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ROYDS CONSULTING

Waiau River Working Party

Tuatapere Water Supply Headworks and Treatment Study



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Waiau River Working Party

Tuatapere Water Supply Headworks and Treatment Study

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1 Introduction

This report was commissioned by the Southland Regional Council's Waiau River Working Party to investigate the water supply headworks of Tuatapere township.

The objectives of the study were to:

— Assess the environmental quality of the existing water sources and the water treatment requirements to provide potable water supply for Tuatapere township from these sources.

— Identify and assess alternative sources of water, headworks development requirements and treatment facilities necessary to provide a durable and sustainable water supply.

— Identify the capital costs and operating and maintenance costs for each option.

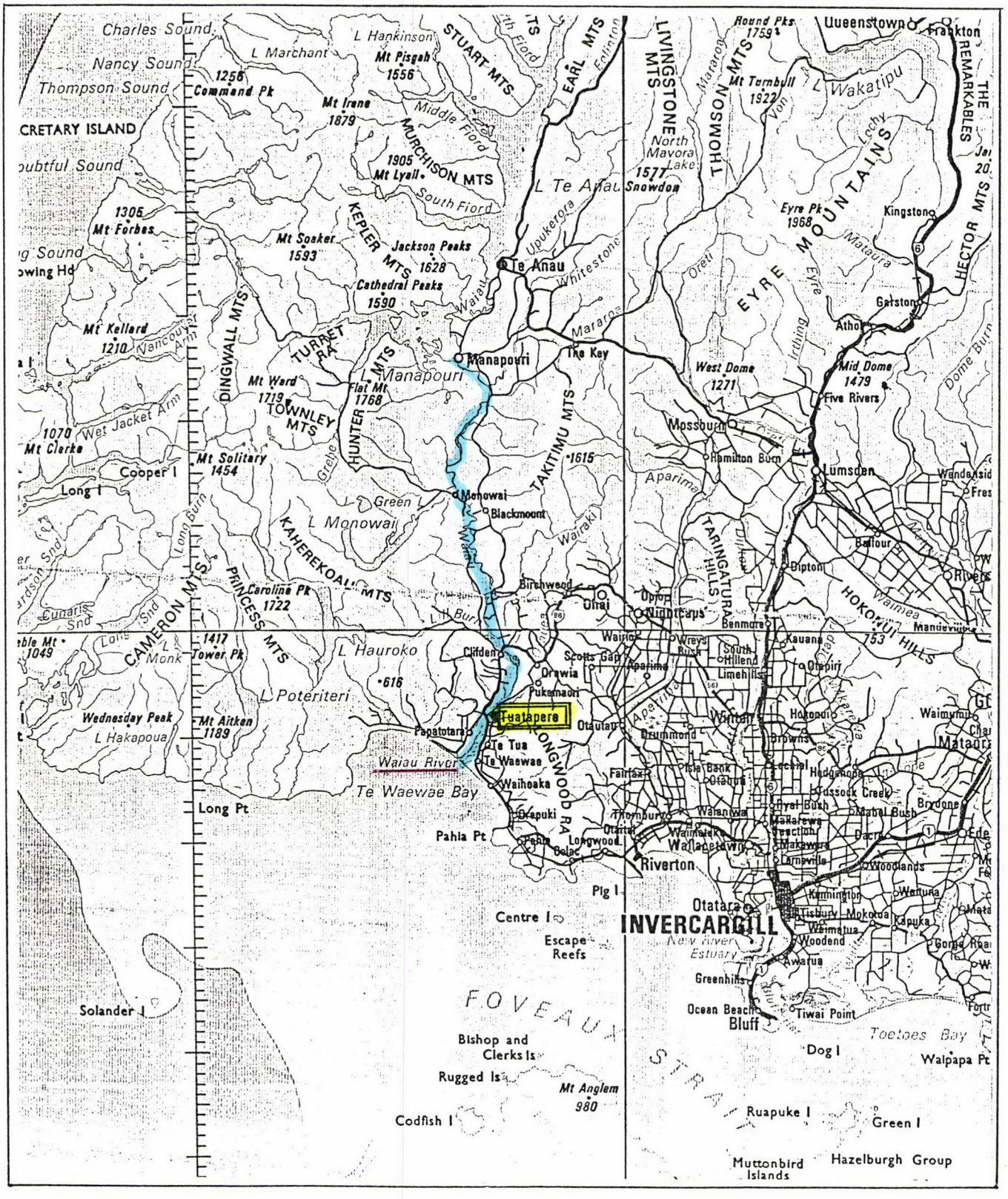


Figure 1: Location Map

2 Summary

Water for the township of Tuatapere is currently sourced from the Waiau River (55% of annual demand) and the "Bush" bore (45% of annual demand).

The Waiau River should be abandoned as a source as it is difficult to treat to a satisfactory level on a sustainable basis. A new bore should be developed as the source for Tuatapere.

The current headworks would receive a D grade: "Unsatisfactory" under the current Ministry of Health grading system.

There are prolonged periods of high turbidity due to freshes in the Waiau catchment and/or disturbances to the natural river channel flow due to control activities in the upper catchment. This makes treatment of water from the Waiau difficult and expensive to upgrade to a "Satisfactory" B grading.

Alternatively, nearby rivers and stream sources are unlikely to be any better than the Waiau. They are likely to be more variable due to lower base flows and there may be problems sustaining a reliable supply from them during dry periods.

The cost of upgrading treatment for surface water sources is more expensive and the operating costs are higher than those for groundwater.

To achieve a stable and aesthetically good supply which is equivalent to at least a B grading for headworks, we recommend the following:

- abandon the Waiau River source and rely on bore water only
- install another bore halfway between the bush bore and the river at about the same depth
- install a new submersible pump capable of $40m^3$/hour in the new bore, to provide for future flows.
- upgrade the existing bush bore (if necessary) and replace the two pumps with one capable of $40m^3$/hour—so that the existing bore can be used as a backup for the new bore
- fit 100mm dia pipework from the new bore to the treatment plant
- install a new aerator
- install an ozone disinfection unit and contact tank
- install a mixing/holding tank and dosing equipment to inject lime to correct the final water pH
- keep the existing chlorination equipment and continue to dose chlorine for residual protection in the reticulation

Table 1 following gives a summary of capital cost and O&M cost estimates for the sources and treatment considered below in Section 3.

Source	Treatment to Achieve a "B" Grading or Better	Capital Cost $ (excl. GST)	O&M $p.a. (excl GST)	Relative Water Quality
1. Waiau River	Raw Water Storage and Full Treatment (flocculation/clarification etc)	335,000	70,000	Good
2. Alternative River Source	(i) Full Treatment or (ii) Full Treatment plus raw water storage (if required)	(i) 285,000 (ii) 355,000	(i) 80,000 (ii) 70,000	Better
3 New Bore (with existing bush bore as backup)	Ozone disinfection taste/odour control and pH correction	200,000	50,000	Best

The capital cost of implementing our recommendations above is in the order of $200,000 (excl GST) and would provide Tuatapere with a good quality, reliable, sustainable, good tasting drinking water, equivalent to at least a Department of Health **B** grading.

The annual operation and maintenance costs for treatment (not including reticulation maintenance) would be in the order of $50,000 p.a. (excl GST).

3 Discussion

3.1 Existing Sources of Supply

The Tuatapere water supply currently provides treated water to the Tuatapere township of 750 population, from two different sources:

(i) Waiau River

(ii) Bush bore

These sources are described below:

3.1.1 Waiau River

Water is drawn from near the bank of the Waiau River and pumped to the adjacent Tuatapere Water Treatment Plant, in the Tuatapere Domain.

There the water is filtered (to remove sediments etc) and chlorinated, before being pumped to the town reservoir to be distributed to consumers around Tuatapere township (Refer photos in appendices).

Each river pump is currently capable of pumping about $50m^3$/hour to the plant.

During times of high sediment load in the Waiau, due to freshes in the catchment or control activities in the upper catchment, the turbidity of the water increases.

Currently when the turbidity reaches a predetermined limit, the raw water supply is switched over automatically from supply by the river pumps to supply by the bush bore pumps.

3.1.2 Bush Bore

The bush bore is located approximately 1100m from the treatment plant, on the town side of the (bush clad) domain.

The bore consists of a steel casing driven down to about 10m below the ground surface and contains two submersible pumps.

Each pump is currently capable of pumping about $27m^3$/hour to the plant.

(Refer photos in appendices)

Bore water is aerated at the treatment plant before being filtered and chlorinated (as for the river water) before being distributed.

Aeration is used to release dissolved carbon dioxide (CO_2) from the water and to help increase the pH of the water, i.e. decrease the acidity.

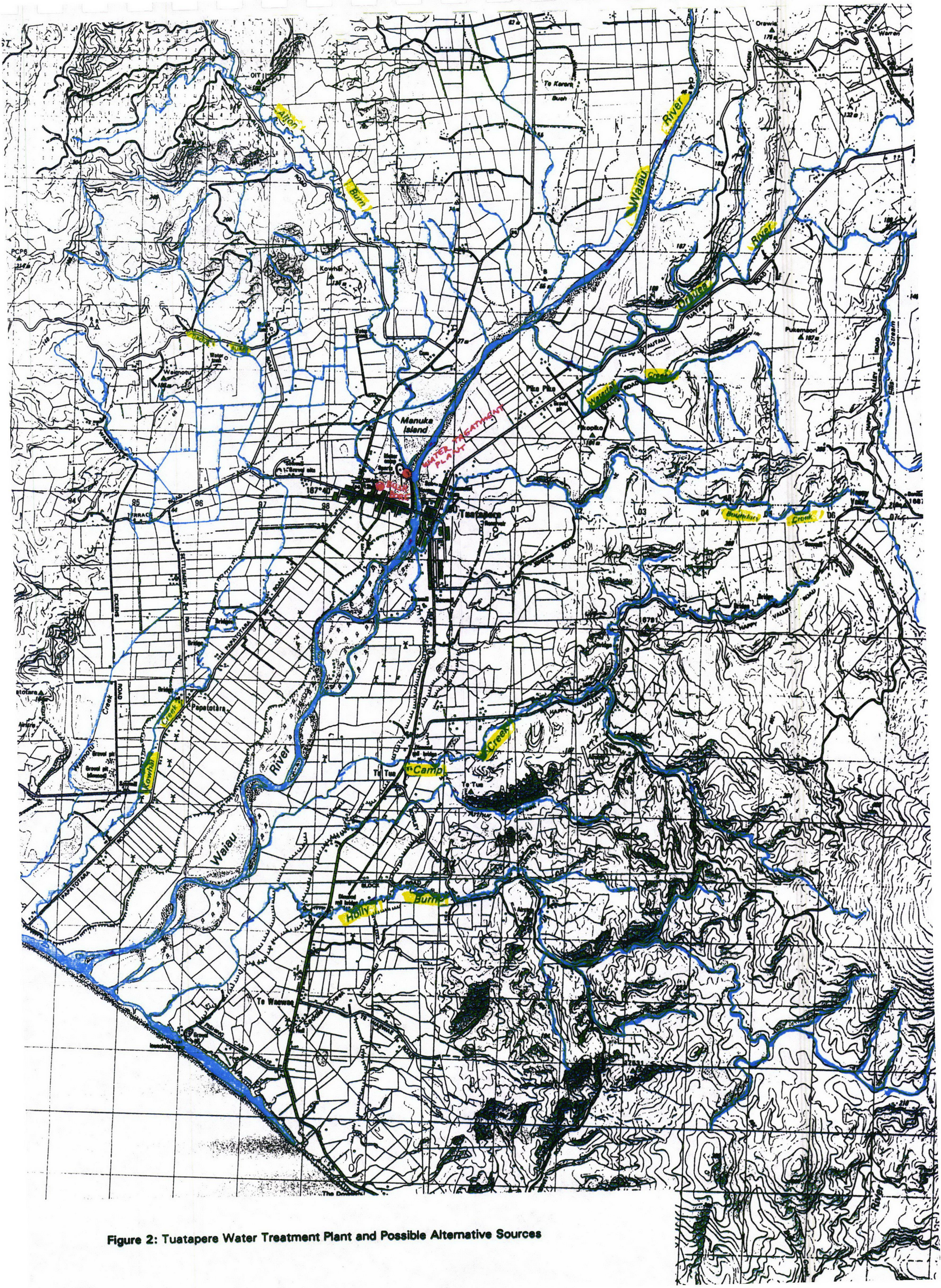


Figure 2: Tuatapere Water Treatment Plant and Possible Alternative Sources

3.2 Alternative Sources

As alternatives to the current sources of raw water, other nearby rivers and streams and/or new bores have been considered.

3.2.1 Nearby Rivers and Streams

Figures 2 identifies waterways and streams within a 5-10km radius of Tuatapere township.

They include:
- Alton Burn
- Waiau River
- Grove Burn
- Kowhai Creek
- Orauea River
- Waterfall Creek
- Boundary Creek
- Camp Creek
- Holly Burn

Of these, only a few streams appear to have sufficient catchments to possibly supply the township of Tuatapere year round with suitable water viz:

(i) Holly Burn
At 7km away this source is located the furtherest from the township. It appears to be supplied by many tributary streams within its approx 3,500 hectares of catchment.

This unprotected catchment consists mainly of native bush and scrub.

The cost of a pipeline alone from this source to the township would be in the order of $280,000.

(ii) Camp Creek
This source is approx 4.5km from Tuatapere with about a 2000ha catchment.

This unprotected catchment consists mainly of farmland with native and exotic trees and scrub.

The cost of a pipeline alone from this source to the township would be in the order of $180,000

(iii) Orauea River
This source is approx 3km from Tuatapere with about a 3000ha catchment.

This particularly "unprotected" catchment consists mainly of flat lying farmland.

The cost of a pipeline alone from this source to the township would be in the order of $130,000.

(iv) Alton Burn

It may be possible to draw water from this source as close as 1km from the existing treatment plant.

It has an unprotected catchment of about 4000ha and consists mainly of native and exotic trees and scrub and some farmland.

The cost of headworks at the river intake and a pipeline from this source to the treatment plant would be in the order of $90,000.

Alton Burn has been considered as an alternative source for cost estimate purposes. However further investigation would be required to check the reliability of supply and quality of raw water.

3.2.2 New Bore(s)

The information contained in reference 1 shows that there are a number of bores around Tuatapere—predominantly for private farm water supply.

From the data it is apparent that a bore drilled on the flats adjacent to the Waiau River and up to 1km from it would probably yield a sustainable supply of raw water. Selection of the bore site would require confirmation by test boring.

The degree of treatment required would need to be ascertained by testing. Any new bore is likely to require the same treatment as the existing bush bore, namely aeration, filtration and disinfection.

3.3 Supply Requirements

3.3.1 Existing Demand

An appraisal was made of the current supply requirements for Tuatapere based on 7 day average pumping records for the plant for the period July 1993 to May 1994.

The demand flows have been plotted below in figure 3.

An average daily demand of 425m^3/day for 750 people or 300 properties is high and needs further investigation.
There is either:

(i) significant leakage from the reticulation
(ii) significant residential demand
(iii) significant commercial demand
(iv) significant industrial or agricultural demand, or
(v) a combination of the above

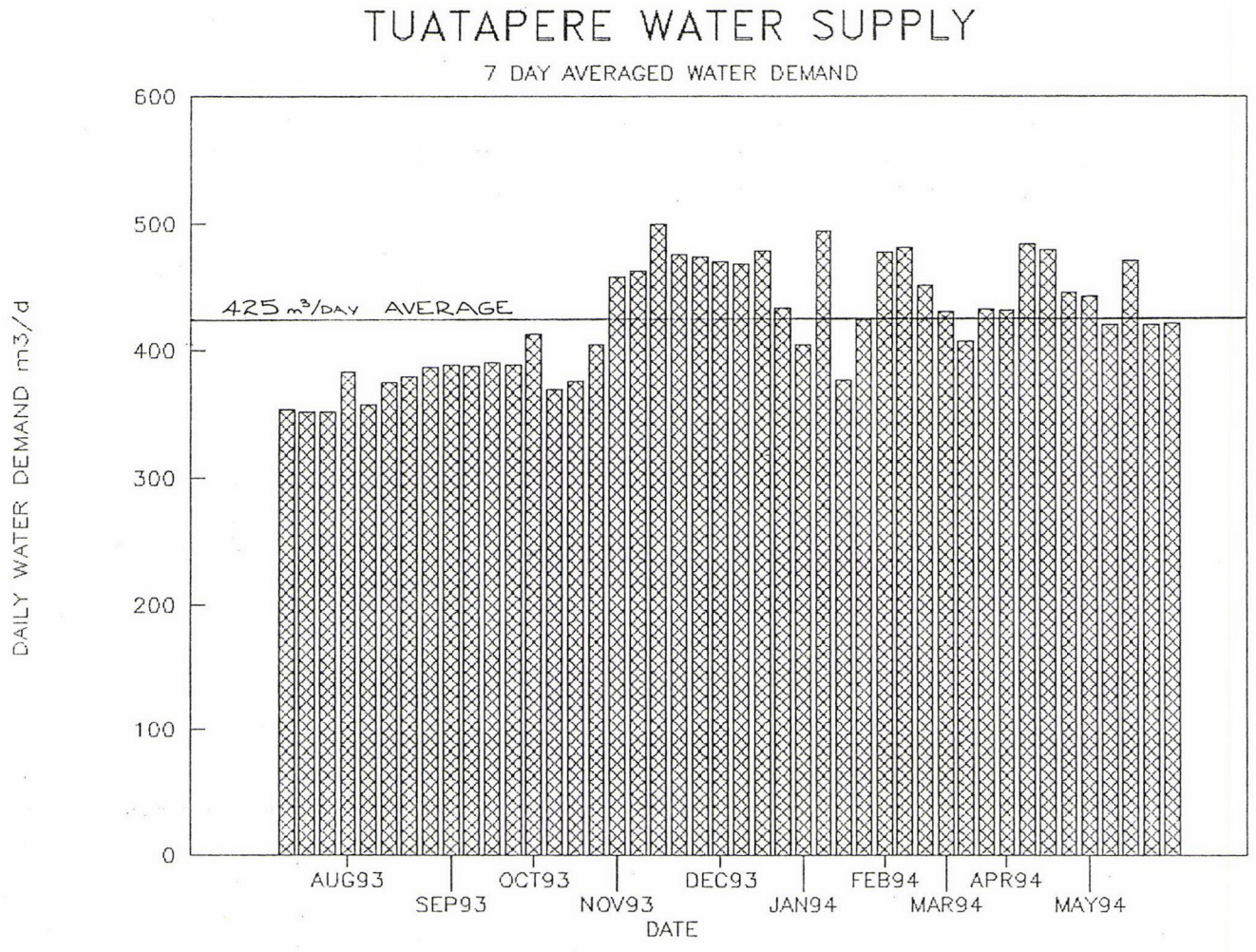


Figure 3: 7 day averaged water demand (m^3/day)

3.3.2 Future Demand

The average daily water use of the town could be expected to rise moderately with an increase in the quality of the supply or with any increase in permanent or holiday resident numbers.

Based on an allowance for a 50% increase in present average flows for sizing future headworks requirements, a flow of 650m^3/day average should be provided for.

Until the population exceeds 2,000, the **instantaneous** demand at any point in the reticulation is set by the N Z Fire Service "Code of Practice for Fire Fighting Water Supplies"; a requirement of 25ℓ/s flow (90m^3/hour). (For fire flows the mains from the reservoir to the town should be 150mm in diameter).

It has been assumed that instantaneous demand peaks through the course of a day would be damped by adequate storage in the town reservoir and the clear water tanks.

3.3.3 Pumping Requirements

The existing pumping arrangement is:

- 2 x 50m^3/hour submersible pumps at the Waiau River intake
- 2 x 27m^3/hour submersible pumps in the Bush Bore. (We are uncertain of the age and condition of these pumps).

To provide for future daily flows of 650m^3/day average, requires raw water pumps with a capacity of at least 40m^3/hour to operate for 16 hours each day. This allows for a future contingency of 8 hours each day for repairs and maintenance and also allows for a peak daily production of 960m^3 if required.

For water quality reasons (among others) we have recommended below in Section 3.4 that a new bore should be established somewhere between the existing bush bore and the Waiau River. This bore should be fitted with a 40m^3/hour capacity pump.

The bush bore would then become the standby bore, if the new bore was ever out of action.

We understand that the bush bore sometimes has difficulty keeping up with demand, and that the pumps sometimes cut out on low level until the bore recharges. For this reason we recommend that replacement of the casing and screen is investigated. The supply problems may be due to the constraint of the casing and/or screen length.

To act as a standby bore to compliment the new (proposed) bore, the two existing (aging) bush bore pumps should be replaced with a single 40m^3/hour capacity submersible.

While it may be possible to relocate the existing river pumps in the bush bore and new bore (this would need to be investigated further) for the purposes of cost estimates we have allowed for fitting new 40m³/hour pumps into each bore.

The cost of installing a new bore (including test bores and investigations) complete with pump and 500m of delivery pipeline etc, and including the replacement of the bush bore pumps with a single 40m³/hour pump, is in the order of $55,000 (+ GST).

3.4 Quality Requirements

3.4.1 Quality Standards

The standards in New Zealand for drinking water quality are the Board of Health "Drinking Water Standards for New Zealand" (NZ DW Standards) 1984. They are based on the WHO Guidelines for Drinking Water Quality (1984).

The new grading system adopted by the Department of Health in 1993 for water supplies sees headworks and distribution systems graded from an "A : Completely Satisfactory — negligible level of risk, demonstrably high quality", to an "E : Completely Unsatisfactory — very high level of risk".

As instructed in our brief, the minimum standard to be considered for Tuatapere is "B : Satisfactory — low level of risk".

Figure 4 summarises these.

(i) **Surface sources from an unprotected catchment**

For the headworks with a surface source from an unprotected catchment to attain a B grade requires:

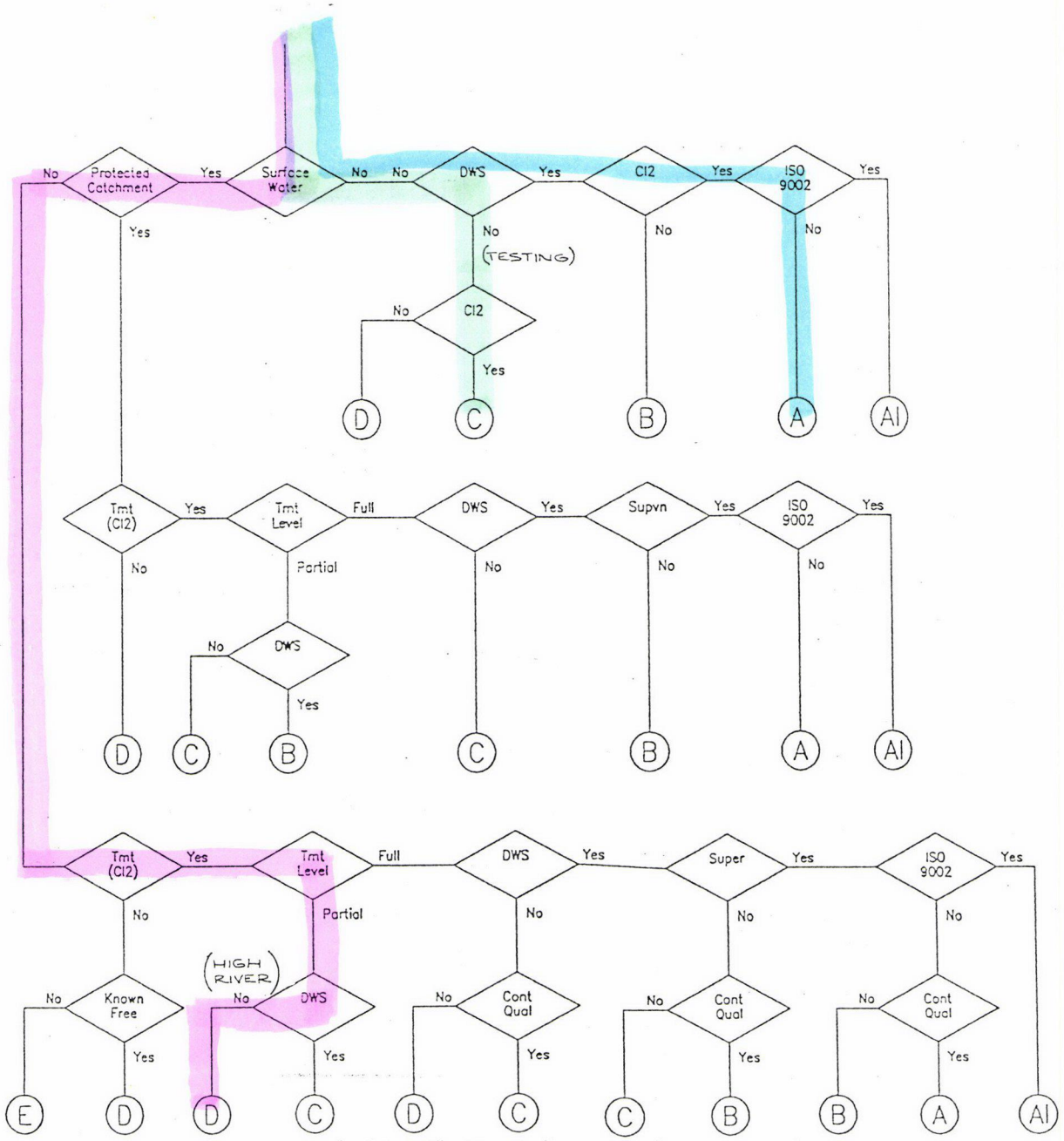
- disinfection with residual, i.e. chlorine residual
- full treatment, e.g. flocculation/coagulation, sedimentation/clarification (if required), filtration and disinfection
- "compliance" with NZDW standards
- either continuous quality control, e.g. regularly calibrated on-line monitoring equipment with telemetered alarms operating **or** appropriately qualified supervision (the District Council staff meet this)

(ii) **Ground sources**

The U.S. Environmental Protection Agency (EPA) criteria for groundwater is water contained beneath the land surface which is not under the direct influence of surface water and does not demonstrate significant and rapid shifts in water characteristics such as turbidity etc or the presence of pathogens such as giardia.

Ground sources, (bores) which meet the EPA criteria and the NZDW standards, with disinfection by chlorine receive an "A" grading.

Figure 4: Ministry of Health 1993 Gradings



Existing River

Existing Bore

Proposed Bore

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However, if the groundwater does not comply with the EPA groundwater criteria (for example it contains giardia protozoans), then it is treated as a surface source. The criteria in (i) above then applies.

(iii) **Meeting the requirements of NZDW standards for grading purposes**

In terms of meeting the NZDW standards for the purposes of the Department of Health Grading, the supply must meet the requirements of the following tables in the Drinking Water Standards:

Treatment—Surface water **must** have full congulation and filtration
—Ground water—no requirement

Table 1—Microbiological and Biological Quality

The requirement of table 1 must be met by the water supply. This requires one sample per month for coliform analysis (for a population of less than 5,000). If insufficient sampling is being carried out to meet this requirement then the supply is not considered to be complying.

Table 2—Inorganic constituents

The water supply must meet the requirements of table 2 for maximum levels of all inorganic constituents listed, but particularly arsenic, cadinium, lead, and mercury.

If an inorganic constituent has never been found to be a problem, it is acceptable to rely on three yearly testing for these.

Table 3—Organic constituents

The constituents in table 3 need only be tested for if their presence is suspected in the water supply.

Organic constituents include chloroform, trihalomethanes, pesticides etc.

Table 4—Aesthetic quality

For the purposes of grading, the Aesthetic Quality characteristics in the NZDW standards to be specifically noted are:

- Turbidity — should not exceed 0.5 NTU for a supply with full treatment and 1 NTU in other cases. Supplies exceeding 1 NTU on a regular basis do not meet either the NZDW standards or giardia treatment requirements of Appendix III.
- Colour — supplies must meet the value of 5 TCU given in the standard.

The Waiau River, when "treated", fails because it does not meet the NZDW Standards under high river flows.

The Bush Bore fails because there is no microbiological testing programme of the source so it is presumed to fail.

3.4.2 Existing Sources

(i) **Waiau River**

For the present partial treatment only of Waiau River Water at Tuatapere, the highest grading possible for the plant is a "C : marginal, moderate level of risk", if the plant complies with NZDW standards.

However, during a fresh or significant disturbance to the main river channel flow, the final water is unlikely to meet the standard due to high turbidity results (> 1.0 NTU for partial treatment), and the highest grading possible at present would be "D : unsatisfactory high level of risk".

Provision of raw water storage to supply the plant with water from times of low river turbidity is unlikely to produce results which fully comply with the NZDW standards without the need for further treatment. Present records indicate the river becomes discoloured for prolonged periods. Provision of sufficient raw water storage would be expensive.

The options are to either provide raw water storage and full treatment or abandon the Waiau River and adopt another more suitable source.

Surface water treatment would involve the addition of chemical coagulants, (to flocculate the fine particles) which produce residuals in the final water. Sludge is also produced which would require special handling and disposal facilities.

For full treatment of surface waters at Tuatapere to perform to a B or higher grading, would involve a high level of skill and time input from the operator.

(ii) **Bush Bore Water**

We are not aware of any tests for Giardia in the bore water. This would need to be done to confirm that the groundwater meets the EPA criteria.

Several tests over the period of several months would be required to check that the source is not contaminated by surface water.

The final water produced from the Bush Bore has a low pH, typically 7.0. This is outside the requirements of table 4 NZDWS which states that the final water pH should lie in the range 7.5-8.5. Coupled with the low hardness and dissolved solids in the water, the final water produced from the bore is moderately corrosive.

pH is not considered a health risk in terms of the grading rules. The rules do not require compliance with table 4 except for Turbidity and Colour.

However, if the water remains moderately corrosive, (i.e. it is not pH corrected) then there could be corrosion by-products formed in the reticulation.

If the Bore Water does not contain Giardia cysts or any faecal coliforms (i.e. complies with table 1 of NZDWS), then this source would currently get a "C" grade for headworks.

The supply is not considered to be "stable and aesthetically good" because of the corrosivity of the final water. If Giardia or coliforms are found in the water (and this is likely) then the water fails the EPA criteria and becomes "surface water" from an unprotected catchment. It is then graded exactly the same as the Waiau River water.

3.4.3 Alternative Sources

(i) **Nearby Rivers or Streams**

While the nearby rivers or streams mentioned in section 3.2.1 are likely to run "cleaner", i.e. less discoloured than the Waiau for a greater time, it is most unlikely that they will remain less turbid than 1.0 NTU during freshes in their respective catchments.

The streams with pastoral catchments will be contaminated with Giardia and Cryptosporidium, as may the bush clad catchments from time to time.

The pastoral catchments are likely to become quite turbid due to clays and silts washed off during periods of rain.

The bush clad catchments are likely to become highly coloured due to decaying plant matter and possibly turbid due to clays and silts.

Therefore, in terms of reliable raw water quality (let alone sustainability of flow throughout the year), the nearby rivers and streams do not offer a significant improvement as an alternative surface water source to the Waiau River.

(ii) **New Bore(s)**

The primary objective of a bore is to avoid the sand/silt/clay turbidity of river waters. The natural filtration through gravel achieves this.

Microbiological levels also diminish very rapidly—the EPA criteria suggests 12 months underground will result in "no bugs" being left at all.

However, groundwater quality does deteriorate with vertical inflows containing organic material. Apart from a "fresh supply of bugs", there is organic material such as vegetable decomposition debris. This latter further decomposes giving CO_2 which makes the water acidic. The pH drops and metals, particularly iron, dissolve into the water. This organic/acid effect appears to diminish after several years or decades.

The Bush Bore is quite acidic. A better bore would be nearer the river (with less organics) but not too close for "river bug" levels.

Advice from a driller who has worked in the area is that the rock/gravel layers are difficult to predict. We have allowed for 5-10 holes of exploratory drilling to seek a satisfactory bore location.

3.5 Ozone Treatment

3.5.1 Ozone Features

For both the Bush Bore and a new bore, ozone has the following features:

- it is a powerful disinfectant and will disinfect all known bugs. This includes cryptosporidium (reference 8/Appendix E) which chlorine will not. However, it does not leave a residual.
- it is a powerful oxidant and will counteract many earthy tastes and odours.
- it will oxidise iron to ensure removal by the sand filters. (Once oxidised, the iron becomes insoluble and precipitates out)
- it will bleach low colour levels out, removing pale brown/yellow colour

We have used ozone recently on similar water with all of the above features, and it has worked very well.

Ozone acts very quickly—within a few minutes—and a small contact tank is all that is required.

We therefore consider ozone to be an appropriate form of treatment of water from a bore water source at Tuatapere.

3.5.2 Ozone Properties

Ozone is a very strong oxidising agent and its use in water treatment has several advantages over chlorine as a disinfectant.

when used prior to filtration (as we have recommended in this report) it will eliminate the formation of toxic THM's (trihalomethanes) which are formed when chlorine is added to water which has some colour (due to dissolved organic matter content).

Ozone will also oxidise iron and manganese which can then be removed in the sand filtration stage (and unlike chlorine, ozone does not change the pH of the water).

The high oxidation strength of ozone makes it a very effective sterilant. A residual of 1.0ppm ($1g/m^3$) after retention (contact time) of one minute (i.e. CT value of 1) will give a 99.9% reduction in coliform and cryptosporidium counts. (The CT value is the **residual** sterilant level in ppm times the contact time in minutes).

Ozone will destroy Legionella and Giardia cysts.

Ozone has a half life of about 20 minutes so in the recommended process with a $10m^3$ contact tank, the CT value could be as high as 5—ensuring sterilisation of the water.

The application of ozone is also beneficial to the filtration stage as it forms a microfloc so it is in itself a "filter aid".

If some residual ozone is allowed to enter the filter it will act as a sterilant and keep the filter surface clean, however if this is the case the filter vessel lining must be ozone resistant (e.g. epoxy coated etc).

A higher level of ozone entering the filter means a higher CT value has been obtained in the contact tank and better sterilisation has been obtained.

In the proposed installation there would be no ozone residual in the clear water tanks, as the ozone would be consumed in the filters.

Because there would be no residual sterilant left in the system, post-sterilisation with chlorine before the clear water tanks is required to give a disinfectant residual, if an A grade is to be attained.

(For further information about ozone refer to Appendix D).

3.5.3 Ozone Installation

A suggested ozone treatment arrangement is shown in the Appendix G.

For treatment of the bore water we recommend an application rate of 2g/m^3 be used.

We estimate this will be required to give a CT value of 1-2 for a 10m^3 contact tank.

An added advantage is obtained for this particular application in the extra aeration obtained will be equivalent to 98 SCFH of air at 2g/m^3 of ozone applied. The additional aeration will aid in the removal of dissolved CO_2.

The ozone generator will require its own air preparation system which is included in our estimates.

The ozone generator as shown on the arrangement in Appendix C would run when the pump does.

3.5.4 Ozone Treatment Costs

The following have been included in the capital cost estimates and O&M costs in Section 3.6:

(i) **Capital Costs**

WT 100E (100g/hr capacity) complete with air preparation system, ozone injector and ozone booster pump	$80,000 (excl GST)

(Installation and commissioning are included in this price)

(ii) Running Costs

Electricity at full power including air preparation
4kW at 10c/kWhr = 40¢/hour

(a) Assuming a 50% duty over one year = $1,750-$3,500pa electricity costs

(b) On/off with bore pump = $4kW/40m^3$

$$\frac{0.40¢/hour}{40m^3/hour} = \frac{1¢}{m^3}$$

(this compares favourably with current chlorine costs of $2¢/m^3$)

Flow:	Present $425m^3$/day	Future $650m^3$/day
Electricity Cost p.a.	$1,550	2,370

(iii) Maintenance Costs

Compressor replacement at say 5 years	$1,000 p.a.
PSA Air dryer media over 7 years	$200 p.a.
Ozonator cell replacement over 10 years	$1,000 p.a.
Total approx	$2,200 p.a.

3.6 Cost Estimates

Table 2 following lists the estimated capital costs of treatment to achieve a minimum of B grade equivalent, for the sources discussed above.

Table 2
Capital Cost Estimates

	Source	Treatment Items	Estimates (excluding GST)	
1.	Waiau River	(i) New 7 day min^m Raw Water Reservoir	160,000	
		(including new pumping facilities from reservoir to top of mixing chamber)		
		(ii) New full treatment plant	130,000	
		• flocculation/coagulation • clarification/sedimentation • filtration • disinfection (using existing chlorination equipment)		
		(iii) Alum sludge pond (including consents)	45,000	
			Total	$335,000
2.	Alternative River Source	(i) Full treatment (as above)	130,000	
		(ii) Pipeline from source to plant (including intake, consents etc)	110,000	
		(iii) Alum sludge pond (including consents etc)	45,000	
			Sub Total	$285,000
		Plus		
		(iv) 2 day min^m raw water reservoir if required	70,000	
			Total	$355,000
3.	New Bore (Plus Existing Bush Bore as Backup)	(i) New Bore - including pump and pipework to the plant	50,000	
		(ii) New pump for bush bore	5,000	
		(iii) Upgrade treatment at existing plant includes: • new aerator on top of a new 10m^3 ozone contact tank • ozone disinfection and odour/taste control • pH correction • (chlorination optional)	145,000	
			Total	$200,000

Note: Estimates exclude GST
Estimates include: 10% contingency
Engineering Costs—Consents, Design, Supervision, Commissioning

Table 3
Treatment Operations and Maintenance Cost Estimates

Source:	1. Surface Water (alternative surface water source)		2. Surface Water (Waiau or alternative)		3. Bore water (new bore)	
Treatment:	Full treatment without raw water storage		Full treatment with raw water storage		Ozone treatment and pH control	
Flow: m^3/day	**Present** 425	**Future** 650	**Present** 425	**Future** 650	**Present** 425	**Future** **650**
1 Electricity (pumping only)	7,800	12,000	8.500	13,000	9,100	14,000
2 "Chemicals" (Alum, Cl_2, Ozone, Lime)	7,200	11,000	6,500	10,000	4,300	6,500
3 Operator (labour & vehicle)	40,000	40,000	30,000	30,000	20,000	20,000
4 Treatment equipment and pump maintenance	15,000	15,000	15,000	15,000	8,000	8,000
TOTAL TREATMENT O&M COST PER ANNUM	$70,000	$80,000	$60,000	$70,000	$42,000	$50,000

Note: (i) All estimates exclude GST
(ii) Items 3 and 4 exclude reticulation, connection, repairs, and maintenance costs

4 Conclusions

From the above discussion we conclude the following:

4.1 Waiau River Source

The Waiau River source is directly affected by the sediment loading of river flows due to flood runoff and control activities in the upper reaches of the Waiau River catchment.

To use this source during high sediment loads, significant raw water storage would be required.

To improve the grading of the existing river water treatment to a B grading would require full treatment. These combined would cost in excess of $335,000 (+GST) to implement.

4.2 Alternative Surface Waters

Alternative surface waters (nearby rivers and streams) would not offer a significant improvement in raw water quality to that of the Waiau, except that sediment loading (turbidity) is likely to be less and occur for shorter periods.

The same full treatment would be required to attain a B grade for headworks. Possible savings, however, could be in raw water storage.

Alternative sources are likely to clear quicker than the Waiau and require less (if any) raw water storage, and would not be subject to disturbances due to control activities.

The cost of alternative surface water sources is high due to the cost of reticulation of the raw water to the plant. The cost to reticulate the water from the nearest alternative source and treat it would be in the order of $285,000 (+GST).

Further investigations would be required to ascertain the quality of alternative surface waters and the sustainability of the source during dry periods.

4.3 Bore Water

Bore water is the preferred source. It offers a regular (good) quality raw water, which is sustainable, and allows a better quality final water to be produced with minimal additional treatment for less cost than the other sources described above (a total cost of approximately $200,000 + GST).

It would also require less plant maintenance and less day to day time involvement by the operator. The treatment O&M costs would range from approximately $42,000 p.a. for present flows of 425m^3/day, to approximately $50,000 p.a. for future flows of 650m^3/day. These costs are less than for the other sources described above.

The water produced from a new bore is likely to taste better, smell better, and be of a more consistent and higher quality than that of surface waters if treated as recommended.

It would be free of Giardia and Cryptosporidium protozoans. At worst it would also be only slightly corrosive, i.e. better than the existing treated river water.

5 Recommendations

We recommend the following:

(i) **Source**

- Abandon the Waiau River as a source, rely instead on groundwater sources.
- Install a new bore, halfway between the existing bush bore and treatment plant, with a $40m^3$/hour pump.
- Replace the two pumps in the existing bore with a single pump of $40m^3$/hour capacity.

(ii) **Treatment**

- Keep the existing plant as it is but add in ozone injection for disinfection of the raw water and to combat taste and odour problems associated with the bore water.

  (Ozone will kill Giardia which is difficult to control with a conventional flocculation/clarification/filtration plant. Ozone also kills Cryptosporidium, which is very difficult to control by conventional (rapid sand) filtration).
- Install a lime mixing/holding tank, dosing pump and injection lines to correct the pH of the final water to control taste and corrosivity.

(iii) **Disinfection and Chlorine Residual**

The disinfection method recommended is by ozone injection. This does not however provide a residual in the reticulated water to guard against subsequent contamination of the treated water. A residual can only be achieved by chlorination.

If chlorine is not wanted in the supply by the Community, then an **audit** of the distribution system needs to be done to identify any potential backflows. The Council would have to run and maintain specific staff training on maintenance procedures to avoid potential contamination and accept a B grade rather than an A. The Health Department have clearly recommended the use of chlorine residuals through their grading system.

The cost of dosing with chlorine is not a major issue (approximately 2 cents per $1m^3$ = 1,000ℓ) especially as the equipment is already in place.

6 References

1 "Waiau River Valley Groundwater Monitoring—Fourth Quarter 1993"
A report by Works Consultancy Services Ltd, December 1993

2 "Waiau River Hydrology"
A report by Southland Regional Council and Works Consultancy Services Ltd, April 1993

3 "Waiau Catchment Water Quality Review"
A report by Robertson Ryder and Associates, June 1993

4 "Cursory Analysis of Tuatapere Water Supply Data"
A report to the Southland Regional Council's Waiau River Working Party by D.C. Riddell, November 1993

5 "Drinking Water Standards of New Zealand"
Department of Health, 1984

6 Water Supply Grading —1992 Draft
—1993 Explanatory Notes
Department of Health

7 Development of Drinking Water Standards for New Zealand
Ministry of Health 1994

8 "Effects of Ozone, Chlorine Dioxide, Chlorine and Monochloramine on Cryptosporidium Parvum Oocyst Viability"
D.G. Korich et all, Applied and Environmental Microbiology May 1990 pp 1423-1428
(a copy of this paper is appended as Appendix E)

Appendices

A Photographs of Existing Sources and Treatment Facilities

B Chemical Analysis Reports of Existing Sources

C Schematics of Treatment Options

D Ozone Brochure

E Effects of Ozone on Cryptosporidium

F Ozone Pilot Plant Results

G Ozone Treatment Arrangement

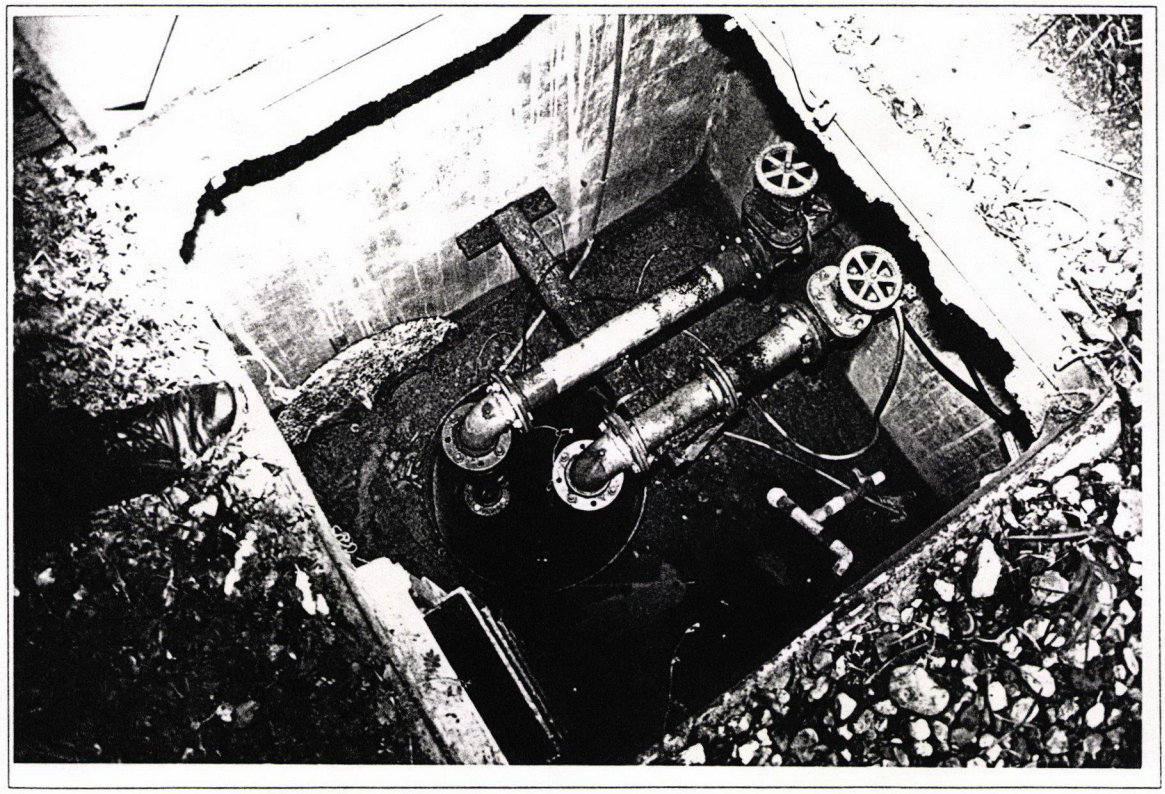
Appendix A: Photos of Existing Sources and Treatment

Tuatapere Water Supply

Photographs of Existing Plant



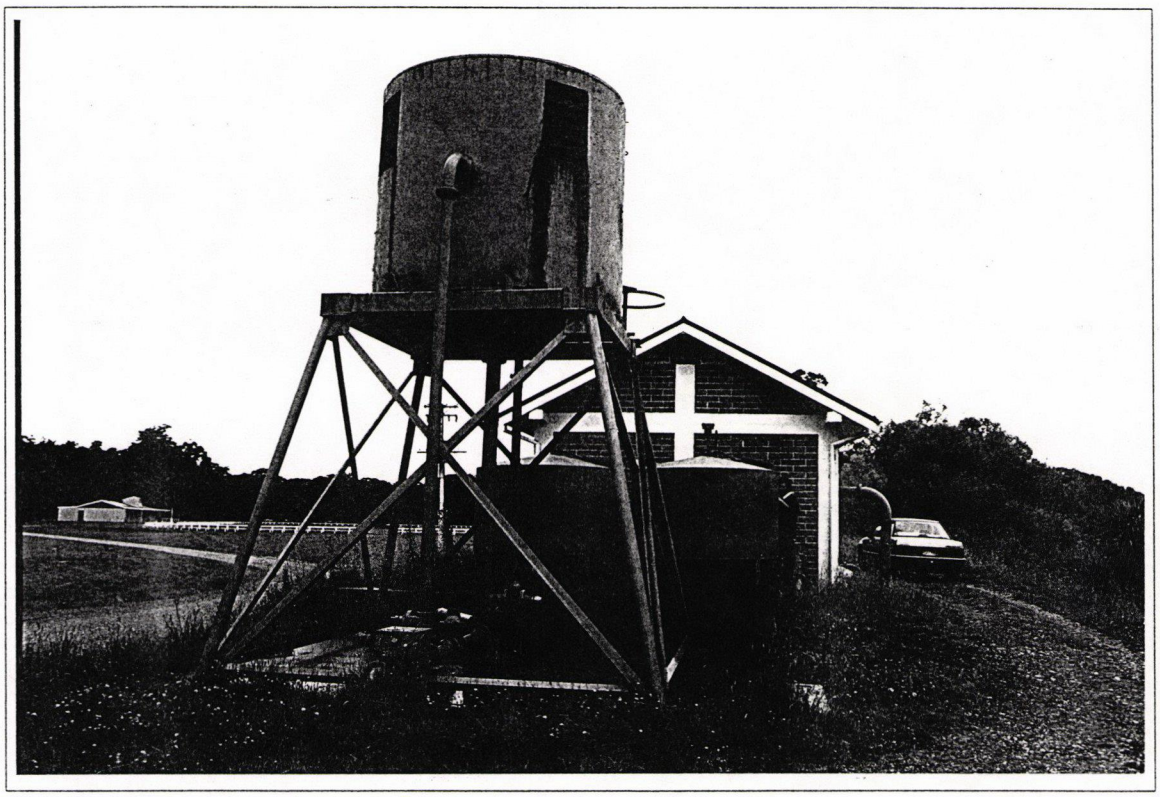
Bush Bore Location



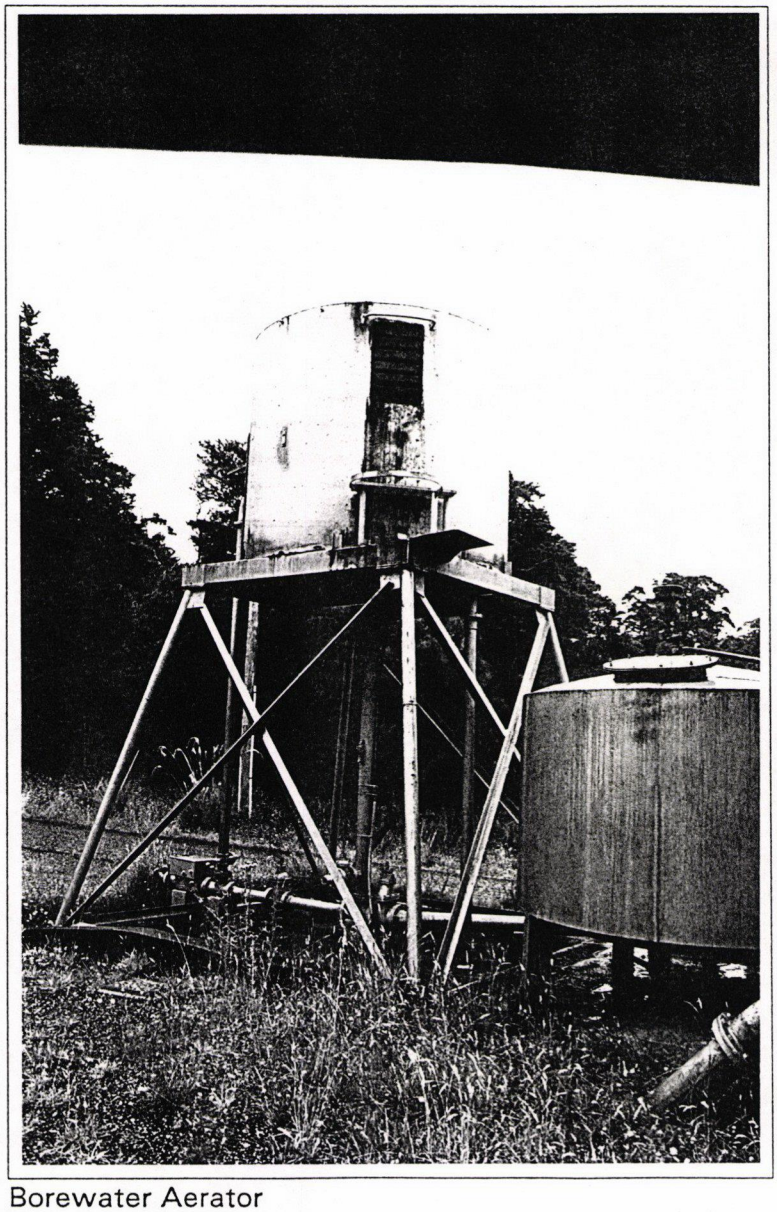
Bush Bore, Pumps (2 No) and Pipework



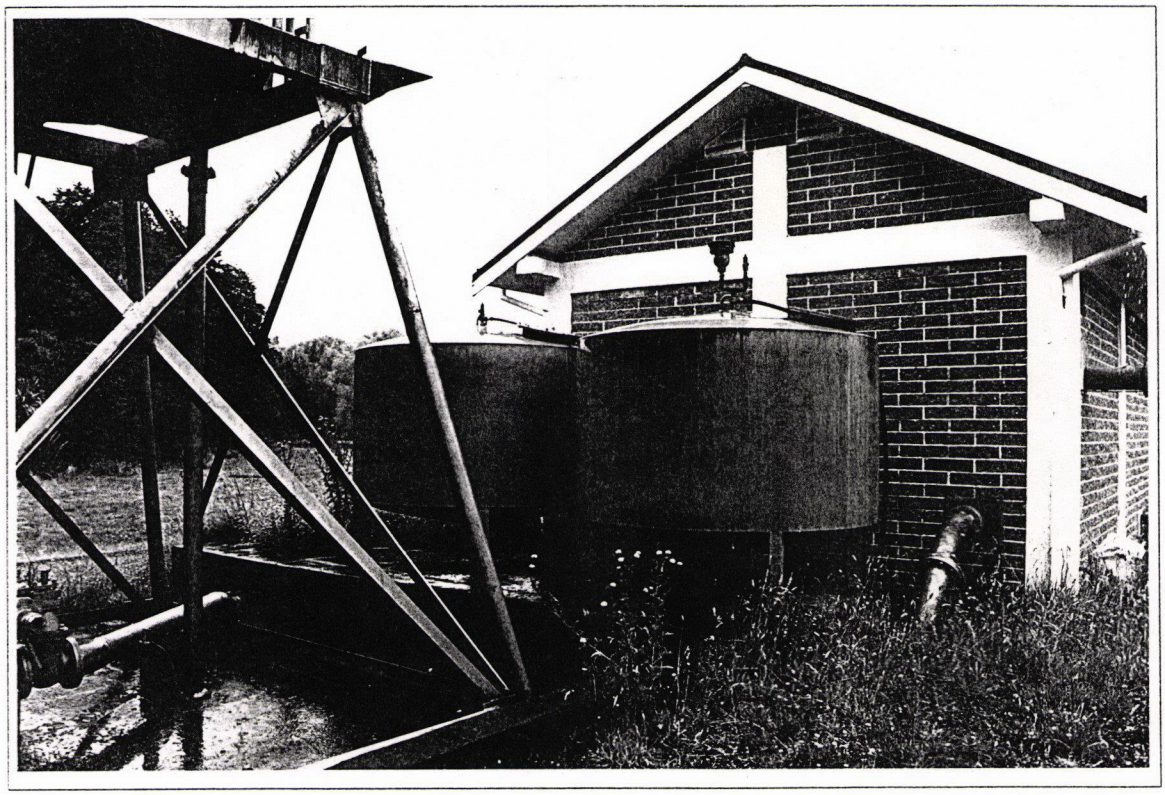
Proximity of Waiau River to Treatment Building



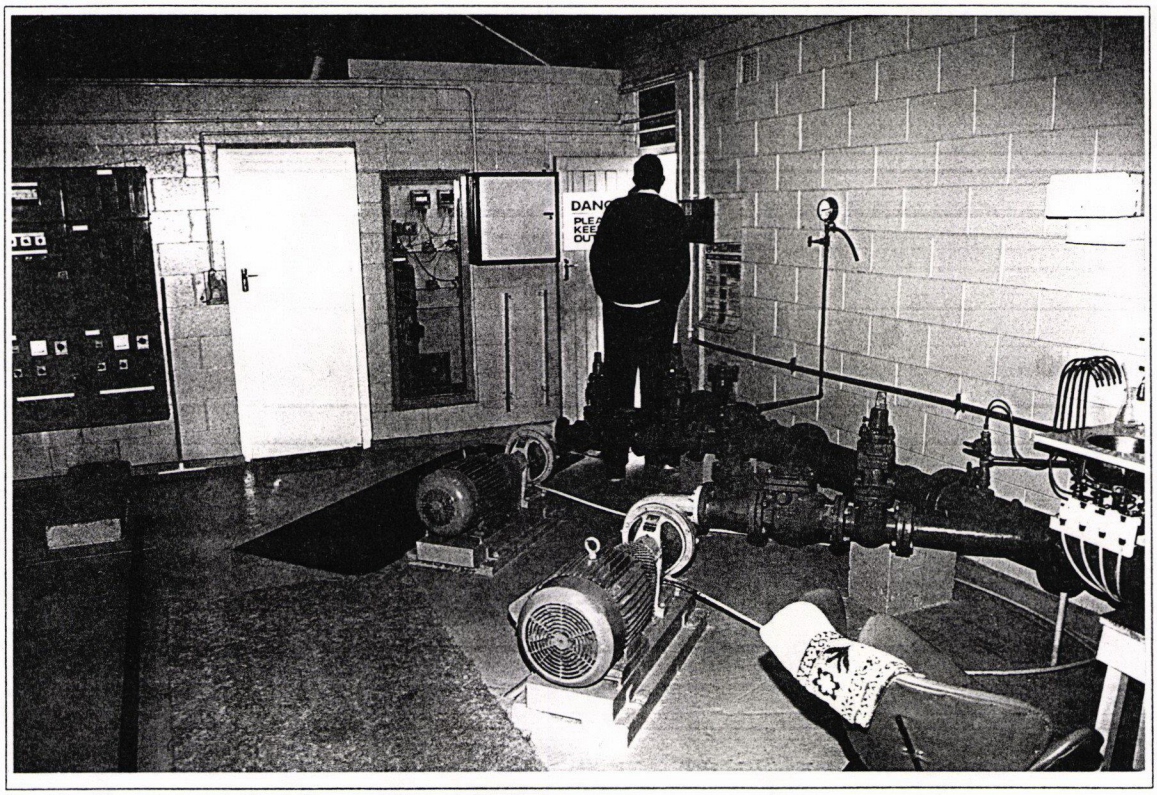
Borewater Aerator, Pressure Filters and Treatment Building



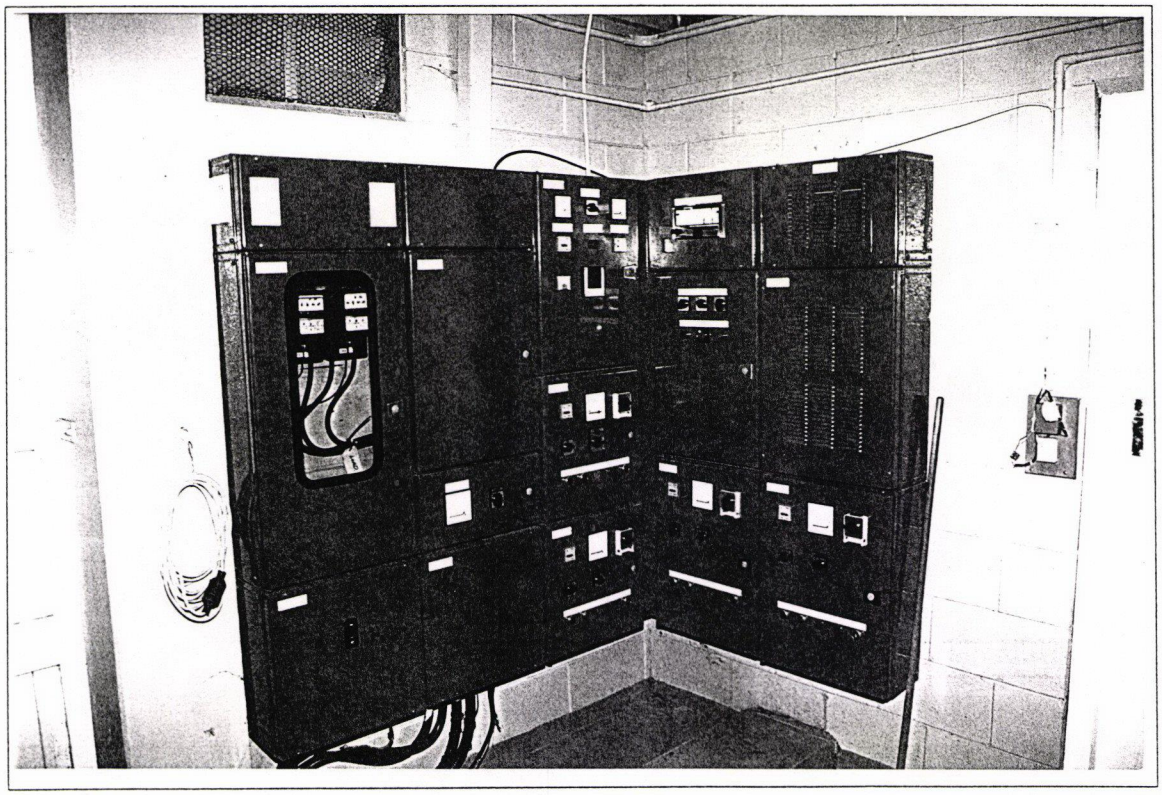
Borewater Aerator



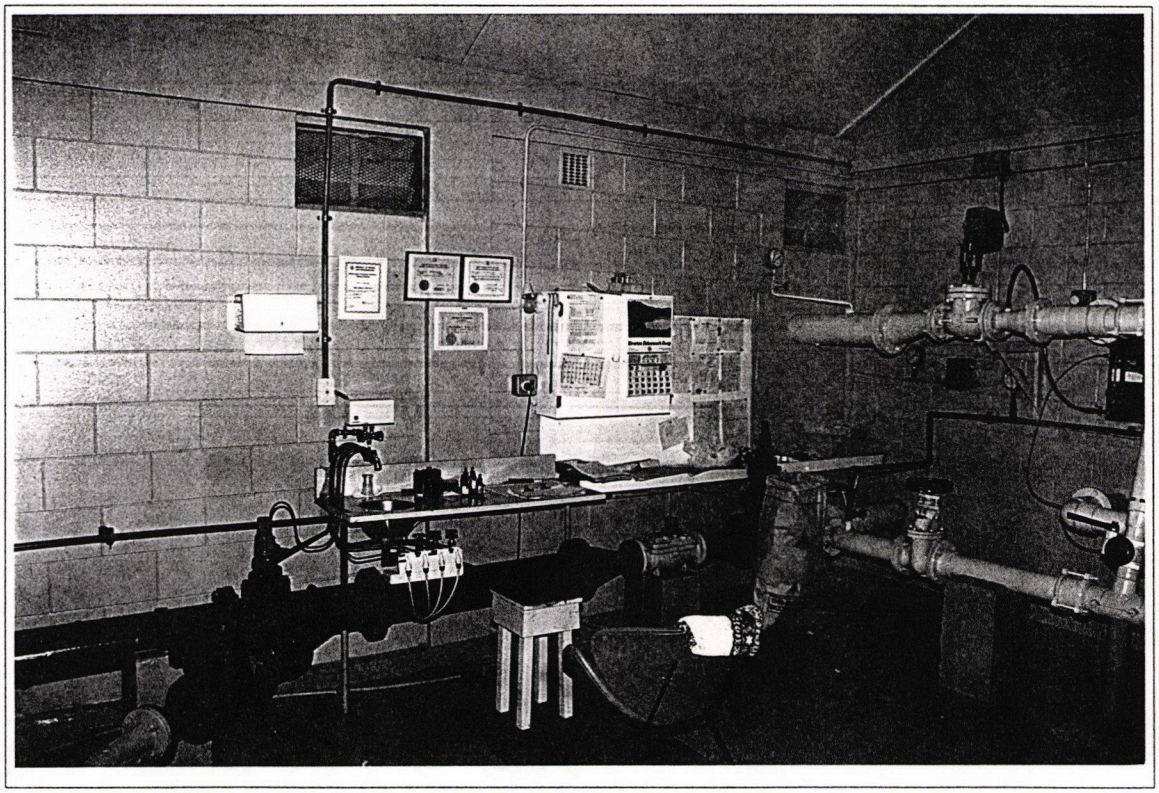
Pressure Filters



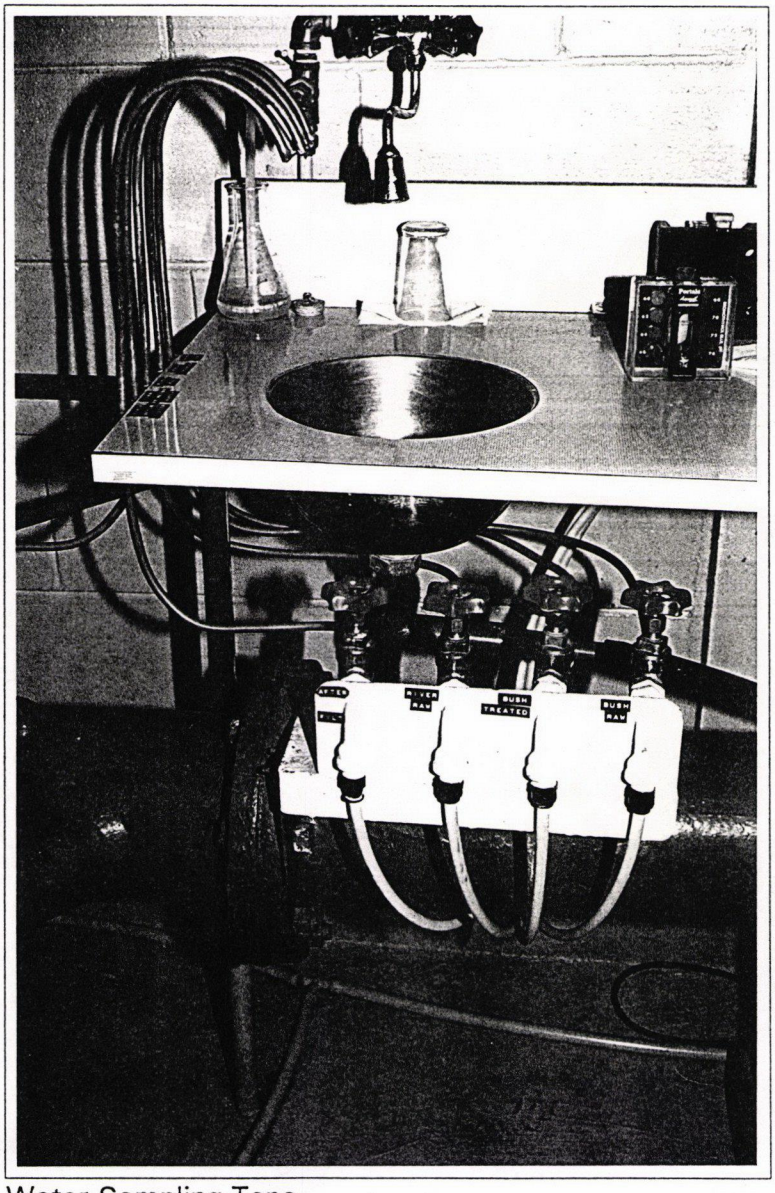
Inside Treatment Building - High Lift Pumps etc



Switchboard

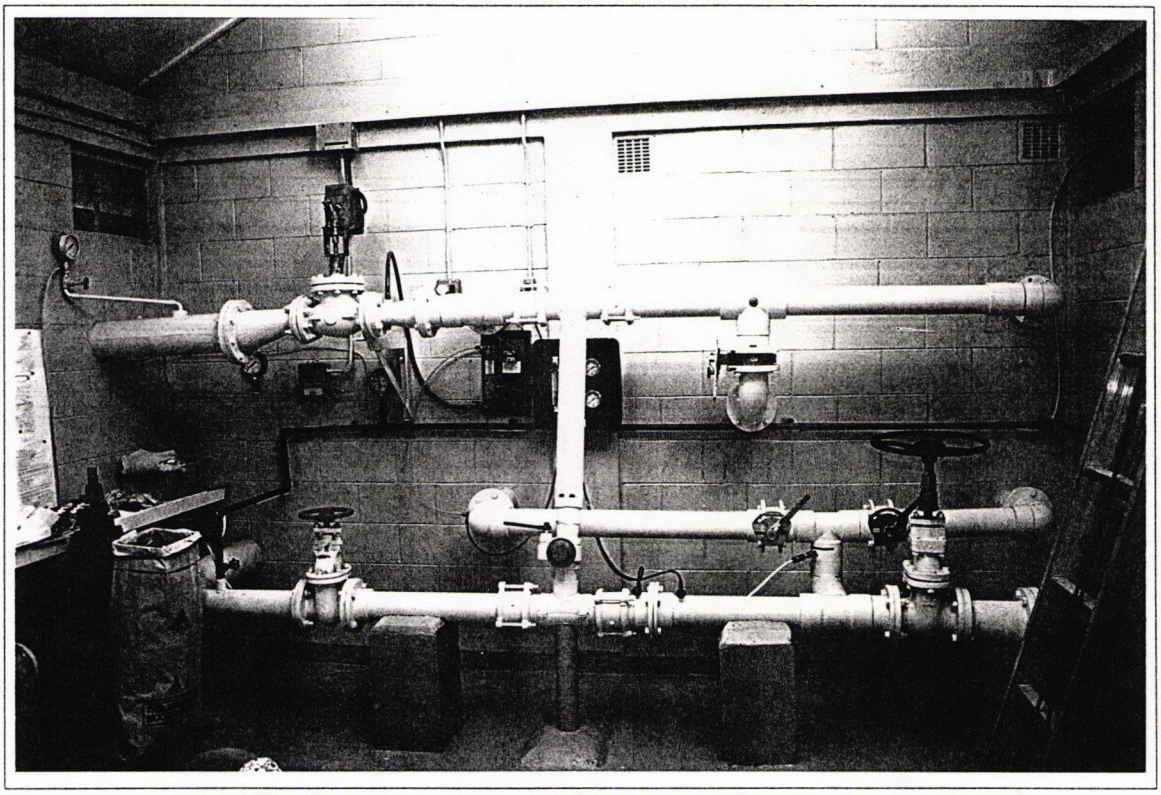


Laboratory/Office Area

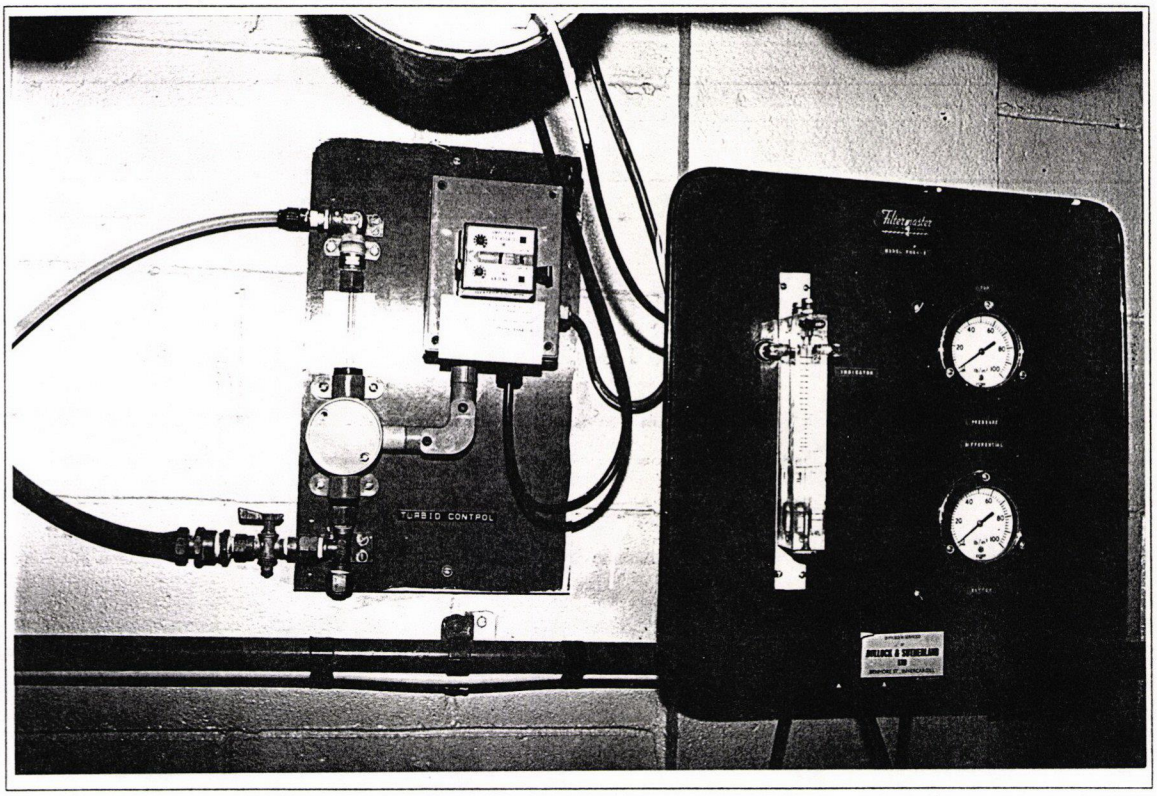


Water Sampling Taps

Tuatapere Water Treatment Plant

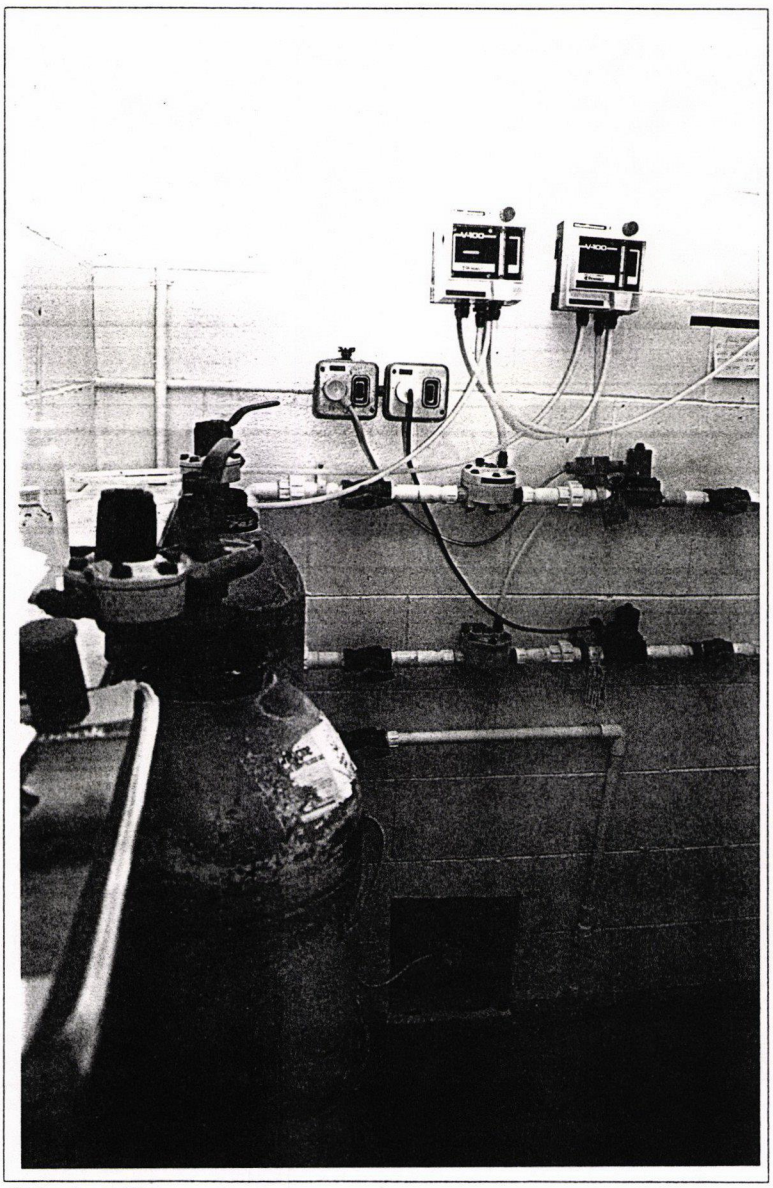


River Water Turbidity Switch and Control Valve and Filter Backwash Valves

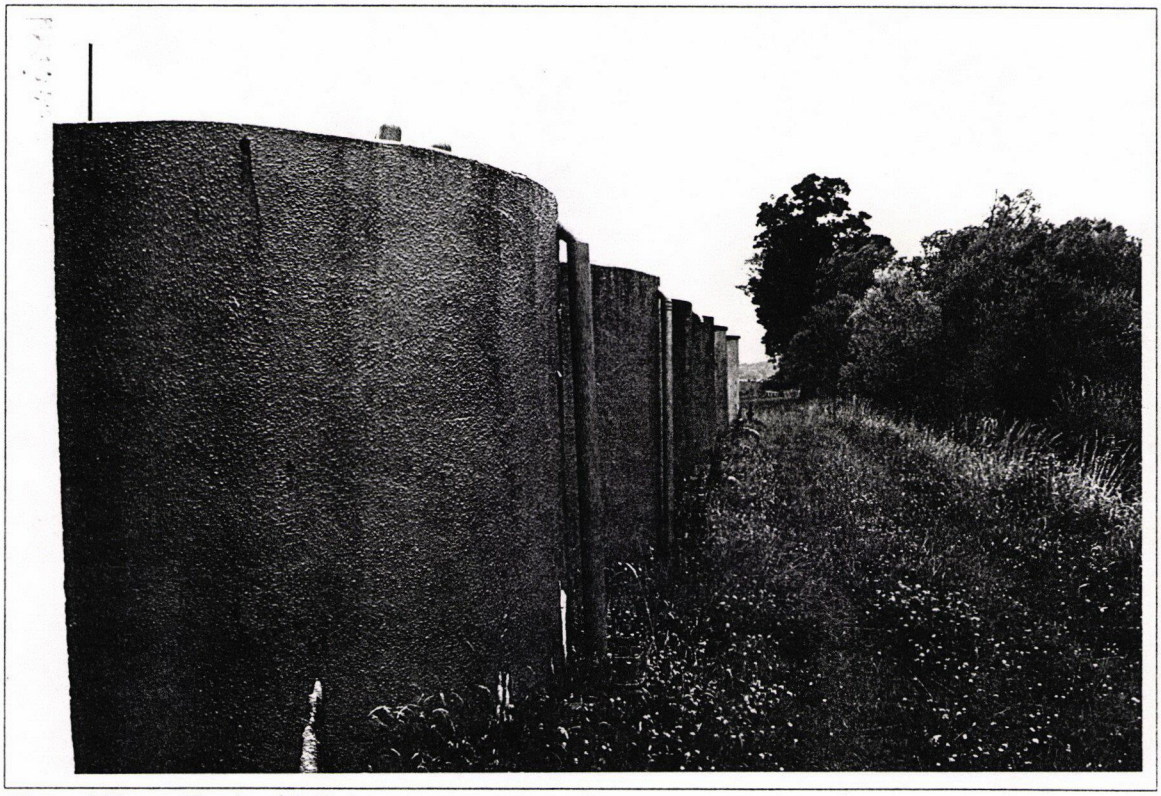


↑ Turbidity Switch

↑ Filtermaster Pressure Differential Meter for Pressure Filters



Chlorine Room



Clear Water Tanks (6 No)

Appendix B: Chemical Analysis Reports

ESR
HEALTH

Southern Health
Health Development and
Community Services Unit
P.O.Box 828
Invercargill
Attention: Cliff Dawson

Job Number: H931190
Client order: –
18 January 1994

REPORT ON THE QUALITY OF WATER

Job registered: 17 December 1993
Number of samples: 3
Reason for Sampling: Health - Resample

SAMPLE DETAILS

Lab No.	Client No.	Taken from	Sampling Location
13292	CD1114	Plant pre Tr	Tuatapere - Waiau River
13293	CD1113	Plant pre Tr	Tuatapere - Bush Well
13294	CD1115	Plant post T	Tuatapere - Treatment Plant

Lab No.	Received	Sampled on	Sampled by
13292	17 Dec 93	13 Dec 93	Cliff Dawson
13293	17 Dec 93	13 Dec 93	Cliff Dawson
13294	17 Dec 93	13 Dec 93	Cliff Dawson

ANALYTICAL RESULTS

	RAW WAIAU RIVER	RAW BUSH BORE	TREATED WAIAU RIVER		
Laboratory No.	13292	13293	13294	units	method
Client Sample No.	CD1114	CD1113	CD1115		
pH	7.6	6.3	7.4	–	phm
Acidity to pH 8.3 (as CO2)	2	40	3	g/m^3	auti
Total Alkalinity to pH4.5 as HCO3	32	51	30	g/m^3	auti
Alkalinity to pH 8.3 (as CO3)	0	0	0	g/m^3	auti
Turbidity	1.1	<0.1	0.25	NTU	tmet
Conductivity at 20°C	9	22	8	mS/m	cmet
Absorbance units (270nm, 1cm cell)	0.05	0.01	0.04	–	spec
Fluoride	<0.2	<0.2	<0.2	g/m^3	ic
Chloride	4.6	26	6.3	g/m^3	ic
Nitrate Nitrogen	0.1	5.3	0.1	g/m^3	ic
Sulphate	3.2	8.3	3.2	g/m^3	ic
Chemical Oxygen Demand (as O)	<4	<4	<4	g/m^3	sdoc
Sodium	4.6	18	4.6	g/m^3	ic
Ammoniacal Nitrogen	<0.04	<0.04	<0.04	g/m^3	ic

Institute of Environmental Science & Research Limited
Christchurch Science Centre
27 Creyke Rd, Ilam, PO Box 29-181, Christchurch, New Zealand
Telephone: (03) 351-6019, Facsimile: (03) 351-0923

A Crown Research Institute

ANALYTICAL RESULTS continued	RAW WAIAU RIVER	RAW BUSH BORE	TREATED RIVER WATER		
Laboratory No.	13292	13293	13294	units	method
Client Sample No.	CD1114	CD1113	CD1115		
Potassium	0.6	1.5	0.5	g/m^3	ic
Reactive Aluminium	0.05	<0.03	<0.03	g/m^3	ecr
Calcium	7.6	17.6	7.8	g/m^3	aa
Magnesium	1.9	5.4	1.9	g/m^3	aa
Copper	<0.02	0.12	0.02	g/m^3	aa
Zinc	0.06	0.21	<0.02	g/m^3	aa
Manganese	<0.02	<0.02	<0.02	g/m^3	aa
Iron	1.2	<0.1	0.1	g/m^3	aa
Nitrite Nitrogen	<0.005	<0.005	<0.005	g/m^3	sulpa

Analytical results relate only to the sample as received.

METHODS OF ANALYSIS

aa	Flame AAS
auti	Auto titrator
cmet	Conductivity Meter
ecr	Eriochrome Cyanine R auto
ic	Ion Chromatography
phm	pH meter
sdoc	Sulphuric/Dichromate Colorim.
spec	Spectrometer
sulpa	Sulphanilamide, auto
tmet	Turbidity Meter

Method precision is available on request.

C J Nokes
Scientist, Water Group

NON-COMPLIANCE WITH NZ DRINKING WATER GUIDELINES

Lab No.	Test		Result	NZ Guideline
13292	Turbidity	RIVER WATER	1.1 NTU	Aesthetic Highest Desirable is 1 NTU
13292	Iron	RIVER WATER	1.2 g/m^3	Aesthetic Excessive is 1.0 g/m^3
13293	pH	BUSH BORE	6.3	Aesthetic Excessive is outside 7.0 - 8.5
13293	Copper	BUSH BORE	0.12 g/m^3	Aesthetic Highest Desirable is 0.05 g/m^3

??!

NEW ZEALAND DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

DSIR Chemistry

18/5YS
V3073/1
V3073/2

13 December 1991

Southland Area Health Board
20 DEC 1991
Health Development Unit
Invercargill

Health Protection Programme
Health Development Unit SAHB
PO Box 828
INVERCARGILL

20 DEC 1991
INVERCARGILL

WATER REPORT – TUATAPERE

Sampling location : CD362 : Bush bore
CD363 : Water treatment plant
Taken : 7/10/91 Received : 11/10/91 Reported : 13/12/91

	Client's No. :	CD362	CD363
ANALYSIS		RAW BUSH BORE	TREATED BUSH BORE WATER (AT PLANT)
Units g/m^3, except pH or unless otherwise stated.			
pH		6.4 ##	7.0 #
Acidity to pH 8.3 (as CO_2)		44	11
Total Alkalinity to pH4.5 as HCO_3		58	56
Alkalinity to pH 8.3 (as CO_3)		NIL	NIL
Turbidity (NTU)		0.31	0.14
Colour (from Absorbance 270nm) TCU		1	1
Absorbance units (270nm, 1cm cell)		0.01	0.01
Chemical Oxygen Demand (as O)		LT 4	LT 4
Ammoniacal Nitrogen		LT 0.04	LT 0.04
Nitrite Nitrogen		LT 0.005	LT 0.005
Nitrate Nitrogen		4.8	4.8
Soluble Phosphate (as P)		LT 0.1	LT 0.1
Sulphate		7.8	7.8
Bromide		0.1	LT 0.1
Chloride		26	27
Fluoride		LT 0.2	LT 0.2
Calcium		18	18
Magnesium		5.1	5.3
Potassium		1.4	1.5
Sodium		18	18
Reactive Silica (as SiO_2)		19	19
Reactive Aluminium		LT 0.03	LT 0.03
Arsenic		LT 0.01	LT 0.01
Boron		LT 0.2	LT 0.2
Cadmium		LT 0.002	LT 0.002
Chromium		LT 0.03	LT 0.03
Copper		LT 0.02	0.02
Iron		LT 0.1	LT 0.1
Lead		LT 0.005	LT 0.005
Lithium		LT 0.01	LT 0.01

	RAW BUSH BORE WATER	TREATED BUSH BORE WATER (AT PLANT)
Client's No. :	CD362	CD363
ANALYSIS (continued)		
Manganese	LT 0.02	LT 0.02
Mercury (mg/m^3)	LT 0.5	LT 0.5
Nickel	LT 0.05	LT 0.05
Selenium	LT 0.005	LT 0.005
Strontium	0.09	0.10
Zinc	0.06	LT 0.02
Total Hardness (as $CaCO_3$)	65	66
Benzo[g,h,i]perylene (μg/m^3)	LT 0.46	
Benzo[a]chrysene (μg/m^3)	LT 0.16	
Benzo[a]pyrene (μg/m^3)	LT 0.06	
Dibenzo[a,h]anthracene (μg/m^3)	LT 0.06	
Benzo[k]fluoranthene (μg/m^3)	LT 0.08	
Benzo[b]fluoranthene (μg/m^3)	LT 0.1	
Chrysene (μg/m^3)	LT 2.3	
Benzo[a]anthracene (μg/m^3)	LT 1.1	
Pyrene (μg/m^3)	LT 3.6	
Fluoranthene (μg/m^3)	LT 2.6	
Conductivity at 20 deg C (mS/m)	23	23

Analytical results relate only to the sample as received.
The letters LT in the above report mean "less than".

This sample does not comply with the following N.Z. Standard Guidelines :
outside desirable range
outside maximum range

The methods of analysis and their precision are available on request.

C.J. Nokes
for Government Analyst

TELARC

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Chemistry

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13 December 1991

Health Protection Programme
Health Development Unit SAHB
PO Box 828
INVERCARGILL

WATER REPORT – TUATAPERE

Sampling location : CD364 : Public toilets, Tuatapere
Taken : 7/10/91 Received : 11/10/91 Reported : 13/12/91

Client's No. : CD364

TREATED BUSH BORE WATER (IN RETIC.)

ANALYSIS

Units g/m^3, except pH or unless otherwise stated.

pH	7.0 #
Acidity to pH 8.3 (as CO_2)	11
Total Alkalinity to pH4.5 as HCO_3	58
Alkalinity to pH 8.3 (as CO_3)	NIL
Turbidity (NTU)	0.18
Colour (from Absorbance 270nm) TCU	1
Absorbance units (270nm, 1cm cell)	0.01
Chemical Oxygen Demand (as O)	LT 4
Ammoniacal Nitrogen	LT 0.04
Nitrite Nitrogen	LT 0.005
Nitrate Nitrogen	4.7
Soluble Phosphate (as P)	LT 0.1
Sulphate	7.7
Bromide	LT 0.1
Chloride	27
Fluoride	LT 0.2
Calcium	18
Magnesium	5.1
Potassium	1.4
Sodium	18
Reactive Silica (as SiO_2)	19
Reactive Aluminium	LT 0.03
Arsenic	LT 0.01
Boron	LT 0.2
Cadmium	LT 0.002
Chromium	LT 0.03
Copper	0.05
Iron	LT 0.1
Lead	LT 0.005
Lithium	LT 0.01

Ilam Research Centre

TREATED BUSH BORE WATER (IN RETIC)

Client's No. : CD364

ANALYSIS (continued)

Manganese	LT 0.02
Mercury (mg/m^3)	LT 0.5
Nickel	LT 0.05
Selenium	LT 0.005
Strontium	0.10
Zinc	LT 0.02
Total Hardness (as $CaCO_3$)	67
Conductivity at 20 deg C (mS/m)	23

Analytical results relate only to the sample as received.
The letters LT in the above report mean "less than".

This sample does not comply with the following N.Z. Standard Guidelines :
outside desirable range

The methods of analysis and their precision are available on request.

C.J. Nokes
for Government Analyst

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14 November 1991

Health Protection Programme
Health Development Unit SAHB
PO Box 828
INVERCARGILL

WATER REPORT – TUATAPERE
Sampling location : CD362 : Bush bore
Taken : 7/10/91 Received : 11/10/91 Reported : 14/11/91

Site No. : CD362

ANALYSIS RAW BUSH BORE WATER
Units are milligrams per cubic metre (mg/m³).

Organochlorine Pesticides	ND
2,4-Dichlorophenoxyacetic acid	ND
2,4,5-Trichlorophenoxyacetic acid	ND
Polychlorinated Biphenyls	ND
Organophosphorus Pesticides	ND
Organonitrogen Pesticides	ND
Benzene	ND
Alkyl Benzenes	ND

Analytical results relate only to the sample as received.
The letters ND above mean "not detected". Detection limits are attached.

The methods of analysis and their precision are available on request.

ETJ Bathurst

E.T.J. Bathurst
for Dominion Analyst

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Gracefield Road, Lower Hutt, Private Bag, Petone, Telephone [illegible], fax [illegible]

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V3073/2
V3073/3

14 November 1991

Health Protection Programme
Health Development Unit SAHB
PO Box 828
INVERCARGILL

WATER REPORT - TUATAPERE

Sampling location : CD363 : Water treatment plant
CD364 : Public toilets, Tuatapere
Taken : 7/10/91 Received : 11/10/91 Reported : 14/11/91

ANALYSIS

Units are milligrams per cubic metre (mg/m^3).

Site No. :	CD363 TREATED BUSH BORE WATER (AT PLANT)	CD364 TREATED BUSH BORE WATER IN RETIC.
Trichloromethane		1.6
Bromodichloromethane		1.1
Chlorodibromomethane	0.5	2.5
Tribromomethane	0.6	1.8
Trichloroethene		1.2

Analytical results relate only to the sample as received.

The methods of analysis and their precision are available on request.

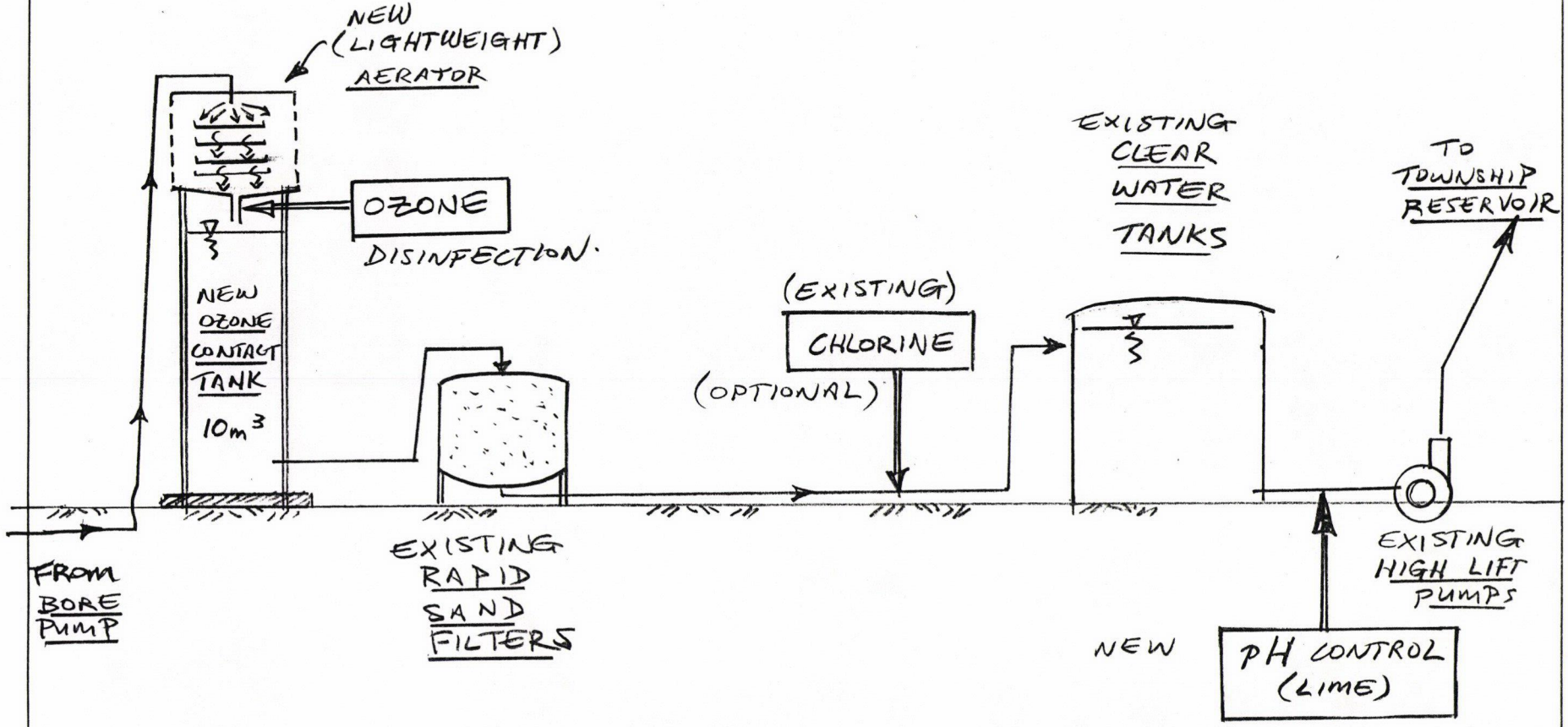
E.T.J. Bathurst
for Dominion Analyst

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Lower Hutt

Appendix C: Schematics of Treatment Options

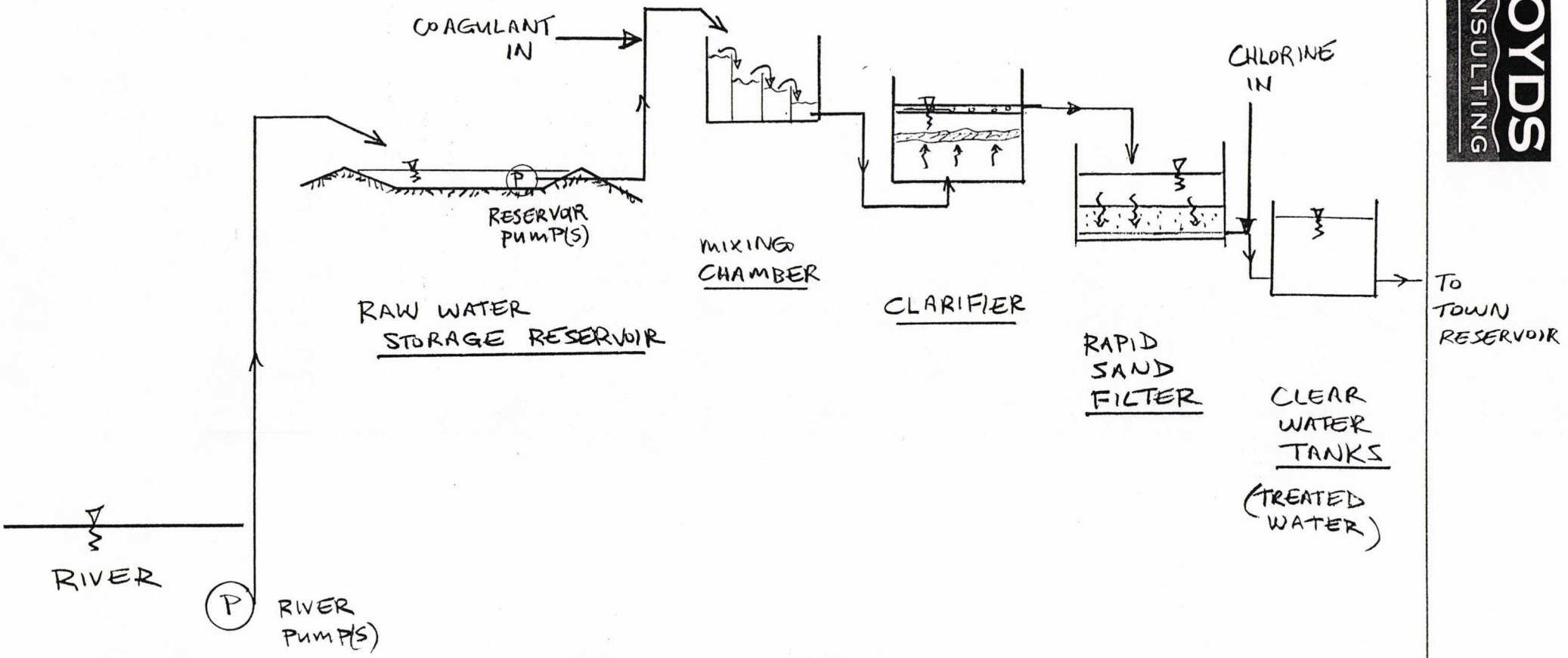


GROUND WATER TREATMENT

SCHEMATIC OF TREAMENT REQUIRED TO ACHIEVE A DEPARTMENT OF HEALTH 'B' GRADE (OR BETTER) EQUIVALENT FOR HEADWORKS (REFER DISCUSSION SECTION 3.0).

ROYDS CONSULTING
ENGINEERS & ENVIRONMENTAL CONSULTANTS

PROJECT
DESCRIPTION
COMPUTED PREPARED BY
REVIEWED CHECKED BY
REF DWGS
PROJECT NO
DATE 19
DATE 19
SHEET OF

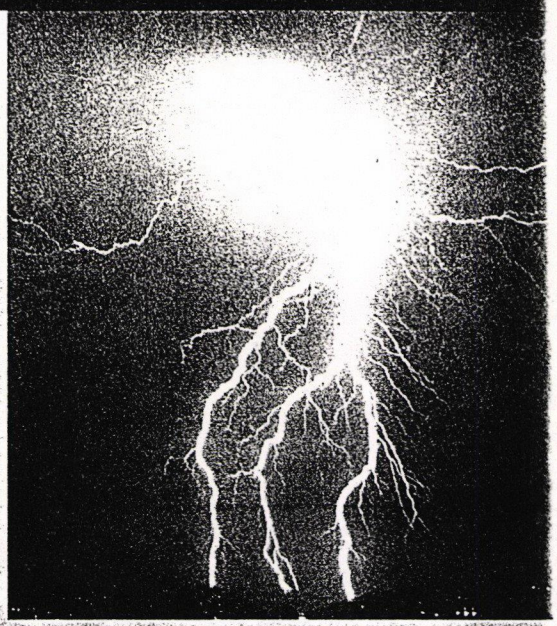


SURFACE WATER TREATMENT

SCHEMATIC OF TREATMENT REQUIRED TO ACHIEVE A DEPT OF HEALTH 'B' GRADE FOR HEADWORKS. (REFER DISCUSSION SECTION 3.0).

Appendix D: Ozone Brochure

WATER AND WASTE WATER TREATMENT



TECHELECTRIC

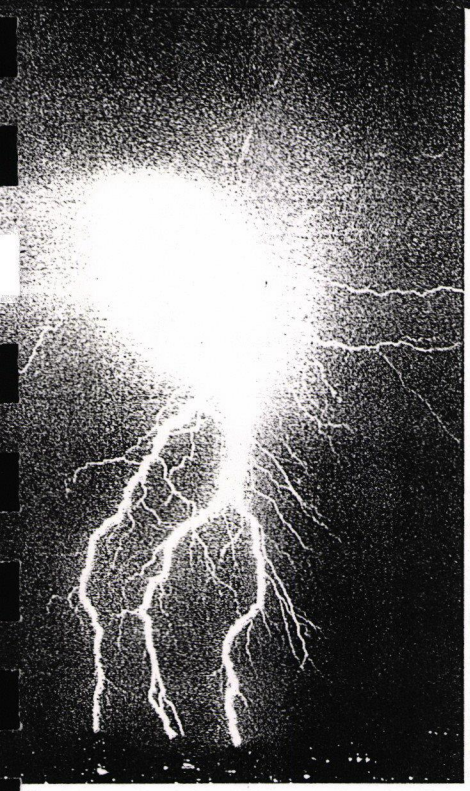
Ozone

Effective

Water

Treatment

Technology



Ozone is a form of oxygen with many commercial and industrial applications. It is a powerful oxidising agent that breaks down or modifies many gaseous and liquid contaminants.

The same conditions that create ozone during an electrical storm can be reproduced to create it in a controlled environment called an ozone generator. It forms ozone from oxygen by an electrical corona discharge.

The unstable nature of ozone means it cannot be stored. It must be generated at the point of use and applied immediately.

Uses

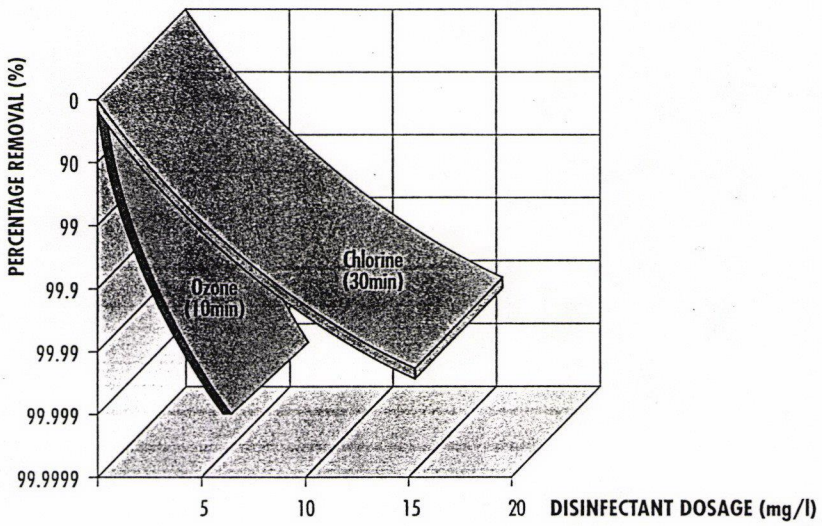
- Ozone can be used as an alternative disinfectant to chlorine in water and waste water treatment. Due to the short life of ozone in water (typically less than 20 minutes) it cannot be used as a final disinfectant when a residual action is required.
- Ozone destroys the chlorine resistant parasites giardia and cryptosporidium which can be present in untreated water supplies.
- Other applications for ozone in water and waste water treatment include:
  - removing metal ions, taste, odour and colour compounds
  - breaking down undesirable chlorinated compounds
  - an aid to flocculation.
- Ozone is also used as an oxidising agent in the chemical and pulp and paper industries.

Benefits

- Ozone is much more effective than chlorine as a disinfectant and as an oxidising agent. It also avoids the disadvantage associated with chlorine of potentially carcinogenic by-products.
- As ozone is created on site and used quickly there are no storage problems.
- Ozone can be used with gases and liquids.
- Ozone enhances flocculation so aids the removal of suspended solids.

Chlorine and ozone are often used together, with ozone as the initial disinfectant and chlorine acting as a residual treatment. Pre-treatment with ozone drastically reduces the amount of by-products formed when chlorine is added. In some instances, where the water supply does not require a residual, and the community prefer chlorine-free treatment, ozone can be used as the only disinfection treatment.

COMPARISON OF VIRUS DESTRUCTION BY OZONE AND CHLORINE



Where Is Ozone Used?

Ozone is used in many New Zealand situations including swimming pools, schools and industrial sites.

Swimming pools – The Wellington Regional Aquatic Centre and the West Auckland Swimming Centre both use ozone to disinfect water.

Cooling towers – Ozone is used to treat water in several closed cycle cooling tower applications. The cooling tower at the Haywards Hill HVDC link is pictured.

Agricultural industry – Several units have been installed on farms to oxidise metal ions and disinfect bore water supplies.

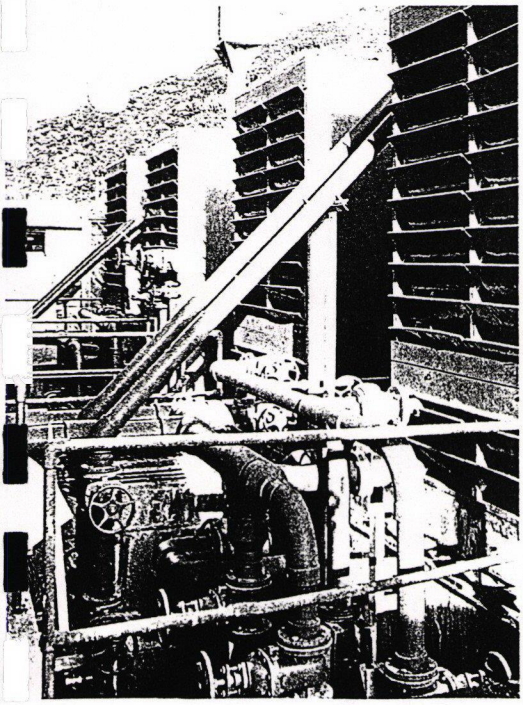
Dairy industry – A unit has been installed in a dairy factory to treat waste condensate water prior to its reuse in the factory.

Water bottling plant – Water disinfection

Schools – Several schools use ozone for drinking water disinfection.

Effluent – Ozone is used to reduce odour at effluent pumping stations.

Pulp and paper industry – Plants overseas use ozone as part of the bleaching sequence.



Glossary

Carcinogenic	–	Cancer producing.
Chlorinated	–	Containing chlorine as part of the molecule.
Corona Discharge	–	A high voltage, nearly continuous spark which excites the gas it passes through to create a glow or corona.
Cryptosporidium	–	A parasitic protozoon that causes a severe intestinal infection in humans.
Disinfection	–	The process by which disease causing micro organisms are destroyed.
Flocculation	–	The formation of large groups from fine particles.
Giardia	–	A parasitic protozoon that causes a severe intestinal infection in humans.
Protozoon	–	A microscopic animal.

Further Information

For further information on ozone treatment and the benefits it could bring to your industry contact your power company.

Appendix E: Effects of Ozone on Cryptosporidium

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Effects of Ozone, Chlorine Dioxide, Chlorine, and Monochloramine on *Cryptosporidium parvum* Oocyst Viability

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Purified *Cryptosporidium parvum* oocysts were exposed to ozone, chlorine dioxide, chlorine, and monochloramine. Excystation and mouse infectivity were comparatively evaluated to assess oocyst viability. Ozone and chlorine dioxide more effectively inactivated oocysts than chlorine and monochloramine did. Greater than 90% inactivation as measured by infectivity was achieved by treating oocysts with 1 ppm of ozone (1 mg/liter) for 5 min. Exposure to 1.3 ppm of chlorine dioxide yielded 90% inactivation after 1 h, while 80 ppm of chlorine and 80 ppm of monochloramine required approximately 90 min for 90% inactivation. The data indicate that *C. parvum* oocysts are 30 times more resistant to ozone and 14 times more resistant to chlorine dioxide than *Giardia* cysts exposed to these disinfectants under the same conditions. With the possible exception of ozone, the use of disinfectants alone should not be expected to inactivate *C. parvum* oocysts in drinking water.

Cryptosporidium parvum, a coccidian intestinal parasite, infects humans and may cause gastroenteric disease. The life cycle is completed in the terminal portions of the small intestine. An environmentally resistant oocyst stage is produced and passed into the environment with host feces. Unlike other coccidia, the *C. parvum* oocyst is fully sporulated and ready to initiate infection upon excretion (8). Numerous cases of cryptosporidial infection have been reported in otherwise healthy people since the first report of an infected three-year-old child in 1976 (19). Immunodeficient individuals, acquired immunodeficiency syndrome patients, and the immunologically naive are especially vulnerable to persistent infection (7).

Waterborne transmission of *C. parvum* recently has been documented (10, 12; B. A. Rush, P. A. Chapman, and R. W. Ineson, Letter, Lancet ii:632, 1989). In 1987, *Cryptosporidium* contamination of a chlorinated and filtered water supply led to an estimated 13,000 cases of gastroenteritis in Carrollton, Georgia (14). Outbreaks of *Cryptosporidium*-related diarrheal illness in Ayershire, Scotland, and Oxfordshire-Swindon, England, recently have been attributed to consumption of contaminated surface water containing oocysts (H. V. Smith, R. W. A. Girdwood, W. J. Patterson, R. R. Hardie, L. A. Green, C. Benton, W. Turloch, J. C. M. Sharp, and G. I. Forbes, Letter, Lancet ii:1484, 1988; P. McIntyre and J. Day, *Oxford Mail*, Oxford, England, 23 Feb. 1989).

Cryptosporidium oocysts are extremely resistant to most commonly used disinfectants. Viability was not affected by exposure to 1.05 and 3% chlorine as sodium hypochlorite for up to 18 h. Long-term exposure to 10% Formalin, 5 to 10% ammonia, and 70 to 100% bleach was deemed necessary to completely eliminate infectivity (6, 21). Thirty minutes of exposure to temperatures above 65°C or below freezing also arrests oocyst infectivity (24). Although the studies of these exposures did not specifically address the use of chlorine in drinking water treatment, it is probable that chlorine disinfection alone is not sufficient to prevent *Cryptosporidium* infection. A recent study which examined the influence of ozone and chlorine dioxide on the viability of *Cryptosporidium parvum* oocysts in drinking water showed that treating demand-free water with 1.11 ppm of ozone (1.11 mg/liter) completely eliminated infectivity in 5 min and that 15 to 30 min of exposure to 0.43 ppm of chlorine dioxide significantly reduced infectivity as measured by oocyst production by mice inoculated intragastrically with 1,000 treated oocysts (20).

Disinfection kinetics of most chemicals commonly used to ensure the safety of drinking water have been reasonably well established for bacteria, viruses, and *Giardia* spp. (16, 26). Little, however, has been reported on the effects of such chemicals on the viability of *C. parvum* oocysts. Using neonatal mouse infectivity and in vitro excystation as measures of viability, we have investigated the effects of ozone, chlorine dioxide, chlorine, and monochloramine on the survival of *C. parvum* oocysts suspended in demand-free buffer in order to estimate the disinfectant concentrations and exposure times needed for oocyst inactivation.

MATERIALS AND METHODS

Oocysts. Contaminant-free *C. parvum* oocysts were recovered from the feces of experimentally infected 2- to 5-day-old Holstein calves by employing sequential discontinuous sucrose gradients followed by isopycnic Percoll gradients (2). The recovered oocysts were suspended in 2.5% (wt/vol) aqueous potassium dichromate solution, counted with a hemacytometer by using a bright-field phase-contrast microscope, and stored at 4°C until needed (8). A volume of the dichromate solution containing 10^8 oocysts was withdrawn for each experiment. Oocysts were used from a given stock suspension as long as excystation remained above 60%. The oocysts were washed three times with 0.025 M phosphate-buffered saline, centrifuged (1,500 × *g* for 10 min), suspended in oxidant-demand-free 0.01 M phosphate-buffered water, and treated with ozone, chlorine dioxide, chlorine, or monochloramine. Oocyst viability was assessed by excystation and neonatal mouse infectivity. The fluorogenic vital dyes fluorescein diacetate and propidium iodide were also tested as indicators of oocyst viability (22). They were not deemed useful for this purpose (D. G. Korich, J. R. Mead, M. S. Madore, N. A. Sinclair, and C. R. Sterling, unpublished data).

* Corresponding author.

Mouse inoculation and infection evaluation. Litters of 3- to 6-day-old neonatal BALB/c mice maintained with their dams were infected per os with disinfectant-exposed oocysts suspended in 2 to 4 μl of NANOpure water. Litter sizes varied naturally, and no attempt was made to standardize the number of mice used in the experiments. Generally, more mice were employed for examining the effects of the more effective disinfectants such as ozone, and fewer were used for the less effective agents such as monochloramine. Washed oocysts recovered from the disinfectant reaction flasks were suspended in NANOpure water, and the oocyst concentration was determined by hemacytometer count. Suspensions containing appropriate concentrations of oocysts were prepared by dilution. A volume calculated to contain the required dose of oocysts was withdrawn and fed to the mice by means of a micropipette. A new pipette tip was used for each different dose administered, but a single pipette tip was used, without flushing, for all mice receiving the same dose. Doses were 600, 6,000, and 60,000 oocysts per neonatal mouse. These doses, which represented multiples of 10, 100, and 1,000 of a previously determined mean infectious dose (ID_{50}) of 60 oocysts, allowed estimates of oocyst inactivation levels of at least 90, 99, and 99.9%, respectively (Korich et al., unpublished data). Oocyst doses fed to the mice were adjusted by an amount based on the control percent excystation observed for each sample of oocysts in order to minimize variation. For example, the oocyst dose was increased by 20% for a control excystation of 80%. This same procedure was employed in the trials used to determine the ID_{50}. Infected animals were sacrificed 7 days postinoculation. Since the ileum is the first region of the gut to be colonized by *Cryptosporidium* spp. and always harbors the greatest number of parasitic developmental stages, approximately 3 cm of the terminal ileum was removed, fixed in 5% Formalin, embedded in paraffin, and sectioned (9). Hematoxylin- and eosin-stained paraffin sections were examined microscopically for evidence of parasites in the microvillous region of villous enterocytes (8). The tissue sections invariably exhibited an all-or-none pattern of infectivity. Tissue specimens from mice that had received at least the ID_{50} contained many *Cryptosporidium* developmental stages, while there were no parasites in specimens from mice that had received less than the ID_{50}. There was never any doubt as to how a given specimen should be scored. Specimens with parasitic stages present were scored as positive; those without were scored negative. Positive specimens always showed numerous parasitic stages (at least 50 to 60 per ×100 microscope field), while no parasites could be found on any sections taken from negative tissue samples. Mouse litters were selected randomly during the course of the experiments to serve as uninfected controls to verify that the colony remained free of incidental *C. parvum* infection. These animals were sacrificed, and the terminal ilea were prepared and examined as above.

Excystation procedure. Washed oocysts were suspended in 0.5 ml of tissue culture phosphate-buffered saline (8% NaCl, 1.15% Na_2HPO_4, 0.2% KCl, 0.2% KH_2PO_4). This suspension was mixed with an equal volume of excysting fluid (0.5% trypsin, 1.5% sodium taurocholate, in tissue culture phosphate-buffered saline) and incubated for 60 min in a 37°C water bath (11). Excysted sporozoites, intact oocysts, and oocyst shells in the suspension were counted under ×400 magnification by using a hemacytometer and phase-contrast microscopy. Microscopic counts performed after in vitro excystation of untreated oocysts often yielded a variable number of sporozoites per shell. This variation appeared to depend on the age (storage time) of the oocyst stock, duration of incubation, composition of the excystation medium, and activity of the trypsin used in the excystation procedure. Therefore, a control excystation with complete counts, with untreated oocysts, was performed in conjunction with each series of disinfectant treatments in order to establish a baseline for calculating and correcting the percent excystation of the treated oocysts. Excystation levels were determined according to a formula adapted from one used for computing excystation of *Giardia* spp. (5): percent excysted = $100 \times S/(S + I)$, and $S = S_1/S_2$. In these equations, S_1 is the number of excysted sporozoites in the treated sample, S_2 is the number of excysted sporozoites per shell in the control, and I is the number of intact oocysts in the treated sample. Percent excystation of the treated oocysts was corrected against the control baseline percent excystation as follows (17): corrected percent excysted = $E \times (100/C)$, where E is the percent excystation in the treated sample and C is the mean percent excystation in the control.

Ozone treatment of oocysts. Ozone was generated with a P-series model P-20 ozonator (Ozone Technology, Inc., Tyler, Tex.). Ozone-demand-free water was prepared by ozonating NANOpure water for 1 h at 2 mg/liter. The water was then boiled for 1 h to remove the ozone and stored in sealed ozone-demand-free glass containers until needed. The glassware was soaked in water containing 2 mg of ozone per liter for 1 h and then dried at 110°C for 5 h to satisfy the ozone demand (25). Experiments were conducted with constant stirring at 25°C in borosilicate glass reactors containing 350 ml of ozone-demand-free water buffered to pH 7 with 0.01 M phosphate and seeded with 10^8 oocysts (2.8×10^5 oocysts per ml). Ozone was bubbled continuously into the water at a rate predetermined to achieve and maintain the desired equilibrium ozone concentration. Washed oocysts suspended in 1 ml of ozone-demand-free buffered water were added after equilibrium was achieved as indicated by no change in ozone concentration during three successive measurements over a 15-min period. Ozone concentration was measured spectrophotometrically by the decolorization of indigo trisulfonate (3). Samples of 50 ml each were withdrawn at 0, 1, 3, and 5 min into centrifuge tubes containing 1 ml of 10% (wt/vol) sodium thiosulfate. The oocysts were then washed and prepared for either excystation or mouse inoculation as described above. At first, a duplicate reactor was simultaneously operated with air rather than ozone. This was abandoned during subsequent experiments, however, when it was determined that there was no difference between untreated control and control reactor excystation rates.

Chlorine treatment of oocysts. Chlorine solutions (pH 7) were prepared with reagent grade sodium hypochlorite in pH 7 demand-free 0.01 M phosphate buffer. The concentration of free chlorine in a freshly prepared standard solution was accurately measured with a Fisher amperometric titrimeter. Dilutions of this standard were used to construct a standard curve for measuring the concentrations of working solutions by the Hellige DPD (*N*, *N*-diethyl-*p*-phenylenediamine) method with a DU-6 spectrophotometer (Beckman Instruments, Inc.) (15). Chlorine-demand-free water was prepared by adding 3 ml of commercial bleach containing approximately 5% active chlorine to 6 liters of NANOpure water in a closed container. The water was held at least 24 h at room temperature (25°C) and then placed in direct sunlight for 6 h. Free chlorine, as determined by the Hellige DPD method, was not detected in chlorine-demand-free water prepared in this manner. All glassware was soaked for 24 h in deionized

water containing 50 mg of free chlorine per liter and was thoroughly rinsed with chlorine-demand-free water prior to use (13). Glass flasks (250 ml) containing 250 ml of chlorine solution were inoculated with 10^8 washed oocysts suspended in 1 ml of demand-free 0.01 M phosphate buffer (4×10^5 oocysts per ml) and stirred constantly. Five 40-ml samples were withdrawn at timed intervals into centrifuge tubes containing 2 ml of 10% $Na_2S_2O_3$. The oocysts were then processed as described above for excystation or inoculation.

Chlorine dioxide treatment of oocysts. A stock solution of pure chlorine dioxide was prepared by reacting 20 ml of 4 N sulfuric acid with a solution containing 10 g of sodium chlorite in 750 ml of distilled water. The gases produced in the reaction were scavenged with a stream of clean compressed air, passed through a saturated solution of $NaClO_2$, and dissolved in 1 liter of chlorine-demand-free water. Chlorine dioxide concentration in the stock solution was measured by titrating iodine released by the ClO_2 from an acidic solution of potassium iodide against a 0.005 N standard solution of $Na_2S_2O_3$ (1). Working solutions of chlorine dioxide were prepared by diluting samples of the stock solution with demand-free phosphate buffer (pH 7). The ClO_2 concentrations in the working solutions were determined by spectrophotometric measurements by the Hellige DPD method in the presence of glycine against a standard curve obtained by appropriate dilutions of the stock solution (1, 15). Measurements made by this method were confirmed by the decolorization of acid chrome violet K (18). The two methods were found to be comparable for measuring pure solutions of chlorine dioxide; but the acid chrome violet K method was easier to use and produced more consistent results than the DPD method did. The experimental design was similar to that described for chlorine with the exception that the reactor vessels were stirred only during sample withdrawal in order to minimize the loss of ClO_2 from the solution.

Monochloramine treatment of oocysts. Fresh stock solutions of monochloramine were prepared for each experiment by mixing equal volumes of a chlorine solution (pH 9 to 10) containing the equivalent of 2 g of HOCl per liter and an $(NH_4)_2SO_4$ solution (pH 9 to 10) containing 31 g/liter (4). Monochloramine concentrations were determined by the Hellige DPD method with the standard curve derived for chlorine. The experimental design was identical to that described for chlorine.

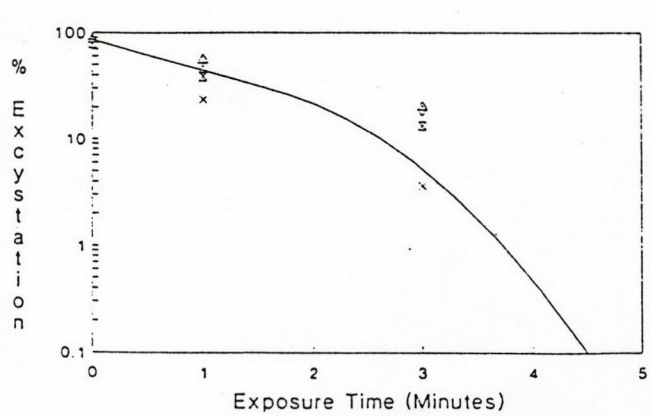


FIG. 1. Decline in mean percent excystation of *Cryptosporidium* oocysts exposed to 1 ppm of ozone at 25°C. Symbols show results of independent trials.

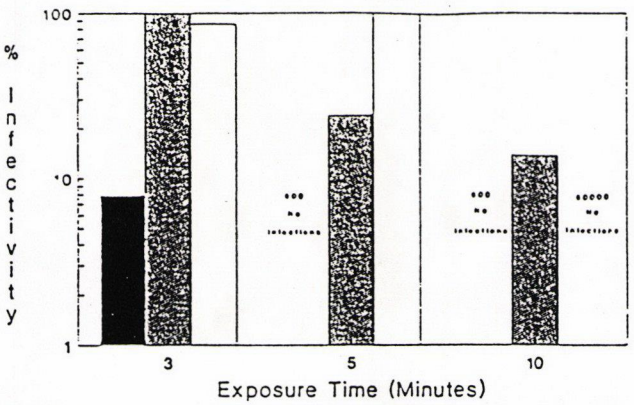


FIG. 2. Loss of infectivity in neonatal mice for *Cryptosporidium* oocysts exposed to 1 ppm of ozone at 25°C. Doses: ■, 600 oocysts; ▨, 6,000 oocysts; □, 60,000 oocysts.

RESULTS

Ozone. Excystation of oocysts exposed to 1 ppm of ozone decreased from 84% upon initial exposure to 0% after 5 min (Fig. 1). The rate of decrease was highest for the first minute of exposure and declined over the next 4 min even though ozone was maintained at a constant 1 ppm. Results of mouse infectivity were similar (Fig. 2). For example, 5 of 21 mice (24%) and 5 of 36 mice (14%) became infected when dosed with 6,000 oocysts exposed to ozone for 5 and 10 min, respectively. All 11 mice dosed with 60,000 oocysts exposed to ozone for 5 min became infected, while none of 21 mice receiving the same number of oocysts exposed to ozone for 10 min became infected. Thus, at least 90% of the oocysts were inactivated when exposed for 3 min, between 90 and 99% were inactivated when exposed for 5 min, and between 99 and 99.9% were inactivated when exposed for 10 min. Based on these data, the approximate $C \cdot t'$ (concentration times time [in minutes]) value for 99% inactivation would be between 5 and 10.

Chlorine dioxide. Excystation of oocysts exposed to 1.3 ppm of chlorine dioxide decreased from 87% upon initial exposure to 5% after 1 h (Fig. 3). Mouse infectivity showed a similar decline (Fig. 4). Two of nine mice (22%) and none of eight mice became infected when dosed with 600 oocysts exposed for 45 and 60 min, respectively, while eight of ten mice (80%) became infected after inoculation with 6,000

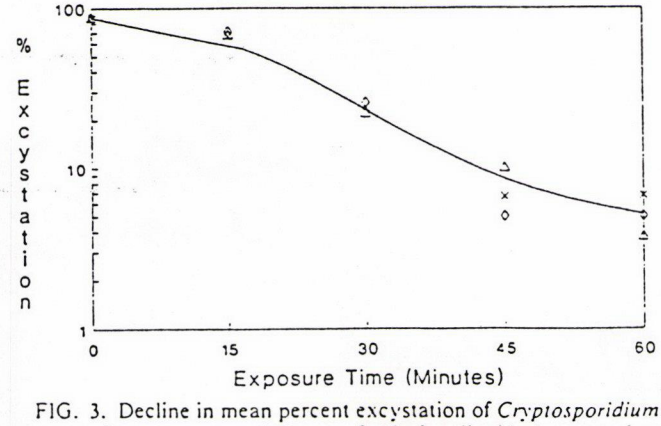


FIG. 3. Decline in mean percent excystation of *Cryptosporidium* oocysts after exposure to 1.3 ppm of chlorine dioxide (measured as parts per million of ClO_2) at 25°C. Symbols show results of independent trials.

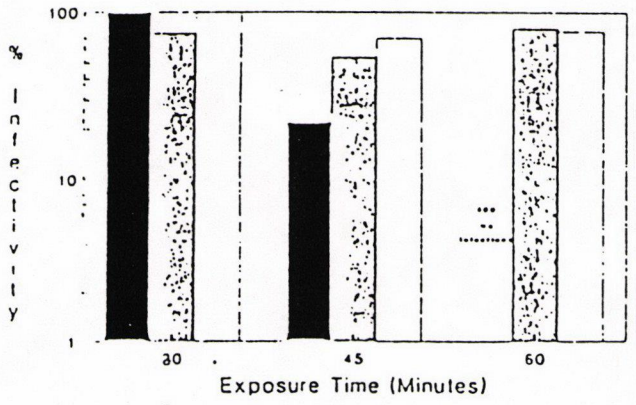


FIG. 4. Infectivity of *Cryptosporidium* oocysts exposed to 1.3 ppm of chlorine dioxide. Doses: ■, 600 oocysts; □, 6,000 oocysts; □, 60,000 oocysts.

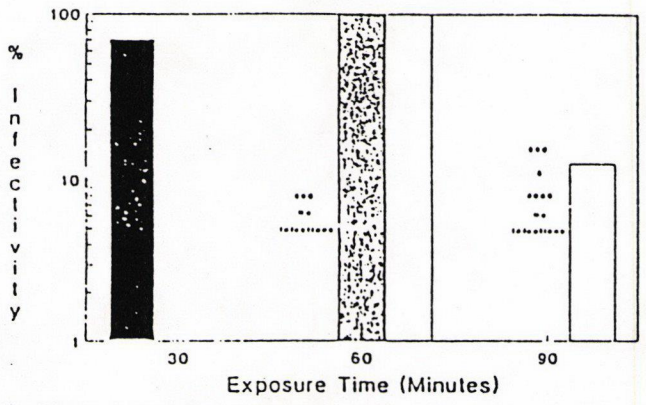


FIG. 6. Infectivity of *Cryptosporidium* oocysts exposed to 80 ppm of chlorine at 25°C. Doses: ■, 600 oocysts; □, 6,000 oocysts; □, 60,000 oocysts.

oocysts exposed for 1 h. Thus, approximately 90% of these oocysts were inactivated after 1 h of exposure. A $C \cdot t'$ value of 78 was calculated based on these data. Excystation of oocysts exposed to 0.6 ppm of chlorine dioxide decreased by only 40% after 1 h of exposure. Measurements showed a rapid decrease in chlorine dioxide concentration after the reaction flask was inoculated with 10^4 oocysts. The ClO_2 concentration dropped from 0.6 ppm to 0.2 ppm after 5 min of exposure. Losses as high as 0.9 ppm occurred during the 1 h that oocysts were exposed to 1.3 ppm of ClO_2.

Chlorine. Excystation of oocysts exposed to 80 ppm of free chlorine decreased from 80% upon initial exposure to 0% after 2 h (Fig. 5). After 1 h, only 20% of oocysts had excysted. Mouse infectivity data were similar (Fig. 6). Five of seven mice (71%) became infected at the 600-oocyst dose level after 30 min of exposure. All mice inoculated with 6,000 or 60,000 oocysts which had been exposed to chlorine for 60 min became infected. Only one of eight mice (12.5%) inoculated with 60,000 oocysts exposed to chlorine for 90 min became infected. There were no infections noted in 22 mice inoculated after 2 h of chlorine exposure. Inactivation after 90 min of chlorine exposure was at least 99%. Based upon these data, a $C \cdot t'$ value of 7,200 was calculated.

Monochloramine. The decline in excystation for oocysts exposed to 80 ppm of monochloramine was similar to that observed with free chlorine (Fig. 7). Excystation decreased from 91% upon initial exposure to 2% after 2 h. Only 10% of the oocysts exposed to 80 ppm of monochloramine excysted after 1 h. Mouse infectivity also showed a similar decline (Fig. 8). Five of eleven (45%), one of ten (10%), and zero of three (0%) mice became infected when dosed with 600 oocysts exposed to monochloramine for 30, 60, and 90 min, respectively. High infection rates were observed in mice inoculated with 6,000 and 60,000 oocysts exposed to monochloramine over the same time periods. Oocyst viability decreased at least 90% over 90 min of monochloramine exposure. A $C \cdot t'$ value of 7,200 was calculated from these data.

DISCUSSION

Measurements of oocyst viability, determined by both excystation and mouse infectivity, indicate that ozone and chlorine dioxide are many times more effective than free chlorine and monochloramine for inactivating *C. parvum* oocysts. Similar results have been obtained for oocyst inactivation by using chlorine with excystation as the sole measure of viability (23). Oocysts treated with 2.25 ppm of ozone for 8 min showed a 99% reduction in oocyst output in mice initially infected with 10^5 oocysts (20). This result, based on ozone levels achieved at the beginning of the experiment but not maintained, may be comparable to our finding that constant exposure of oocysts to 1 ppm of ozone for 10 min reduced infectivity by approximately the same

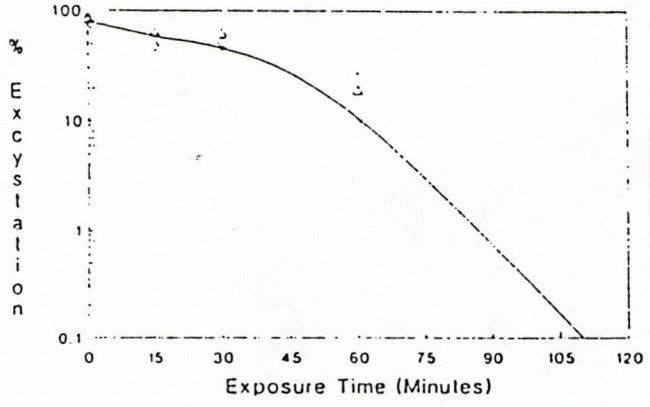


FIG. 5. Decline in mean percent excystation of *Cryptosporidium* oocysts after exposure to 80 ppm of chlorine (measured as parts per million of Cl_2) at 25°C. Symbols show results of independent trials.

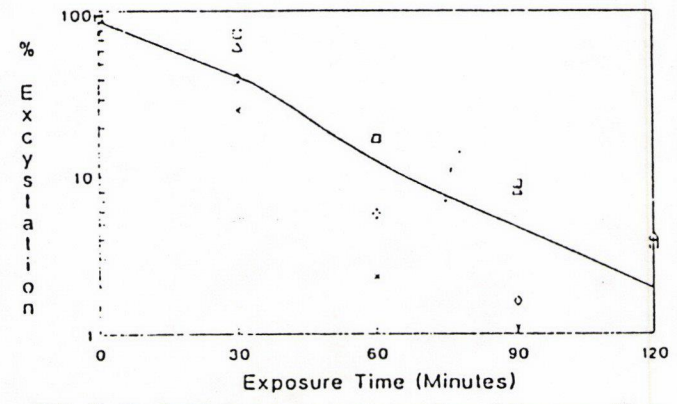


FIG. 7. Decline in mean percent excystation of *Cryptosporidium* oocysts exposed to 80 ppm of monochloramine at 25°C. Symbols show results of independent trials.

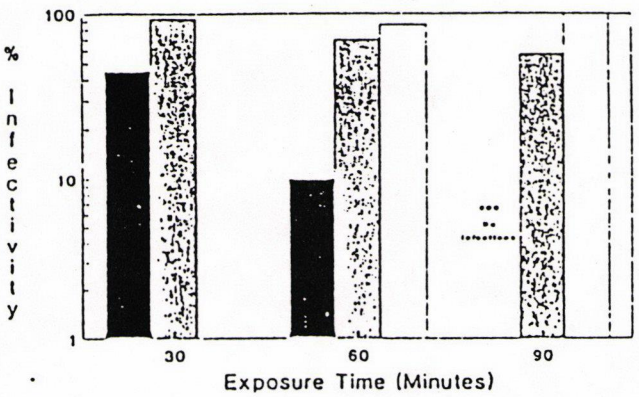


FIG. 8. Infectivity of *Cryptosporidium* oocysts exposed to 80 ppm of monochloramine at 25°C. Doses: ■, 600 oocysts; □, 6,000 oocysts; □, 60,000 oocysts.

amount. Data reflecting oocyst inactivation by chlorine dioxide, however, do not agree. Mice infected with oocysts exposed to 0.43 ppm of chlorine dioxide for 30 min showed a 94.3% reduction in oocyst output in another study, while we were only able to observe 90% oocyst inactivation as measured by mouse infectivity after exposure to 1.3 ppm for 1 h, i.e., roughly the same level of inactivation by three times the concentration for twice as long an exposure time (20).

Any test for disinfectant effectiveness must ultimately depend upon some measure of oocyst viability. Unfortunately, a quick, easy, reliable, and completely reproducible test is not yet available. We assessed inactivation by uptake of the vital dyes fluorescein diacetate and propidium iodide, excystation, and mouse infectivity. The vital dyes proved to be totally unreliable for predicting *C. parvum* oocyst viability even though they have been used successfully for determining *Giardia* viability (22; D. G. Korich, J. R. Mead, M. S. Madore, C. R. Sterling and N. A. Sinclair, poster session, American Society for Microbiology annual meeting, 1989). Furthermore, we observed a large apparent increase in excystation after there should have been none. These anomalous observations proved to be an artifact of the counting procedure. Oocysts exposed to high disinfectant concentrations or for long times at lower concentrations appeared to have excysted, i.e., were empty, when in fact their contents had been destroyed by the disinfectant. Sporozoites were conspicuously absent from such suspensions. To avoid subsequent errors, we counted and factored in the number of sporozoites produced. This revised procedure gave reasonably good agreement between excystation and infectivity as indicators of viability. Even so, viability estimates based on excystation alone should be regarded with caution, since the sensitivity of the estimate depends not only on the accuracy of the counting procedure but also on the age (storage time) of the oocysts. When excystation is compared with infectivity as an indicator of oocyst inactivation after treatment with 1 ppm of ozone, note that excystation (Fig. 1) showed 100% inactivation after 5 min of exposure while infectivity (Fig. 2) showed at least 99 to 99.9% inactivation after 10 min. Infection occurred with oocysts treated with ozone for 5 min even though excystation indicated otherwise. Similar comparisons may be made with the other disinfectant treatments used. Oocysts stored in dichromate solution longer than 6 months cannot reliably be used for disinfection studies because low levels of excystation (below 60%) are frequently observed. Mouse infectivity was the most sensitive indicator of oocyst inactivation under all the experimental conditions tested. Since some 20% of the oocysts produced during *C. parvum* infections are autoinfective, only a small dose of oocysts is required to produce a conspicuous infection (9). Microscopic examination of terminal ileum tissues, therefore, provides unequivocal evidence of infection.

The strategy for estimating disinfectant $C \cdot t'$ value was based on our determination that the ID_{50} for neonatal BALB/c mice was approximately 60 oocysts. Inability to produce infection with an incremental $\log_{10}$-increasing dose of the ID_{50} implied that level of oocyst inactivation. An absence of mouse infection with a dose of 600 oocysts equates to at least a 90% level of inactivation, no infection with 6,000 oocysts equates to a 99% level, and no infection with 60,000 oocysts equates to at least 99.9% inactivation. The $C \cdot t'$ values expressed herein must be regarded as estimates because they are based on only a single disinfectant concentration. A more accurate treatment, strictly applying the Watson equation ($k = C^n t$), requires using the results of a number of experiments with different disinfectant concentrations to find the value of n. When plotted on double logarithmic paper, the concentrations (C) and the times (t) needed for a given inactivation level result in a straight line with slope n (16). By assuming that $n = 1$, however, it is possible to make useful comparisons between these $C \cdot t'$ values and those for *Giardia* spp. Such comparisons show that *C. parvum* is many times more resistant than *Giardia* spp. are to these commonly used drinking water disinfectants. The $C \cdot t'$ value of 5 to 10 obtained for 99% ozone inactivation of *C. parvum*, for example, is at least 30 times greater than the $C \cdot t'$ of 0.18 ($n = 1.1$) required to achieve the same inactivation level of *Giardia lamblia* (26), while the $C \cdot t'$ value of 78 obtained for 90% inactivation of *C. parvum* oocysts by ClO_2 is at least 14 times higher than the 5.3 ($n = 1.37$) reported for 99% inactivation of *Giardia muris* (J. G. Leahy, M.S. thesis, Ohio State University, Columbus, 1985). Further infectivity studies need to be performed at different disinfectant concentrations in order to confirm the $C \cdot t'$ values. It is evident, however, that with the possible exception of ozone, the use of disinfectants alone cannot be expected to inactivate *C. parvum* oocysts.

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Appendix F: Ozone Treatment

Royds Consulting
Pilot Plant Trial Results

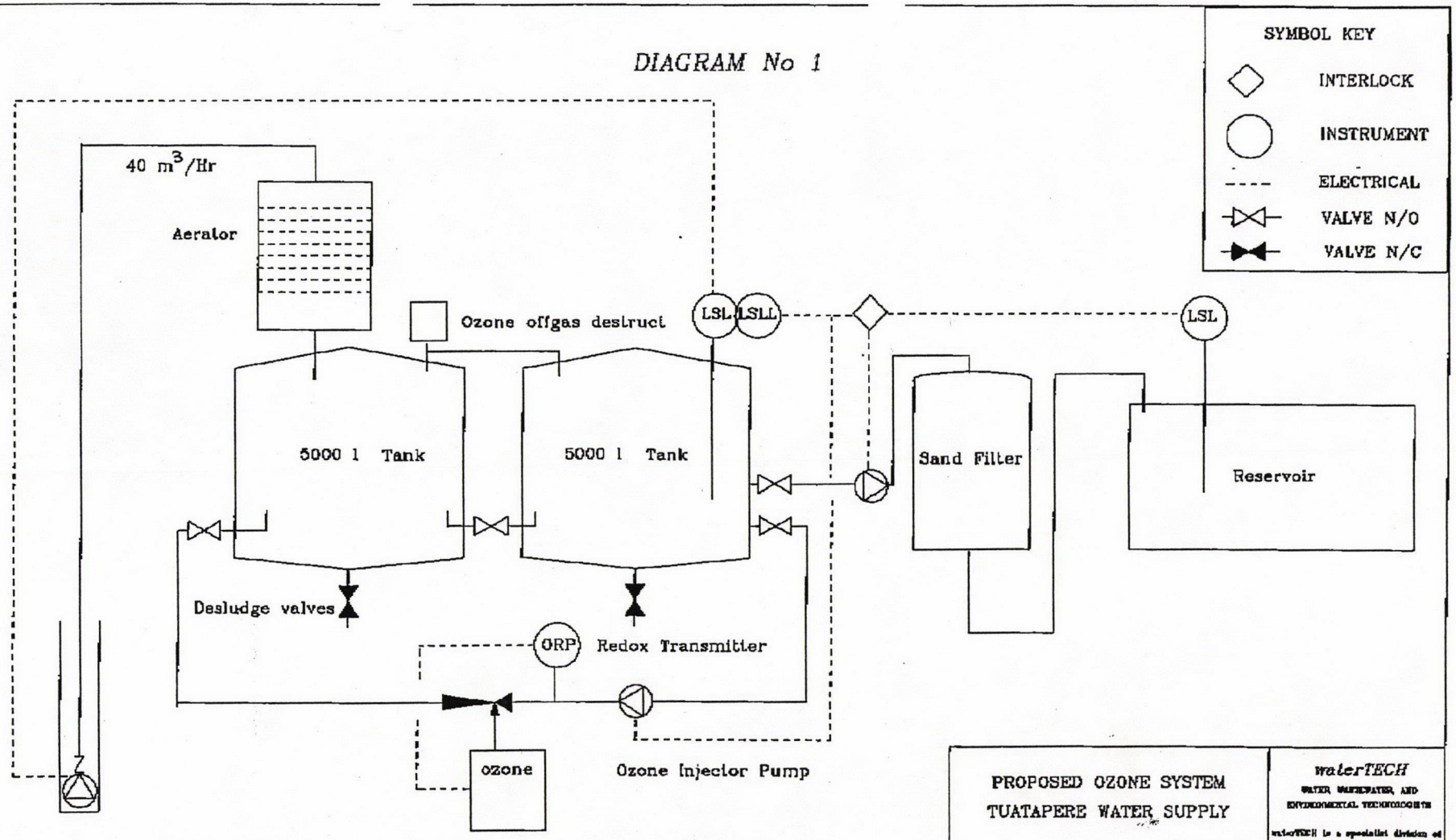
	Untreated	Ozonated	Post Filter
Absorbtion at 270_{nm}	0.043	0.010	0.006
Absorbtion at 254_{nm}	0.051	0.007	0.005

	Raw	Ozonated
Turbidity NTU	3.0	0.3

Taste and odour are subjective tests and therefore cannot be quantified. The visual appearance of the raw water which had a distinct yellow colour was also visually improved with ozonation.

Appendix G: Ozone Treatment Equipment Layout

DIAGRAM No 1



PROPOSED OZONE SYSTEM
TUATAPERE WATER SUPPLY

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