as:

   - Effectiveness of the treatment process.
   - The degree of control, skill and supervision needed to achieve good performance.
   - Technical support required for operation - special skills needed for maintenance and repair.
   - Safety and handling precautions required.
   - Process reliability.
   - Climatic effects (water temperatures).
   - Effect of different water quantities and qualities.
   - Level of development of current technology.
   - Public acceptance.
   - Economic considerations.

4. Write three reports outlining the results of the investigation of II.1-3 for organic and inorganic chemicals, and microbial contaminants.

III. DELIVERABLES

1. Critical Review of Organic Treatment Efficiencies - 10 copies due March 31, 1995

2. Critical Review of Inorganic Treatment Efficiencies - 10 copies due March 31, 1995

3. Critical Review of Bacterial Treatment Efficiencies - 10 copies due March 31, 1995

4. Prepare 35 mm slides for use in presentations. These would include photographs of relevant items such as field work (if appropriate) and a summary of the main findings of your investigation.
   due March 31, 1995

IV. REPORTING REQUIREMENTS

1) The Contractor is to provide draft and final reports in the style and format outlined in the NRBS Style Manual. A copy of the Style Manual entitled "A Guide for the Preparation of Reports" will be supplied to the contractor by the NRBS.

2) Ten copies of the Draft Report along with an electronic disk copy are to be submitted to the Project Liaison Officer by March 31, 1995.

Three weeks after the receipt of review comments on the draft report, the Contractor is to provide the Project Liaison Officer with two unbound, camera ready copies and ten cerlox bound copies of the final report along with an electronic version.

3) The final report is to include the following: an acknowledgement section that indicates any local involvement in the project, Project Summary, Table of Contents, List of Tables, List of Figures and an Appendix with the Terms of Reference for this project.

Text for the report should be set up in the following format:

a) Times Roman 12 point (Pro) or Times New Roman (WPWIN60) font.
b) Margins; are 1" at top and bottom, 7/8" on left and right.
c) Headings; in the report body are labelled with hierarchical decimal Arabic numbers.
d) Text; is presented with full justification; that is, the text aligns on both left and right margins.
e) Page numbers; are Arabic numerals for the body of the report, centred at the bottom of each page and bold.

- If photographs are to be included in the report text they should be high contrast black and white.
- All tables and figures in the report should be clearly reproducible by a black and white photocopier.
- Along with copies of the final report, the Contractor is to supply an electronic version of the report in Word Perfect 5.1 or Word Perfect for Windows Version 6.0 format.
- Electronic copies of tables, figures and data appendices in the report are also to be submitted to the Project Liaison Officer along with the final report. These should be submitted in a spreadsheet (Quattro Pro preferred, but also Excel or Lotus) or database (dBase IV) format. Where appropriate, data in tables, figures and appendices should be geo-referenced (latitude and longitude).

4. All figures and maps are to be delivered in both hard copy (paper) and digital formats. Acceptable formats include: DXF, uncompressed E00, VEC/VEH, Atlas and ISIF. All digital maps must be properly geo-referenced (latitude and longuitude).

5. All sampling locations presented in report and electronic format should be geo-referenced. This is to include decimal latitudes and longitudes (to six decimal places) and UTM coordinates. The first field for decimal latitudes / longitudes should be latitudes (10 spaces wide). The second field should be longitude (11 spaces wide).

V. CONTRACT ADMINISTRATION

The Project Liaison Officer (Component Coordinator) for this project is:

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