WATER TREATMENT IN AUCKLAND

Auckland's water (like water throughout New Zealand) is a combination of water from dams and water from underground springs. Depending on the source of the water, it has different contaminants: metallic ions, organic compounds and biological materials. To make this water safe to drink, most of these have to be removed. Fluoride is also commonly added to the water during the treatment process as fluoride strengthens teeth. Thus water treatment usually involves aeration and settling followed by a variety of chemical treatments as follows.

Step 1 - Coagulation
Alum ($Al_2(SO_4)_3.18H_2O$) is added to the water to cause any small particles suspended in the water to clump together and settle out. .

Step 2 - Flocculation
Polyelectrolytes are added to create even heavier particles that will settle more readily.

Step 3 - Sedimentation
The floc (heavier particles) is settled out in clarifiers shaped like inverted pyramids.

Step 4 - Filtration
The water percolates down through sand to remove any solid material remaining. The water now meets the relevant standards for turbidity.

Step 5 - Final water treatment
The water is disinfected with sodium hypochlorite to destroy organic and nitrogenous matter, to precipitate out iron and manganese and to destroy bacteria and viruses. Lime is added to bring the pH up towards 8.0 (so that the water won't corrode pipes) and fluoride is added to reduce tooth decay in those who drink the water.

INTRODUCTION

Watercare Services is responsible for the provision of bulk water to the Auckland metropolitan area. The Councils in this area purchase water from Watercare Services and distribute it to their consumers.

The average consumption is approximately 300 000 m^3/day. Water from four dams in the Hunua ranges is treated at the Ardmore Filter Station while water collected in five dams in the Waitakere ranges is treated at the Huia and Waitakere Filter Stations. Water from a small dam to the east of Papakura is treated at the Papakura Filter Station. These dams provide about 97% of Auckland’s water. An underground source at Onehunga provides the remaining 3%.

The water is treated to comply with the Drinking Water Standards for New Zealand.

Characteristics of the Lake Water

The lake water characteristics reflect the catchment soil types, inhabitants and activities present within the catchments. The catchments are predominantly bush covered and are largely unaffected by human activity. The following characteristics are of relevance in the treatment of this water:

Iron and manganese
These elements occur naturally in the catchments and are present in the water in soluble and insoluble forms. In excessive amounts they discolour the water, staining whiteware and imparting bad tastes and odours. Treatment processes are necessary to reduce the concentrations of these elements to tolerable levels.

Turbidity
The water has low to moderate turbidity, that is particulate material suspended in the water. The water is of light brown appearance requiring turbidity removal to meet standards.

Hardness
The water is soft as the concentrations of calcium and magnesium compounds are low. The water does not need to be softened.

Heavy metals
Heavy metals such as lead and mercury occur naturally in trace amounts. These elements are toxic to humans but as the concentrations in the water are very low and well within Drinking Water Standards specific treatment for them is not needed.

Nitrates, ammonia, phosphates, sulphates
These compounds originate from agricultural, domestic and industrial activities. At high concentrations they are harmful to humans ingesting the water and promote algal and weed growth in lakes. Fortunately, due to the nature of the catchments, these compounds are not present at troublesome levels so specific treatment for them is not needed.

Biological
Bacteria, viruses and protozoa are present due to animal activity within the catchments. Treatment for these pathogens is needed.

WATER TREATMENT IN THE CATCHMENT LAKES

The lakes store water for periods ranging from several months to several years. This period of storage allows time for the heavier suspended material to settle thereby reducing the turbidity of the water. Additionally the storage allows time for many biological pathogens to die off naturally.

It is important that oxidising conditions are prevalent in the lake water. Under these conditions soluble iron and manganese are precipitated and settle to the bottom of the lakes. This is the primary mechanism by which iron and manganese is removed from the water.

During the winter months the body of the lake water is at or near a uniform temperature and is mixed by wind action at the surface. This natural mixing helps to maintain a good quality water. It also serves to control the growth of algae by mixing the surface water, where algae grow, to deeper depths away from sunlight where the algae die off.

Over the summer months the surface water quickly warms and becomes less dense than the deeper water. The water stratifies into three layers of differing temperature and density. The epilimnion is the upper layer and comprises less dense warm water. The lowest layer is the hypolimnion which comprises the most dense cool water. Between these two layers is the thermocline, a relatively small region where the temperature drops quickly from that of the epilimnion above to the hypolimnion below. Resistance to mixing between waters of differing density develops leaving the mixing effect confined to the surface. The deeper water then becomes depleted in oxygen and the quality of the water deteriorates as conditions become anaerobic. Under these conditions iron and manganese dissolve. This is prevented by artificially mixing the lake. Air is pumped into perforated pipes laid along the lake beds. The rising bubble curtain creates circulation within the lakes to mix the water and maintain oxidising conditions thereby improving the quality of the water.

Apart from controlling iron and manganese, aeration decreases the carbon dioxide content in the water and therefore its corrosiveness on pipes and fittings. Additionally aeration reduces foul tastes and odours associated with gases dissolved in the water, for example, hydrogen sulphide.

Samples of water are regularly taken from the lakes at varying depths. These are tested for a range of parameters including temperature, dissolved oxygen, iron, manganese, turbidity, organic content, algae and alkalinity. These tests enable the quality of the water at differing depths in the lakes to be established. This information is used to determine whether the lakes should be artificially aerated and from which intake valve water should be abstracted.

The intake valves are located within towers in the lakes. These towers are sometimes attached to the dams. The valves are spaced typically about 8 to 9 meters apart vertically. Water is taken through the valve with the best quality water. Generally though this is the valve closest to the surface. The valves are fitted with screens to remove coarse suspended and floating material. The screens also prevent fish entering the delivery to the filter stations.

The typical quality of the water taken for supply can be seen in **Table 1**. Iron and manganese is within Drinking Water Standards as a result of the lake management practices described above. Treatment at the filter stations is needed to remove turbidity and disinfect microbiological organisms to make the water safe to drink.

WATER TREATMENT AT FILTER STATIONS

Step 1 - Coagulation

The first stage of treatment is coagulation. The coagulant generally used in the treatment of Auckland’s water is aluminium sulphate ($Al_2(SO_4)_3.18H_2O$), commonly known as alum.

The aluminium sulphate is produced locally by the reaction of sulphuric acid on imported aluminium trihydrate. The aluminium trihydrate is produced from bauxite. The alum is supplied in liquid form being 47% w/w aluminium sulphate.

The aim of coagulation is to destabilise the particles suspended in the raw (untreated) water so that they can clump together and settle out due to greater particle weight. The particles are generally colloidal and are predominantly negatively charged. As like charges repel they are

Table 1 - Typical analysis of Auckland waters (average results of weekly tests from throughout 1995)

		Ardmore		**Papakura**		**Huia**		**Waitakere**		**Onehunga**		**Standards**	
Analysis		**Raw**	**Final**	**Raw**	**Final**	**Raw**	**Final**	**Raw**	**Final**	**Raw**	**Final**	**MAV**	**Guideline**
Total Coliforms	No. per 100 mL	7	0	329	0	24	0	69	1	124	0		
Faecal Coliforms	No. per 100 mL	2	0	199	0	16	0	61	0	54	0	Nil	
Total Organisms	per mL	68	0	771	1	67	0	407	2	93	1		
pH		7.0	7.8	6.9	7.9	7.0	7.8	6.9	7.7	7.3	7.7		6.5-8.5
Turbidity	NTU	3.5	0.13	16.2	0.18	4.2	0.14	4.0	0.15	0.24	0.15	0.5	
Suspended Solids	mg L^{-1}	3.1	0.06	12.8	0.07	2.2	0.09	2.3	0.09	0.28	0.04		
Conductivity	mS m^{-1} @ 25^{o}C	7.8	10.4	9.4	14.1	10.8	14.0	11.4	14.1	22.2	22.9		
UV absorption	1cm, 254nm (m.f.)	0.08	0.011	0.22	0.030	0.18	0.020	0.18	0.010	0.010	0.010		
Chloride	mg L^{-1} Cl	11.6	12.6	15.5	17.3	20.0	21.6	22.2	23.0	18.0	20.0		250
Fluoride	mg L^{-1} F	0.04	0.86	0.04	0.03	0.02	0.85	0.01	0.83	0.16	0.15	1.5	0.7-1.0
Sulphate	mg L^{-1} SO$_4^{2-}$	2.2	8.4	3.3	19.0	3.1	13.1	3.1	13.0	14.7	15.2		
Alkalinity	mg L^{-1} CaCO$_3$	13.9	17.0	13.0	16.8	14.7	15.7	14.1	14.3	57.3	58.2		
Calcium hardness	mg L^{-1} CaCO$_3$	8.7	19.4	9.2	29.8	11.0	22.7	10.6	22.8	25.5	25.5		
Magnesium hardness	mg L^{-1} CaCO$_3$	6.3	6.0	7.1	7.0	9.7	9.8	9.7	9.7	37.6	37.2		
Total hardness	mg L^{-1} CaCO$_3$	15	25	16	37	21	33	20	33	63	63		200
Aluminium	mg L^{-1} Al	0.15	0.02	0.46	0.02	0.31	0.02	0.28	0.02	0.01	0.03		0.15
Iron (total)	mg L^{-1} Fe	0.34	<0.01	1.72	<0.01	0.58	<0.01	0.63	<0.01	0.01	<0.01		0.2
Manganese (total)	mg L^{-1} Mn	0.03	<0.01	0.07	<0.01	0.03	<0.01	0.01	<0.01	<0.01	<0.01	0.5	0.05
Sodium	mg L^{-1} Na	8.4	9.0	10.5	11.4	12.4	13.4	13.4	13.5	19.8	22.5		200
Potassium	mg L^{-1} K	1.16	1.11	1.89	1.86	0.89	0.89	0.97	0.98	3.39	3.29		

held apart by electrostatic repulsive forces. These particles give the water its cloudy or turbid appearance. The alum neutralises the negative charges present on the particles thereby allowing natural particle motion processes to bring them into contact with each other and form larger particles called floc. Coagulation is most effective when the alum is thoroughly and rapidly dispersed throughout the volume of water before floc formation. To achieve this the alum is added into regions where the water is turbulent, the turbulence being produced by mechanical mixers, weirs or sparges in the raw water flow.

The coagulation of turbidity by alum is pH dependent. If the pH is too low or too high then soluble aluminium species form rather than the sought insoluble species. The target pH varies with the characteristics of the water but for Waitakere and Hunua water is in the range 6.0 to 7.0.

Alum is an acid salt as it contains some sulphuric acid. This acid reacts with the alkalinity present in the water to lower the pH. The water must contain sufficient alkalinity to ensure the pH does not drop out of the target range when the alum is added. If the water does not contain sufficient natural alkalinity then lime is added to the water before the alum is added.

The amount of alum that is needed to coagulate the water cannot be predicted theoretically due to the many natural constituents in the water that react with alum. A laboratory process known as jar testing is used to determine the alum dose needed. In this procedure differing quantities of alum are added and stirred into each of six jars containing the raw water to be coagulated. After mixing for a set time the solutions are allowed to settle. The correct alum dose is the dose that produces the least turbid settled water and the greatest volume of settled material.

Alum is added to the raw water at doses that range from 12 to 30 mg L^{-1}. The raw waters have turbidities that typically range from 2 NTU to about 40 NTU.

Step 2 - Flocculation

Flocculation occurs after coagulation and is the process whereby the destabilised colloids are brought into contact to agglomerate to larger sized floc. The process is assisted by mixing in purpose designed tanks which are baffled to provide the sought mixing effect and are sized to provide the time necessary for floc to develop. If the mixing effect is insufficient then floc formation is diminished and if too great then floc is broken up by the high turbulence.

Flocculation is assisted by the addition of a polyelectrolyte several minutes after the alum is added to assist in the growth of floc to larger sizes. Polyelectrolytes are long chain organic molecules of high molecular weight. Cationic (positively charged) polyelectrolytes are used to assist the alum and enmesh the floc to create heavier particles that will settle more readily.

Polyelectrolyte is added to the alum dosed water at doses that range from 0.02 to 0.2 mg L^{-1}.

Step 3 - Sedimentation

The flocculated water is introduced into the bottom of clarifiers for the removal of flocculated material.

The clarifiers are shaped like inverted pyramids. The water flows up from the bottom and because the cross sectional area increases in the direction of flow the flow velocity decreases. The design of the tanks enables equilibrium to be reached between the particle settling velocities and the water upflow velocities. Larger particles with greater settling velocities become suspended near the bottom of the clarifiers while smaller particles with lesser settling velocities become suspended near the top. A sludge blanket of suspended particles is produced in the clarifiers through which the flocculated water passes. The blankets enmesh smaller particles suspended in the upflowing water to produce clear water at the surface of the clarifiers. The clear water is decanted off into troughs. Sludge from the clarifier blankets is removed periodically to maintain the sludge blanket level at the desired height.

The clarifiers typically reduce the turbidity of the water to less than 1 NTU.

Step 4 - Filtration

Water from the clarifiers is channelled through to filters for additional suspended solids removal. The water percolates down through graded sand which traps any floc carried over from the clarifiers. The filtered water is collected in underdrains in the bottoms of the filters.

A filter produces good quality, low turbidity water for about 24 to 48 hours at which time the sand becomes clogged with entrapped material. At this time the filter is taken out of service and is ‘washed’.

Washing commences with air scouring. Air is pumped into the underdrains and rises up through the sand. This agitates the sand and loosens the dirt that has adhered to it. The air is followed by water which washes out the loosened dirt. Once the dirt has been washed out the filter is returned to service.

The filters typically reduce the turbidity of the water to less than 0.2 NTU.

Step 5 - Final Water Treatment

This involves three separate processes: disinfection, pH adjustment and fluoridation.

Step 1 - Disinfection

The water is disinfected to kill harmful micro-organisms and make it safe to drink. This is done using either gaseous chlorine or sodium hypochlorite. In both cases the active agent, once added to water is hypochlorous acid.

Sodium hypochlorite is used at the larger filter stations and is manufactured on site. Electrolytic cells are used to produce the hypochlorite from saturated salt (sodium chloride) solutions. The hypochlorite is produced at a strength of about 0.7% available chlorine. Approximately 3.5 kg of salt is needed to produce 1 kg of available chlorine in this process. A by-product is hydrogen gas which is vented off to atmosphere.

There are a number of factors that affect chlorination and its disinfection capabilities, these being:

- Suspended solids in the water which impede disinfection by absorbing chlorine and shielding micro-organisms. The treatment process seeks to maximise solids removal to minimise this affect;

- Organic matter in the water which reacts with chlorine to form trihalomethanes which are carcinogens. Again the treatment process seeks to maximise organic removal to minimise this affect;

- The pH of the water which affects the rate of disinfection (**Figure 1**). When the pH is low chlorine is present mainly as molecular chlorine with some hypochlorous acid. When the pH is about 5.0 the chlorine is present mainly as hypochlorous acid. At higher pH's hypochlorite ions are present along with hypochlorous acid. These three products are always in equilibrium but their proportions are pH and temperature dependent. As the primary disinfecting agent is hypochlorous acid disinfection is quicker at low to moderate pH's. However at high pH's chlorine residuals last much longer. This is important for the maintenance of chlorine residuals in the distribution system to provide protection against bacterial regrowth and contamination during maintenance work;

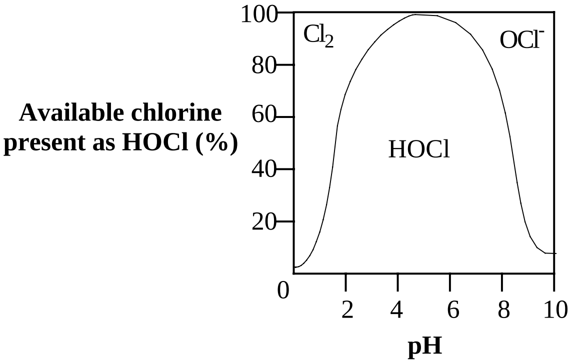

Figure 1 - The forms of chlorine in water

- Reaction with organic nitrogenous materials, such as proteins and amino acids, to form organic chloramine compounds. These chloramines retain the oxidising power of chlorine but are not as effective as hypochlorous acid;

- The alkalinity of the water. This tends to buffer the water against significant changes in pH following the addition of chlorine. If the water is low in natural alkalinity then pH correction may be needed;

- Iron and manganese. Chlorine is a powerful oxidant that quickly precipitates iron. Manganese is precipitated, but at a slower rate;

- Temperature. Disinfection by chlorine is less effective at lower temperatures;

- Contact time. Different bacteria and viruses require different times in contact with chlorine to effect a kill. The higher the chlorine dose the quicker the kill rate. Following chlorination the water circulates through chlorine contact tanks to provide the required time for disinfection to take place before the water passes to the consumers.

- The chlorine dose applied has to be sufficient to react with organic matter, iron, manganese and other reducing substances and still leave sufficient chlorine for disinfection.

Step 2 - pH Adjustment
Auckland's surface waters are soft with low alkalinity and are therefore potentially corrosive on pipe systems. The addition of chlorine can significantly lower the pH due to the poor buffering ability of the water.

Lime is added to the water to raise its pH to approaching 8.0 and lower its corrosivity. At this pH there is still sufficient chlorine present as hypochlorous acid to effectively disinfect the water.

Step 3 - Fluoridation
Fluoride in the form of hydrofluosilicic acid is added to the water to reduce dental decay in consumers. The natural fluoride content of the water is lifted to lie within the range 0.70 to 1.0 mg L^{-1}, this being the level required by the Drinking Water Standards for New Zealand.

It is typically supplied as a solution containing 15 to 20% hydrofluosilicic acid of which 79% is the fluoride ion.

After this the water is safe for drinking and is piped to homes and businesses throughout Auckland.

Article written by Geoff MacKenzie (Watercare Services Ltd.).