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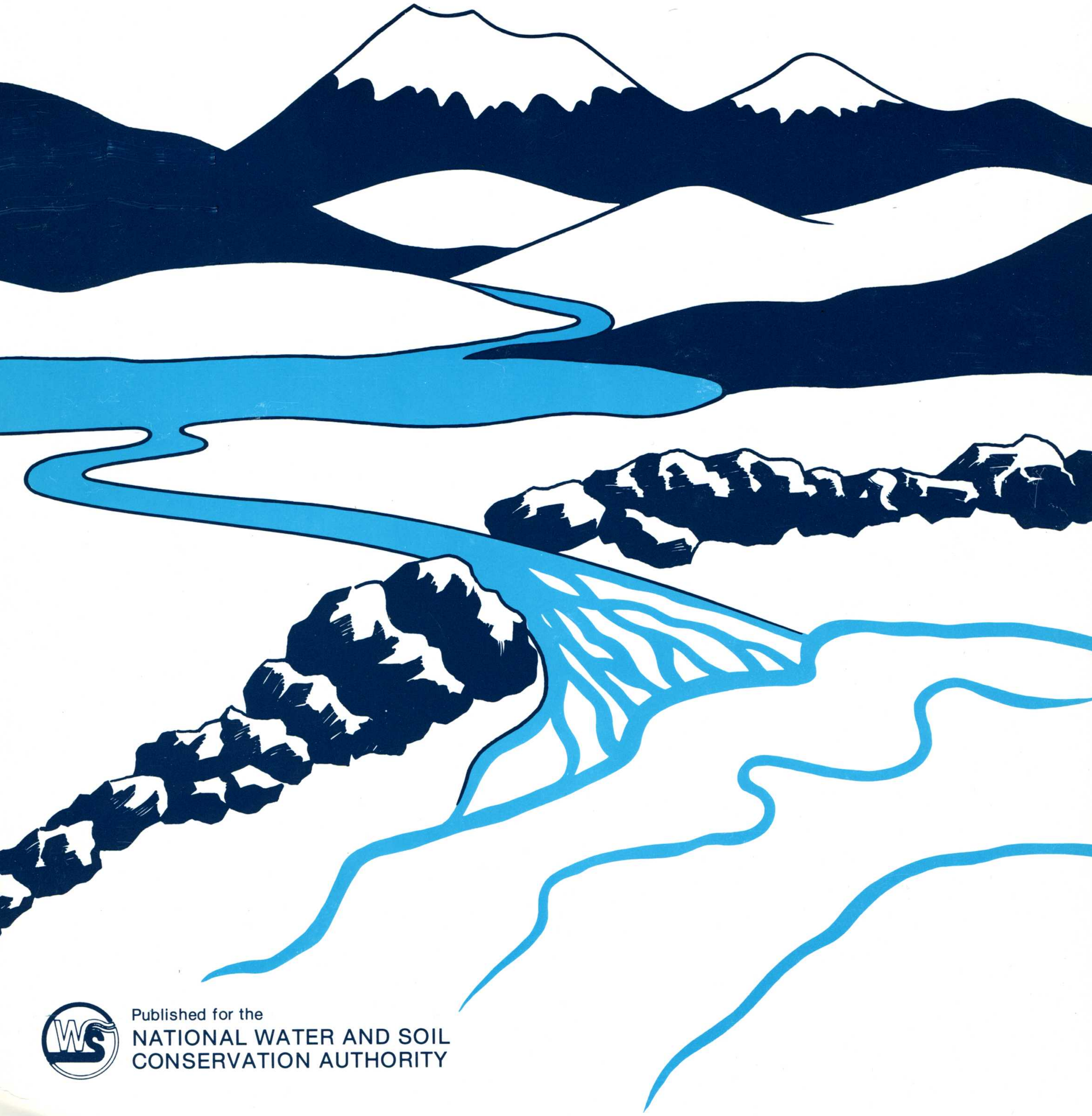

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WATER QUALITY OF THE LOWER CLUTHA RIVER

AN ASSESSMENT OF THE POTENTIAL WATER QUALITY IMPACT OF PROPOSED HYDRO-ELECTRIC DEVELOPMENT

by

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SUMMARY

A survey has been carried out in order to characterise the existing water quality of the Lower Clutha River in the reach where hydro-electric development is proposed between Lake Roxburgh and Tuapeka Mouth. Some tributaries have also been sampled. (The survey emphasises physical and chemical aspects of water quality but also includes consideration of the microbiota but not higher organisms.) The results of this survey together with data reported earlier on the water quality of the Upper Clutha River and Lake Roxburgh show that the Clutha River is a very high quality water resource in terms of most existing and likely future uses. The only feature of the water quality likely to impair some water uses is a moderately high turbidity (low clarity) associated with fine-grained suspended sediment. The tributaries have reasonably high quality water and are too small to have any discernable effect on the quality of the Lower Clutha River.

Hydro-electric development of the Lower Clutha River is not expected to have any significant water quality impact; indeed water quality changes in respect of most variables may not even be detectable given background variability. There seems to be little chance of increased algal biomass in the waters of the Lower Clutha River unless there are marked changes in land use patterns in the catchment. Only suspended sediment content and associated clarity could be significantly affected by development. There is a possibility that the Clutha River will in future be more frequently turbid than at present because of the increased residence time of murky flood waters in a chain of hydro-electric reservoirs. During the construction phase storm runoff and discharge of dewatering effluents high in suspended sediment may affect the river. Some suggestions to minimise impact of these suspended sediments on water clarity are made.

INTRODUCTION

The proposed Lower Clutha River hydro-electric power development will result in a change from a flowing river environment to a lake environment in all or most of the reach from Lake Roxburgh to Tuapeka Mouth. The purpose of this report is to examine likely impacts of the proposed developments on water quality (i.e. composition of the water as it affects present and future uses of the river).

The impact of hydroelectric development on the Lower Clutha water quality is likely to be similar for, say, a high dam at Tuapeka Mouth or a series of low dams from Roxburgh to Tuapeka Mouth. Thus the present report does not compare the relative impact of various engineering options outlined in MWD (1984). In any case assessment of likely water quality impacts can only be made in a general way because hydro-electric development of the Upper Clutha River is proceeding at the time of writing and this may have some (probably small) impact on the water quality of the Lower Clutha (Biggs and McBride, 1981).

The specific objectives of the study of water quality reported herein (part of the overall aquatic resource assessment) were as follows :

1 Describe the quality of the Lower Clutha water resource.

2 Assess the value of the resource regionally and nationally in water quality terms.

3 Predict changes in water quality likely to result from hydro-electric development.

4 Indicate consequences of changes in quality to man's activities and river biota.

5 Indicate potential for water quality manipulation to enhance floral and faunal resources.

This report will consider objectives 1 and 2 under the heading "Existing Water Quality" and objectives 3, 4 and 5 under the heading "Water Quality Impacts of Hydro-electric Development".

EXISTING WATER QUALITY OF THE LOWER CLUTHA RIVER AND ASSOCIATED TRIBUTARIES

BACKGROUND

The source of the Lower Clutha River is Lake Roxburgh, an impoundment created by construction of Roxburgh Dam some 129 km from the river mouth (Fig. 1). None of the tributaries in the reach from Roxburgh Dam to the Pomohaka River is sizeable compared with the Clutha River. (Mean annual discharge of the Clutha at Roxburgh Hydro is 490 $m^3.s^{-1}$ and tributaries from Roxburgh Hydro to Tuapeka mouth contribute only about 2% more water). Thus the water quality of the Lower Clutha is largely determined by the water quality in Lake Roxburgh. This water is derived mainly from the large oligotrophic glacial lakes: Wanaka, Hawea and Wakatipu via the Upper Clutha River system.

Biggs and McBride (1981) have summarised information on the Upper Clutha River including Lake Roxburgh and have emphasised the generally high quality of this water resource. In particular, nitrogen and phosphorus concentrations are much lower than those values likely to indicate eutrophic conditions in lake waters (Vollenweider, 1968) and phytoplankton biomass was found to be very low. Biggs and McBride (1981) have suggested that Clutha water as far downstream as Lake Roxburgh is phosphorus-limited for plant growth on the basis of N:P ratios.

Some information is available from other sources on the water quality of Lake Roxburgh. Winter (1964) reported that Secchi depth in the lake varied from 0.3-3 m and sometimes changed rapidly across visible fronts in the lake surface water after flood events. Jowett and Hicks (1981) reported studies on the suspended sediment budget of Lake Roxburgh. On average 80% of the suspended sediment entering the lake was retained over a 21 month period but retention was lower during a major flood event (Jowett, 1979).

The "baseline" water quality of the Lower Clutha River is described by the Otago Catchment Board (1981). This report suggests high quality water in almost all respects (near-saturation dissolved oxygen, very low biochemical oxygen demand and low nutrient levels). Faecal coliform concentrations measured on a few occasions in the Lower Clutha River were all low (less than 200 cells/100 ml) except in the very lowest reaches, downstream of the areas of concern with regard to hydro-electric development. Two sets of results on the quality of the Tuapeka River (Fig. 1) demonstrate fairly good quality water.

SURVEY DESIGN AND METHODS

The present study was designed to assess water quality impacts of hydro-electric development in the Lower Clutha River between Roxburgh Dam and Tuapeka Mouth. For this purpose a special sampling programme was carried out. The two main concerns relating to water quality changes on hydro-electric development of the Lower Clutha River are :

1 eutrophication (nutrient enrichment), and

2 problems with suspended sediment and associated turbidity.

Subsidiary concerns are with corrosiveness of water towards engineering structures and impacts of irrigation return waters. Sampling and analysis was directed to addressing these concerns and took account of existing information.

Sampling was carried out mainly by the staff of the Ministry of Works and Development Hydrological Field team based at Alexandra Residency, Dunedin Works District. A reconnaissance was carried out by jet boat on 17 March 1982 and a more compehensive survey was conducted by jet boat in 25 November 1982. These surveys also included sampling of tributaries as well as the main stem river. Thereafter 7 sampling surveys at river sites only were carried out bimonthly until January 1984. Secchi depths were observed monthly at a jetty near Roxburgh Dam. A special survey of tributaries for pH, turbidity, conductivity, dissolved oxygen and temperature was made by the Alexandra Hydrological Field Party team at the request of the Ministry of Agriculture and Fisheries fisheries consultants on 21 November 1983.

Samples were taken by bucket below the tailrace at Roxburgh Power Station (upstream of the potential development area), Beaumont Road Bridge (midway downstream along the potentially impacted reach of the river) and at Clydevale Road Bridge (downstream of the potential development area) (Fig. 1). Samples were obtained by bucket at tributary sites close to the confluence with the Lower Clutha River but upstream of any backwater effect.

At each sampling location, field observations and instrument measurements were recorded and water samples obtained. pH, water temperature, dissolved oxygen concentration and turbidity were measured in the sampling bucket (fresh sample) using a HORIBA U-7 "Water Quality Checker" and electrical conductivity was measured using a TRIAC meter. Two 1l polythene bottles were filled from a sample bucket and placed in an ice chest for airfreight to the Water Quality Centre laboratory. (Analyses for the 17.3.82 reconnaissance were performed by the Hydrology Centre Laboratory, MWD, Christchurch.) A 150 ml sample preserved with Lugols iodine was also dispatched for algal enumeration. Analytical methods (Table 1) used in the Water Quality Centre laboratory are standard (APHA, 1975) except for minor modifications as documented in various Water Quality Centre reports.

SURVEY RESULTS

Table 2 lists water quality measurements for the Lower Clutha River at site 10 (Roxburgh Hydro-station), site 20 (Beaumont) and site 30 (Clydevale) on the eight, bimonthly surveys. (Table 3 gives data for the March 17 reconnaissance.)

The water quality of the Lower Clutha River did not display statistically significant longitudinal trends showing that tributary discharges have no significant effect on this reach. Random variations in quality between Roxburgh and Clydevale most likely reflect the sampling of different water masses, the distinct characteristics of which derive from upstream of Lake Roxburgh rather than from influences on water quality in the lower river. Temporal variability in water quality of the Lower Clutha River appears random, except for seasonality (as is usual) in temperature and dissolved oxygen.

The statistics in Table 4 show that the overall water quality of the Lower Clutha River is "very high" as was reported by Biggs and McBride (1981) for the Upper Clutha River. The Lower Clutha River can be characterised as a very dilute and relatively soft calcium-bicarbonate water on the basis of low conductivity (ECT, EC), low calcium (Ca) and magnesium (Mg) levels and the dominance of calcium among the cations and bicarbonate (TA-is mainly due to bicarbonate) among the anions. The other ionic species (Cℓ, SO_4, Na, K) are all relatively low. The dissolved oxygen content (DO$) of the water was almost always very close to saturation at the measured temperatures (TEMP$) and pH (pH$, pH) was always in the "acceptable" and usual range of 6-9. Both the low chemical oxygen demand (COD) values and the low light absorbances of membrane-filtered water samples (A270F, A400F) demonstrate that organic content of the water is very low.

Dissolved nutrient levels (dissolved reactive phosphorus, DRP; ammonium-nitrogen, NH_4; nitrate-nitrogen, NO_3) in the Lower Clutha River are low or very low (Table 4). Total Kjeldahl nitrogen (TKN) is also low. These low nutrient levels are consistent with a picture of low productivity water draining oligotrophic feeder lakes e.g. Wanaka (Stout, 1980).

Biggs and McBride (1981) have suggested that the Clutha River waters are phosphorus-limited for algal growth, thus bioavailable phosphorus is the nutrient of most interest here. "Total" phosphorus (TP), actually phosphorus extractable by the standard persulphate digestion procedure (APHA, 1975), is quite variable in the Lower Clutha River (Table 2) but averages 25 $g.m^{-3}$ (Table 4). On average 25% of the total phosphorus is dissolved-P (TDP in Tables 2-4). On many occasions in Table 2 TDP was equal to DRP within experimental error but sometimes exceeded DRP when, apparently, a significant proportion of TDP was organic-bound. Typically all dissolved-P is considered potentially bioavailable but only a portion of total particulate-P (TPP = TP - TDP) can be mobilized. Lee et al. (1979) have suggested 20% of TPP may be "ultimately bioavailable".

To obtain some idea of the likely bioavailability of TP, samples were taken from the Lower Clutha on 21 January 1985 and subjected to the sodium-hydroxide extraction procedure of Cowan and Lee (1976). This extraction probably mobilizes all particulate phosphorus which could be ultimately bioavailable (organic-P, adsorbed-P and aluminium- or iron-bound P). The results of this experiment (details of which are available from the author) show that about 20% of TPP in the Lower Clutha River is NaOH-extractable, in agreement with the rule-of-thumb of Lee et al. (1979). On this basis the average "bioavailable-P" in the Clutha River is estimated to be about 10 $g.m^{-3}$.

Total algal cell counts in the Lower Clutha River during the period of study were low (10-50 $cells.ml^{-1}$; Judi Hewitt, WQC, pers. comm.). Corresponding chlorophyll-a values, while not measured directly in this study for operational reasons, would not have exceeded 2 $mg.m^{-3}$ (Dr R.D. Pridmore, WQC, pers. comm.). Again this is consistent with an oligotrophic system. A maximum chlorophyll-a concentration of 6 $mg.m^{-3}$ could be expected with a bioavailable phosphorus concentration of 10 $g.m^{-3}$ (Pridmore and McBride, 1984; Pridmore et al., 1985; suggesting that presently the algae in the Clutha River are flushed through the system too rapidly to permit them to approach the theoretical maximum biomass.

The sparse algal flora of the Lower Clutha consists of a fairly diverse assemblage dominated by diatoms such as *Melosira* spp. and *Fragilaria* spp. (Judi Hewitt, WQC, pers. comm.). The silicon values (Si) in Tables 2 and 4 are sufficient to support biomasses of diatoms much higher than observed (diatoms use silica (SiO_2) in construction of frustules-hard cell walls).

The relatively high turbidity (TURB$, TURB) caused by suspended sediment in the Lower Clutha River is perhaps the only water quality characteristic likely to impair some water uses. The high turbidity is consistent with low Secchi depths (SECCHI) in Lake Roxburgh which indicate low visual water clarity. The river has a milky bluish-green appearance and is not ideal for swimming and contact recreation since the clarity is often lower than the commonly adopted criteria of 1.2 m (e.g. Hart, 1974). In any case swimming is not a major use of the river because temperatures, even in mid to late summer, typically do not exceed 18°C (Mosley, 1982). The turbidity of the Lower Clutha is produced by the fine-grained suspended sediment (SS) comprising glacial flour and loessic material. Much of this material is in the form of minute flakes of micaceous minerals (derived from schistose rocks) which have extremely low fall velocities and do not settle out in the relatively short residence time (approximately 1.7 days) in Lake Roxburgh. Most (90% - Jowett and Hicks, 1981) of the suspended sediment load comes from the Kawerau River particularly the Shotover subcatchment.

It should not be inferred from the high turbidity (low Secchi clarity) of the

Lower Clutha River that aquatic plants are severely light-limited. In this water light is highly scattered but not strongly absorbed and the euphotic depth (depth at which photosynthetically active radiation falls to 1% of the surface value) may be as deep as 10 m (plants would be expected to grow down to this depth).

None of the tributaries of the Lower Clutha River in the reach from Lake Roxburgh to Tuapeka Mouth have any appreciable influence on the water quality of the Lower Clutha River. However, the quality of some of the tributary waters is of interest from the fisheries perspective particularly in the case of known spawning streams such as Blackcleugh Burn (Jellyman, 1984). Table 5 lists some water quality data for tributaries of the Lower Clutha River between Lake Roxburgh and Tuapeka Mouth. The data are too limited for detailed water quality assessment but do suggest that the tributaries are dilute or very dilute, soft waters which are quite distinct in character from the Lower Clutha itself. The most distinctive feature of the tributaries is a yellow colouration caused by dissolved humic substances derived from boggy upland drainage. The correspondingly high organic content is reflected in moderately high chemical oxygen demand (COD) and light absorbance (A270F, A400F) values. Nutrient levels are somewhat higher than in the Lower Clutha although by no means "high" in absolute terms. Overall the water quality of the tributaries might be considered "reasonably high".

COMPARATIVE WATER QUALITY OF THE LOWER CLUTHA RIVER

Table 6 shows the major ionic composition and conductivity of the Lower Clutha River compared with the world average freshwater (Livingstone, 1963) and with some other rivers in New Zealand (Bryers, 1985). The Lower Clutha River is seen to be dilute even by New Zealand standards and very dilute on a world basis.

The calcium content is relatively high compared to other New Zealand rivers and bicarbonate moderately high. In comparison with the other rivers listed in Table 6 and on consideration of available data on all variables listed in Table 1 the Clutha River is perhaps the highest quality water overall. Only the relatively high suspended sediment content of the Clutha River, with its associated turbidity, is likely to militate against some water uses. For example, the water clarity is marginal for contact recreation.

In summary, the Lower Clutha River is notable both regionally and nationally as a large, high quality flowing water which represents a valuable water resource in water quality terms. The water quality is probably close to the pristine state as noted by Biggs and McBride (1981), and is sufficiently good to support most existing and potential water uses.

WATER QUALITY IMPACTS OF HYDRO-ELECTRIC DEVELOPMENTS

POTENTIAL WATER QUALITY CHANGES AND THEIR CONSEQUENCES

The main hydraulic consequence of hydro-electric development of a river is increased water residence time and reduced water velocities. The effects of impoundment of water in a river are normally of concern from the perspective of increased phytoplankton growth with consequent degradation of water quality. Increased production of phytoplankton results in increased turbidity (reduced clarity), increased organic content of the water and changed water colour, and thus overall reduction in aesthetic and recreational values and change in ecological character. More severe problems are possible, particularly if deoxygenation of bottom waters of hydro-electric reservoirs occurs with consequent nutrient recycling, smells, tastes, algal scums and severe reduction in fish habitat.

In the future, the Clutha River may be similar to the Waikato system in having a chain of hydro-electric stations operated in tandem. Hydro-electric development on the Waikato River (8 dams), has increased residence time between the source at the outflow of oligotrophic Lake Taupo (very high quality, clear-Secchi depth about 14 m - and blue coloured water) and the most downstream dam (Karapiro) from perhaps three days to about 27 days (Magadza, 1979; Strachan, 1979). Nutrient loads, particularly on Lake Ohakuri, the first major reservoir, promotes growth of algae to eutrophic levels during this flow time so that water in the Waikato River at Karapiro is usually somewhat turbid and degraded for some recreational purposes. The catchment of the Waikato River is, however, more intensively developed for agriculture and forestry than the Clutha catchment.

The present nutrient status of the Clutha system is apparently oligotrophic (Biggs and McBride, 1981; this report). The "potentially bioavailable" average phosphorus concentration of about 10 $g.m^{-3}$ reported here corresponds to the threshold of mesotrophy (OECD, 1982) but evidently at present the residence time of water in the Clutha system is not sufficient for algal biomass to even approach the maximum "carrying capacity" (about 6 $mg.m^{-3}$ chlorophyll-a) corresponding to this phosphorus concentration. However, the residence time (V/Q where V is volume and Q is flow) of the water in the Clutha system will be greatly increased in the future. To the existing residence time of Lake Roxburgh (1.7 days from data in Jowett and Hicks, 1981) will be added the V/Q for (in likely order of construction, given approval) Lake Dunstan (V/Q = 11 days, MWD, 1977), the impoundments of Luggate and Queensberry schemes (V/Q about 5 days, Biggs and McBride, 1981) and the impoundments of the Lower Clutha. If a high dam is built at Tuapeka (Scheme B in MWD, 1984) residence time in the Lower Clutha will be roughly 10 days and the cumulative residence time of water in the Clutha will be of the order of 30 days, sufficient time for the algal biomass in water passing Tuapeka Mouth to have reached the maximum yield under most growth conditions. This water will be at most marginally mesotrophic if present phosphorus loading continues. Water colour is not expected to change significantly from the present typical bluish-green hue.

Some increase in nutrient loading to the Clutha system must be expected from an increased irrigated area of land (McCallion, 1980) and (at least temporarily) from the limited areas of inundation of terrestrial soils, particularly septic tank drainfields (Close, 1984). It is difficult to decide how much of an increase in bioavailable phosphorus such developments will produce. However, given the very large dilution in the Clutha River it seems unlikely that increases in phosphorus concentrations would be detectable above background variability (Table 2) unless there are marked changes in land use patterns in the catchment.

If average bioavailable phosphorus concentrations were to double from the present 10 $g.m^{-3}$ to about 20 $g.m^{-3}$ (an unlikely scenario), maximum chlorophyll-a concentrations in the furthest downstream impoundment could reach about 14 $mg.m^{-3}$ (Pridmore et al., 1985), a "mesotrophic" condition. However even mesotrophic status is unlikely to cause any significant changes in water quality of the Lower Clutha River. Since none of the reservoirs in the Clutha system are expected to stratify, no significant deoxygenation of bottom waters will occur on oxidation of dead algae and associated organics. The Secchi depth to be expected with a chlorophyll a concentration of 14 $mg.m^{-3}$ is approximately 4.5 m (Vant and Davies-Colley, 1984) suggesting that any reduction in clarity brought about by the algal biomass would be masked by the fine suspended sediments which presently reduce the average Secchi depth to about 1 m (Table 4). With chlorophyll-a levels as high as 14 $mg.m^{-3}$ there would be a shift in water hue from the present typical bluish-green to a green.

In some countries basin-wide irrigation has caused major salinisation and other water quality problems but considering the limited scale of proposed increased irrigation and the very high dilution provided by the Lower Clutha, no significant impacts of irrigation on water quality are foreseen (McCallion, 1980).

The water in the Lower Clutha River is probably mildly aggressive towards structural concrete and steel in spite of dominance of ionic species by calcium and bicarbonate. (The Langelier index is negative). Since the ionic composition of the Clutha River water is not expected to change appreciably on hydro-electric development no increase in corrosiveness is foreseen. In particular the degree of undersaturation of calcium carbonate is not expected to increase, nor is the concentration of organic matter (which can accelerate corrosion) likely to increase.

The turbidity (light scattering) associated with suspended sediment is probably of more concern than the mass of suspended sediment in the Lower Clutha River. Turbidity reduces water clarity and thus affects aesthetic and recreational quality of the water and also affects the vision of aquatic animals, notably that of salmonid fish which prey by sight. The impoundment of water on the Lower Clutha is likely to continue the trends effected by hydro-electric reservoirs on the Upper Clutha and Lake Roxburgh in changing the quantities and frequency distributions of suspended sediment concentrations (and associated water turbidity) in the Lower Clutha River.

Some insight into the long-term effects of impoundment on water clarity of the Lower Clutha River can be gained from analysis of available data for Lake Roxburgh as reported by Biggs and McBride (1981), Jowett (1979) and Jowett and Hicks (1981). Table 7 compares selected data collected by Biggs and McBride (1981) (but not used in their report) upstream of Lake Roxburgh on the Clutha River at Alexandra and downstream at Roxburgh Hydro-station. The data in Table 7 suggests that the trapping efficiency of Lake Roxburgh for light-scattering materials is considerably lower than the 80% efficiency reported by Jowett and Hicks (1981) for suspended sediment mass. The fact that Lake Roxburgh improves clarity of the water to a much lesser extent than would be suggested by the high trapping efficiency for suspended sediment can be explained in terms of specific scattering (scattering per unit suspended sediment concentration) of fine as opposed to coarse particles. The very fine-grained materials contribute disproportionately to the total light scattering and it is these same fine particles which do not settle out in Lake Roxburgh because their fall velocities are so low.

The data of Table 7 are insufficient for examining the effect of Lake Roxburgh on frequency distributions of clarity in the Clutha River. However, in the study of the suspended sediment budget of Lake Roxburgh (Jowett and Hicks, 1981) a large number of transmittance measurements (Spectronic 20 at 450 nm, 12.7 mm path length cuvettes) were obtained to provide a rough guide to suspended sediment content of water samples. Reduction in transmittance of light in a water like the Clutha River should be almost entirely the result of light scattering. The transmittance measurements from September 1977 to September 1978 kindly supplied by Mr Jowett (then of Power Division, MWD) were transformed to give absorbances :

$$A(450) = \log_{10}(1/T)$$

where T is transmittance and A(450) is absorbance (optical density) at 450 nm. The variable A(450) would be expected to behave almost identically to A400U reported in the present study and thus would correlate very closely with turbidity and Secchi disk clarity.

Fig. 2 shows the frequency distributions of A(450) on a log probability graph for Alexandra and Roxburgh Hydro-station. Superimposed on the figure are approximate scales of A400U, turbidity (TURB) and Secchi disk clarity (SECCHI). The relationships between the variables A400U, TURB and SECCHI were obtained from correlations based on data in Table 2 and the ratio of A400U to A(450) was found to be approximately unity from theoretical considerations of the wavelength dependence of scattering (Davies-Colley, 1983).

At both Alexandra and Roxburgh Hydro-station the curves in Fig. 2 are convex-up showing that the distributions of turbidity are even more positively skewed than a log-normal distribution. In the range between the 20 and 80 percentiles, that is, for 60% of the time, the curve is straight and the distribution is well-fitted by a log-normal probability function but at high turbidities (exceeded only 20% of the time) turbidities of a given magnitude are exceeded more frequently than a log-normal model would predict. The mean absorbance at Alexandra (22 units) is greater than at Roxburgh Hydro (15.1 units). Overall the shape of the two turbidity distribution curves in Fig. 2 are similar although high turbidity events are more frequent upstream than downstream of Lake Roxburgh.

There has been some concern that a chain of hydro-power storage reservoirs on the Clutha River would result in fairly constant and relatively high turbidities which may have an adverse affect on fisheries and scenic quality of the Clutha River. This situation might arise when relatively dirty floodwaters mix with clear waters in the chain of hydro reservoirs and remain in the system longer than at present. The resulting water of moderate to high turbidity might be more environmentally damaging than water which occasionally is very turbid but is mostly clear. Fish can "hide-out" in turbid floodwaters and resume feeding and normal behaviour when the water clarifies but predation (by sight) might be severely affected if the water continued to flow in a relatively turbid condition for many days. Scenic quality would also be affected and the river would become more like the Waitaki River which is always very "milky" in appearance.

Unfortunately the data for Lake Roxburgh are not suitable for examining this possibility. Fig. 2 shows that Lake Roxburgh does not damp out turbidity fluctuations to any extent (with the exception of very high turbidities), probably because residence time (1.7 days) in this reservoir is too short for such an effect to be discerned. However, in the future when the cumulative residence time in the Clutha system is of the order of 30 days (see above) murky flood waters will be held up in the chain of hydro dams rather than flushing rapidly through the system. There is the possibility that consequent changes in time distribution of turbidity will result in waters leaving the most downstream Clutha impoundment being significantly more frequently turbid ("milky") than at present.

A further potential problem associated with turbidity is that of shoreline erosion by wave action on the proposed storage reservoirs. Jowett and Hicks (1981) discounted this mechanism as a significant source of sediment to Lake Roxburgh. Wave erosion is also unlikely to be a significant source of sediment and turbidity in the Lower Clutha impoundments because :

a Wind fetch on long narrow reservoirs is limited except in the direction of the long axis, thus wave action will also be limited.

b The soils at proposed shoreline levels are mostly coarse-grained gravels with only thin coverings of suspendable silt-sized material (MWD, 1984).

c Level fluctuation in the proposed reservoirs is likely to be small (less than 1 m).

There is, however, a possibility that localized discoloration of reservoir waters will occur in areas of wave erosion.

During construction of dams and other works associated with hydro-power development of the Lower Clutha, bare soil areas will inevitably be exposed with consequent risk of generation of suspended sediment during rainstorms.

Excavations below the water table will require dewatering and discharge of the dewatering effluent will also impose a suspended sediment load on the river, probably a more-nearly continuous load than storm runoff. The high suspended sediment content of dewatering effluents has caused some problems with construction of the Clyde Dam upstream of Lake Roxburgh and this environmental impact has had to be considered in planning of the Luggate and Queensberry schemes on the Upper Clutha River.

POTENTIAL FOR WATER QUALITY MANIPULATION FOR ENVIRONMENTAL ENHANCEMENT

Given the large volumetric flow of the Clutha River the potential for water quality manipulation seems small but equally the large flow confers significant resistance to water quality degradation. Very likely only the operating regime of the chain of power stations could be used to manage water quality (via manipulation of water discharge) once materials have actually entered the Clutha water, so the emphasis should be on preventing materials entering in quantities which will degrade water quality. We will consider here only the potential for minimising entry of materials into the river which could degrade water quality.

The impact of dissolved materials likely to enter the Lower Clutha River as a result of hydro-power development is expected to be minor or even undetectable. However, some impact of suspended matter and associated turbidity is expected during the construction phase from dewatering effluents, and storm runoff from construction sites. Diversion to settling ponds before discharge to the Lower Clutha River could provide a solution to this problem. However, although settling ponds may remove the bulk of suspended solids in a matter of days or even hours, the turbidity may well be little changed because most of the light scattering is caused by the very fine-grained particles which have the lowest settling velocities. A practical solution to the problem of turbidity may be to construct ponds on permeable soils to function as soakage pits thus avoiding discharge of turbid water to the river. Alternatively, alum coagulation and flocculation before discharge may be practical. Alum coagulation of fine-grained sediment in dewatering effluents has been applied with success by Mines Division, Ministry of Energy at the Maori Farm State Coal Mine west of Huntly.

In order to minimise impact on the Lower Clutha River of turbidity-producing suspended sediments, control on the quality of discharged construction waste waters may be necessary. This quality control should take into account mass flow loadings on the Lower Clutha River. Thus a simple, blanket suspended sediment value (e.g. the 80 $g.m^{-3}$ maximum recommended for dewatering effluent in the Luggate and Queensberry schemes (Commission for the Environment, 1982)) is not practical since it does not take into account available dilution in the river. In any case, since turbidity is of more environmental concern than suspended sediment mass, the control criterion should be in terms of turbidity rather than $g.m^{-3}$ suspended matter. This has advantages for monitoring in that a simple in-line turbidimeter could be employed to give a continuous record of effluent quality compared to discontinuous (and labour intensive) suspended solids assays. In practice the criterion for turbidity could be expressed :

$$\frac{Q_{effluent}}{Q_{river}} \times TURB_{effluent} < X$$

where Q is flow and TURB is turbidity. On consideration of the statistics for turbidity in Table 4 an appropriate value for the turbidity criterion, X, might be 1 F.T.U.

The impact of shoreline erosion on turbidity in the Lower Clutha has been dismissed as insignificant to the Clutha River as a whole (see above). However, minimising even local discolouration of water along shorelines by keeping water level fluctuation in reservoirs to a minimum (expecially during the first few years of operation during which time some beach development may take place) might be a worthwhile goal.

CONCLUSIONS

1 Data collected in this study and gleaned from other reports show that the Lower Clutha River is of very high water quality overall with regard to existing and future water uses.

2 The Lower Clutha water can be characterised as a dilute calcium bicarbonate water which is close to its pristine state in terms of nutrient status. The water appearance is characteristically a visually attractive bluish-green and slightly milky colour.

3 The only water quality characteristic of the Lower Clutha River which is likely to impair some water uses is a rather low clarity (average Secchi depth approximately 1 m) caused by fine-grained suspended sediment. In all other respects the river is notable as a large and valuable resource in water quality terms, both regionally and nationally.

4 The tributaries of the Lower Clutha River, being small compared with the river, have no discernable effect on water quality in the reach from Lake Roxburgh to Clydevale. These tributaries are dilute waters of fairly high quality although some are noticeably yellow-coloured by organic constitutents.

5 Water quality changes brought about by hydro-electric development of the Lower Clutha are likely to be slight or undetectable with regard to dissolved constituents and growth of phytoplankton. Only the suspended sediment content and associated clarity could potentially be impacted.

6 During the construction phase, storm runoff and discharge from construction sites of dewatering effluents high in suspended sediments could degrade river water clarity. The use of settling basins or (preferably) soakage pits could reduce the potential impact of construction site drainage.

7 When a chain of hydro-dams has been constructed on the Clutha River, both

upstream and downstream of Lake Roxburgh, there is the possibility that the frequency distribution of turbidity in the Lower River will be significantly different from the present. Turbidity in the future may be less variable on average but more frequently "moderately high" because of the longer residence time of murky floodwaters.

8 Overall, water quality impacts of the proposed development are expected to be slight. Thus no major undesirable consequences for uses of the river are foreseen. However, since potential for water quality manipulation of a river the size of the Clutha appears to be very limited, care should be taken to prevent any materials entering this important water resource in quantities which could degrade water quality.

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FIGURES

FIG. 1 :

Map of the Clutha River System showing sites sampled in this study on the Lower Clutha and its tributaries.

FIG. 2 :

Frequency distributions of absorbance (light scattering) at Alexandra and Roxburgh Hydro-Station on the Clutha River. Data were calculated from transmittance measurements (Mr I G Jowett, Power Division, MWD, pers. comm.) obtained in a study by Jowett and Hicks (1981) of the suspended sediment budget of Lake Roxburgh. Data are plotted as percent of time that absorbances (450 nm, 12.7 mm cell) are less than given values. Approximate scales of absorbance at 400 nm (10 mm cell) (A400U) turbidity (TURB) and Secchi disk clarity (SECCHI) are based on correlations between these variables using data obtained in the present study.

TABLE 1 : LOWER CLUTHA RIVER WATER QUALITY IDENTIFIERS

FLOW	($m^3.s^{-1}$ at Roxburgh Hydro Station)
SECCHI	(Secchi depth, m)
pH$	*(HORIBA U7 pH)
ECT	*(Conductivity, Triac meter, micromhos/cm corrected to 25°C
TURB$	*(HORIBA U7 turbidity)
TEMP$	*(HORIBA U7 temperature °Celcius)
DO$	*(HORIBA U7 dissolved oxygen, $g.m^{-3}$)
pH	(pH)
EC	(Conductivity, micromhos/cm corrected to 25°C)
TURB	(Turbidity, HACH 2100A, FTU)
A270F	(Absorbance at 270 nm in a 1 cm cell of membrane-filtered water)
A270U	(ditto except unfiltered)
A400F	(absorbance at 400 nm in a 1 cm cell of membrane-filtered water)
A400U	(ditto except unfiltered)
SS	(Suspended solids, $g.m^{-3}$)
TA	(Total alkalinity, $g.m^{-3}$ as $CaCO_3$)
DRP	(Dissolved reactive phosphorus, $mg.m^{-3}$)
NH_4	(Ammonia-nitrogen, $mg.m^{-3}$)
NO_3	(Nitrate-nitrogen, $mg.m^{-3}$)
TP	(Total phosphorus, $mg.m^{-3}$)
TDP	(Total dissolved phosphorus, $mg.m^{-3}$)
TKN	(Total kjeldahl nitrogen, $mg.m^{-3}$)
$C\ell$	(Chloride, $g.m^{-3}$)
Si	(Silicon, $g.m^{-3}$)
SO_4	(Sulphate, $g.m^{-3}$)
COD	(Chemical oxygen demand, $g.m^{-3}$)
Na	(Sodium, $g.m^{-3}$)
K	(Potassium, $g.m^{-3}$)
Ca	(Calcium, $g.m^{-3}$)
Mg	(Magnesium, $g.m^{-3}$)

All analyses by standard Water Quality Centre, MWD methods. Methods are almost identical at the Hydrology Centre, MWD, Christchurch.

*Field measurements

TABLE 2 : WATER QUALITY DATA FOR THE LOWER CLUTHA RIVER

SITE 10 = Roxburgh Hydro-station, Site 20 = Beaumont and Site 30 = Clydevale

SITE	DATE	TIME	FLOW	SECCHI	pH$	ECT	TURB$	TEMP$
10	821125	15.46	900	0.95	7.7	61	6	13.1
20	821125	12.35	-	-	7.7	61	4	13.0
30	821125	9.53	-	-	7.6	62	3	12.0
10	830111	9.48	710	1.50	7.2	64	4	15.5
20	830111	11.05	-	-	7.6	66	2	16.1
30	830111	12.35	-	-	7.7	65	2	16.3
10	830315	11.00	700	0.80	7.5	-	3	15.2
20	830315	12.45	-	-	7.7	68	5	15.7
30	830315	13.30	-	-	7.6	68	4	15.6
10	830524	9.20	800	1.20	7.0	59	4	8.0
20	830524	11.00	-	-	6.9	58	6	7.3
30	830524	11.45	-	-	7.9	58	7	7.3
10	830718	10.05	675	1.50	7.2	63	1	6.8
20	830718	11.45	-	-	8.2	64	3	5.9
30	830718	13.30	-	-	8.0	65	3	6.3
10	830926	10.15	860	0.30	7.1	58	16	8.0
20	830926	11.30	-	-	7.3	56	30	8.2
30	830926	13.15	-	-	7.5	56	34	8.6
10	831121	8.45	1200	0.60	6.6	61	7	11.8
20	831121	12.30	-	-	7.1	58	8	11.6
30	831121	13.30	-	-	7.2	57	10	11.4
10	840123	9.30	600	1.40	7.3	64	1	15.1
20	840123	10.45	-	-	7.2	63	1	15.3
30	840123	14.00	-	-	7.3	62	1	15.1

DO$	pH	EC	TURB	A270F x10^{3}	A270U x10^{3}	A400F x10^{3}	A400U x10^{3}	SS
10.9	7.69	67	6.1	15	37	2	17	8.0
11.9	7.67	66	6.1	16	37	2	17	8.4
11.1	7.72	67	6.1	14	37	2	18	14.7
15.6	7.53	65	3.3	13	29	-	-	6.2
10.4	7.73	68	2.9	14	28	-	-	5.1
14.1	7.72	67	2.8	14	29	-	-	5.0
9.8	7.73	72	5.7	18	28	3	11	5.6
9.1	7.74	72	9.6	31	48	6	19	25.8
9.2	7.76	73	9.0	40	59	10	22	14.8
12.0	7.62	63	3.4	18	30	3	12	7.1
11.9	7.54	63	5.3	24	35	4	13	10.8
11.8	7.67	63	4.8	25	39	4	15	10.2
11.9	7.72	74	3.8	23	40	4	13	6.5
11.8	7.71	76	4.2	31	50	5	16	9.7
11.8	7.75	75	3.7	31	50	5	16	7.0
12.1	7.35	66	23.0	7	104	5	64	42.3
11.8	7.40	64	31.0	14	159	6	88	56.1
11.7	7.23	64	38.0	21	191	8	108	73.1
11.9	7.75	65	7.1	17	47	2	26	18.1
12.0	7.71	64	8.4	19	54	3	31	24.3
11.7	7.78	65	9.2	18	54	3	31	27.3
11.1	7.72	70	2.2	10	19	2	7	3.0
11.4	7.71	70	2.3	12	22	2	10	4.6
10.9	7.60	71	2.4	13	23	2	8	4.1

TABLE 3 : WATER QUALITY DATA OBTAINED ON THE 17 MARCH 1982 RECONNAISSANCE ON THE LOWER CLUTHA RIVER. (ANALYSES PERFORMED AT THE HYDROLOGY CENTRE, MWD, CHRISTCHURCH)

SITE	pH	EC	TEMP	DOSAT %	DRP	NH_4	NO_3	TP	TKN
ROXBURGH (10)	7.8	63	16	114	1	8	30	4	52
BEAUMONT (20)	7.8	65	14	120	2	8	41	8	58

TABLE 4 : SUMMARY STATISTICAL PARAMETERS FOR THE LOWER CLUTHA RIVER DATA FROM ROXBURGH HYDRO, BEAUMONT AND CLYDEVALE COMBINED

	FLOW	SECCHI	pH$	ECT	TURB$	TEMP$	DO$	pH	EC
MIN	600	0.30	6.60	56	1	5.9	9.10	7.23	63.3
MAX	1200	1.50	8.20	68	34	16.3	15.60	7.78	76.0
MEAN	806	1.03	7.42	61.6	6.9	11.6	11.58	7.65	68.0
MEDIAN	710	0.95	7.30	62	4	11.8	11.80	7.71	67.0
	800	1.20	7.50		4	12.0	11.80	7.71	67.0
ST DEV	188	0.44	0.37	3.6	8.5	3.7	1.34	0.14	4.0
NO OF OBS	8	8	24	23	24	24	24	24	24

	TURB	A270F $\times 10^3$	A270U	A400F $\times 10^3$	A400U $\times 10^3$	SS	TA	DRP	NH_4
MIN	2.2	7	19	2	8	3.0	26.0	1.0	1.0
MAX	38.0	40	191	10	108	73.1	30.0	5.0	14.0
MEAN	8.4	19	52	3	26	16.6	27.3	2.3	5.2
MEDIAN	5.3	17	37	3	17	8.9	27.0	2.0	5.0
	5.7	18	39			9.7	27.0	2.0	6.0
ST DEV	9.2	7.9	41	2	27	17.7	1.0	1.1	3.3
NO OF OBS	24	24	24	21	21	24	24	24	24

	NO_3	TP	TDP	TKN	Cl	Si	SO_4	COD	Na
MIN	24	7	1.0	30	0.4	1.2	2.2	0.9	0.90
MAX	115	94	17.0	200	1.8	2.3	5.3	2.0	2.54
MEAN	47	25	5.5	78	1.0	1.5	3.9	1.3	1.53
MEDIAN	40	16	3.0	60	0.9	1.4	3.9	1.0	1.40
	41	17		60	0.9	1.4	3.9	0.5	1.50
ST DEV	21	21	4.9	45	0.4	0.3	0.7	0.6	0.43
NO OF OBS	24	24	21	24	24	24	24	8	24

	K	Ca	Mg
MIN	0.53	8.82	0.70
MAX	0.73	11.10	1.20
MEAN	0.60	10.01	0.84
MEDIAN	0.58	10.02	0.76
	0.59	10.06	0.80
ST DEV	0.05	0.58	0.15
NO OF OBS	24	24	24

TABLE 5 : WATER QUALITY DATA FOR TRIBUTARIES OF THE LOWER CLUTHA RIVER

NAMES	DATE	pH	EC	TEMP	DOSAT %	DRP	NH_4
TEVIOT	820317	7.60	33.00	12.5	114	2	13
TALLA	820317	7.70	40.00	11.0	118	4	8
BEAUMONT	820317	7.70	41.00	9.0	110	4	8
BLACKCL.	820317	7.60	70.00	9.0	101	14	4
TUAPEKA	820317	7.40	86.00	9.5	90	8	16
TEVIOT	821125	7.41	27.00	-	-	4	5
TALLA	821125	7.50	34.00	-	-	7	2
BEAUMONT	821125	7.35	36.00	-	-	7	3
BLACKCL.	821125	7.63	66.00	-	-	12	5
TUAPEKA	821125	7.55	90.00	-	-	14	14
TEVIOT	831121	-	-	-	-	-	-
BENGER	831121	-	-	-	-	-	-
TIMA	831121	-	-	-	-	-	-
TALLA	831121	-	-	-	-	-	-
BEAUMONT	831121	-	-	-	-	-	-
CARSON	831121	-	-	-	-	-	-
BLACKCL.	831121	-	-	-	-	-	-
TUAPEKA	831121	-	-	-	-	-	-

NAMES	NO_3	TP	TKN	TIME	FLOW	SECCHI	pH$	ECT
TEVIOT	23	30	340	-	-	-	-	-
TALLA	30	13	140	-	-	-	-	-
BEAUMONT	25	6	92	-	-	-	-	-
BLACKCL.	95	13	85	-	-	-	-	-
TUAPEKA	96	33	148	-	-	-	-	-
TEVIOT	1	22	226	14.57	7	-	7.1	25
TALLA	37	19	144	13.33	1	-	7.4	32
BEAUMONT	8	12	106	12.47	1	-	7.3	33
BLACKCL.	28	17	223	11.32	1	-	7.6	58
TUAPEKA	81	33	25	10.18	3	-	7.5	87
TEVIOT	-	-	-	10.00	-	-	7.1	24
BENGER	-	-	-	15.00	-	-	7.7	79
TIMA	-	-	-	10.25	-	0.5	7.1	84
TALLA	-	-	-	10.45	-	-	7.3	30
BEAUMONT	-	-	-	12.00	-	2.0	6.0	27
CARSON	-	-	-	12.45	-	-	7.3	76
BLACKCL.	-	-	-	13.00	-	-	7.5	59
TUAPEKA	-	-	-	14.00	-	1.5	7.3	85

NAMES	TURB$	TEMP$	DO$	TURB	A270F $\times 10^3$	A270U $\times 10^3$	A400F $\times 10^3$	A400U $\times 10^3$
TEVIOT	-	-	-	-	-	-	-	-
TALLA	-	-	-	-	-	-	-	-
BEAUMONT	-	-	-	-	-	-	-	-
BLACKCL.	-	-	-	-	-	-	-	-
TUAPEKA	-	-	-	-	-	-	-	-
TEVIOT	2	13.4	10.7	3.0	160	177	24	32
TALLA	2	12.5	11.7	2.2	127	139	21	25
BEAUMONT	1	11.6	11.0	1.6	111	121	16	21
BLACKCL.	2	12.3	11.5	1.0	87	92	12	14
TUAPEKA	4	11.9	10.2	2.3	118	132	17	25
BENGER	0	15.0	10.5	-	-	-	-	-
TIMA	9	11.1	10.8	-	-	-	-	-
TALLA	1	10.3	11.7	-	-	-	-	-
BEAUMONT	1	10.8	11.6	-	-	-	-	-
CARSON	0	11.0	11.1	-	-	-	-	-
BLACKCL.	1	9.5	11.7	-	-	-	-	-
TUAPEKA	2	11.2	10.9	-	-	-	-	-

NAMES	SS	TA	TDP	Cl	Si	SO_4	COD	Na
TEVIOT	-	-	-	-	-	-	-	-
TALLA	-	-	-	-	-	-	-	-
BEAUMONT	-	-	-	-	-	-	-	-
BLACKCL.	-	-	-	-	-	-	-	-
TUAPEKA	-	-	-	-	-	-	-	-
TEVIOT	2.8	6.5	12	3.4	1.2	3.5	11.10	2.50
TALLA	2.0	9.0	12	4.2	1.2	3.4	9.10	3.60
BEAUMONT	1.0	9.5	10	4.6	2.0	3.7	4.60	3.80
BLACKCL.	1.3	16.0	14	8.9	4.8	3.2	6.70	6.50
TUAPEKA	1.9	24.5	26	8.7	4.5	5.7	7.50	7.60
TEVIOT	-	-	-	-	-	-	-	-
BENGER	-	-	-	-	-	-	-	-
TIMA		-	-	-	-	-	-	-
TALLA	-	-	-	-	-	-	-	-
BEAUMONT	-	-	-	-	-	-	-	-
CARSON	-	-	-	-	-	-	-	-
BLACKCL.	-	-	-	-	-	-	-	-
TUAPEKA	-	-	-	-	-	-	-	-

NAMES	K	Ca	Mg
TEVIOT	-	-	-
TALLA	-	-	-
BEAUMONT	-	-	-
BLACKCL.	-	-	-
TUAPEKA	-	-	-
TEVIOT	0.69	1.10	0.55
TALLA	0.42	1.60	0.68
BEAUMONT	0.46	1.60	0.77
BLACKCL.	0.97	3.50	1.32
TUAPEKA	1.20	5.40	2.46
TEVIOT	-	-	-
BENGER	-	-	-
TIMA	-	-	-
TALLA	-	-	-
BEAUMONT	-	-	-
CARSON	-	-	-
BLACKCL.	-	-	-
TUAPEKA	-	-	-

Analysis of tributary waters collected on 17 March 1982 were carried out by the Hydrology Centre, MWD, Christchurch.

TA	DRP	NH_4	NO_3	TP	TDP	TKN	Cl	Si
28	2	4	39	14	3	55	1.0	1.5
26	4	2	40	16	5	48	0.7	1.5
27	2	4	41	17	1	34	0.7	1.3
28	2	8	36	10	-	48	0.9	1.3
27	2	3	24	10	-	45	0.9	1.3
27	2	2	35	10	-	60	0.8	1.4
27	1	8	37	19	1	60	0.9	1.3
28	4	6	49	48	17	90	1.2	1.4
27	3	7	49	34	17	115	1.3	1.5
36	1	[illegible]	46	12	1	30	0.8	1.3
26	2	1	55	15	3	40	0.9	1.4
26	2	2	55	15	3	35	1.1	1.5
30	2	3	73	11	3	55	1.3	1.8
30	3	2	115	21	7	85	1.8	2.3
27	2	1	93	12	3	150	1.7	2.0
26	4	8	47	50	5	110	1.2	1.7
26	3	8	52	67	9	200	1.4	1.7
26	2.5	6	54	94	9	175	1.4	1.7
26	1	7	32	28	3	60	0.4	1.3
26	1	9	36	26	3	85	0.5	1.3
26	1	8	34	31	3	70	0.5	1.3
27	3	14	27	7	3	40	0.6	1.3
27	5	6	27	7	3	105	0.7	1.3
28	1	5	24	29	13	75	0.7	1.2

SO_4	COD	Na	K	Ca	Mg
3.9	0.9	0.90	0.61	9.90	0.70
3.6	-	0.94	0.64	9.80	0.71
3.8	1.8	0.94	0.61	10.20	0.72
4.5	-	1.20	0.58	11.10	0.71
4.8	-	1.28	0.55	11.07	0.73
4.4	-	1.38	0.58	10.79	0.73
2.9	-	1.53	0.59	10.67	0.80
3.9	-	1.86	0.63	10.48	0.89
3.4	-	1.96	0.63	10.37	0.91
5.0	1	1.50	0.57	10.14	0.84
4.8	2	1.68	0.56	10.02	0.88
3.8	2	1.76	0.56	9.74	0.88
3.9	-	2.06	0.62	10.06	1.16
4.6	-	2.54	0.64	9.68	1.20
4.2	-	2.49	0.65	9.62	1.19
3.6	1	1.60	0.69	9.17	0.89
4.6	1	1.62	0.69	8.99	0.90
4.0	1	1.73	0.73	8.82	0.92
3.5	-	1.21	0.56	10.25	0.74
2.2	-	1.25	0.55	10.22	0.75
5.3	-	1.27	0.57	10.22	0.75
3.4	-	1.30	0.54	9.75	0.75
3.0	-	1.30	0.55	9.60	0.76
3.8	-	1.40	0.53	9.60	0.76

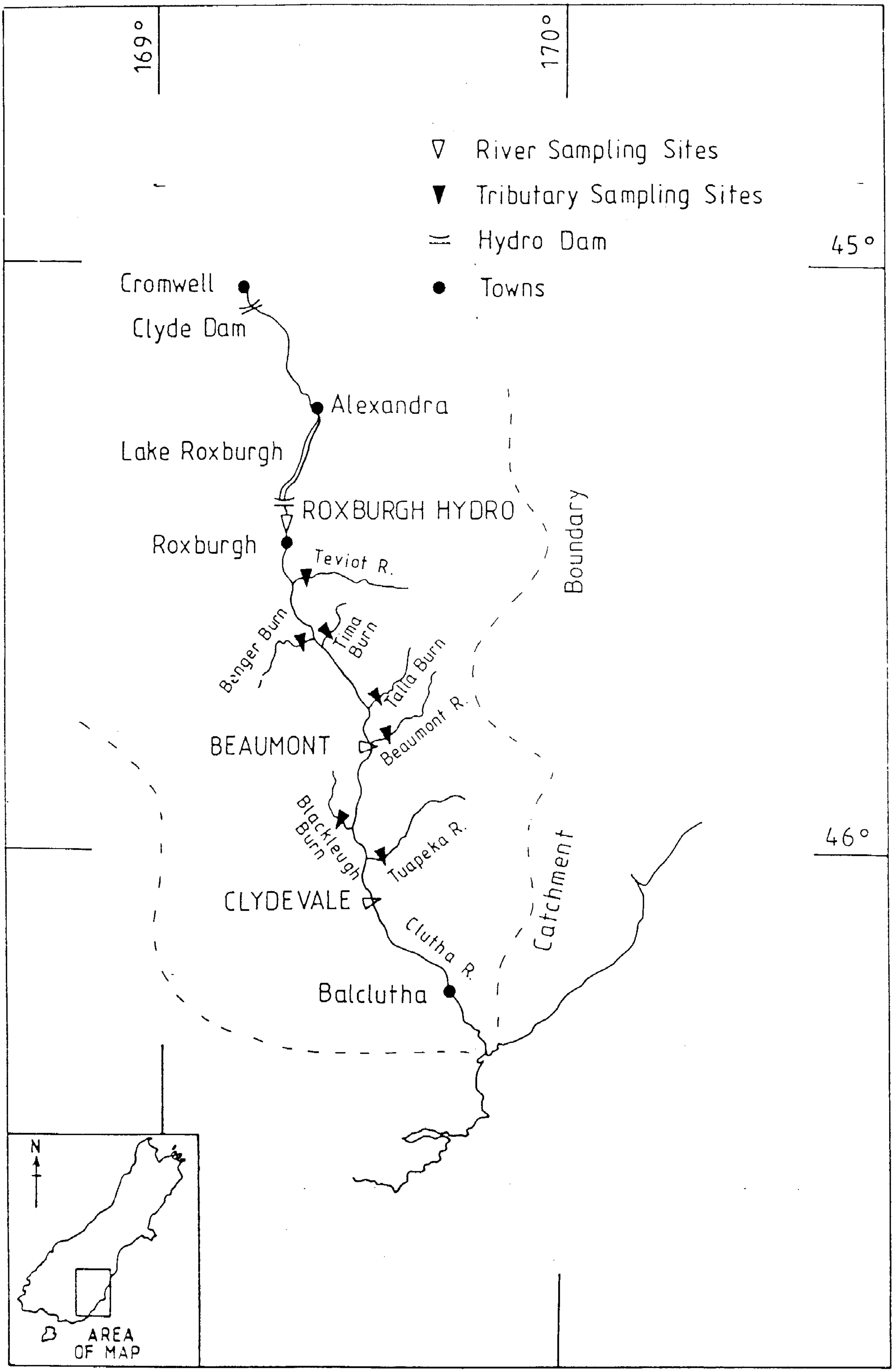
TABLE 6 : COMPARISON OF SOLUTE CONCENTRATIONS IN NEW ZEALAND RIVERS WITH THE WORLD FRESHWATER AVERAGE (after Bryers, 1985).

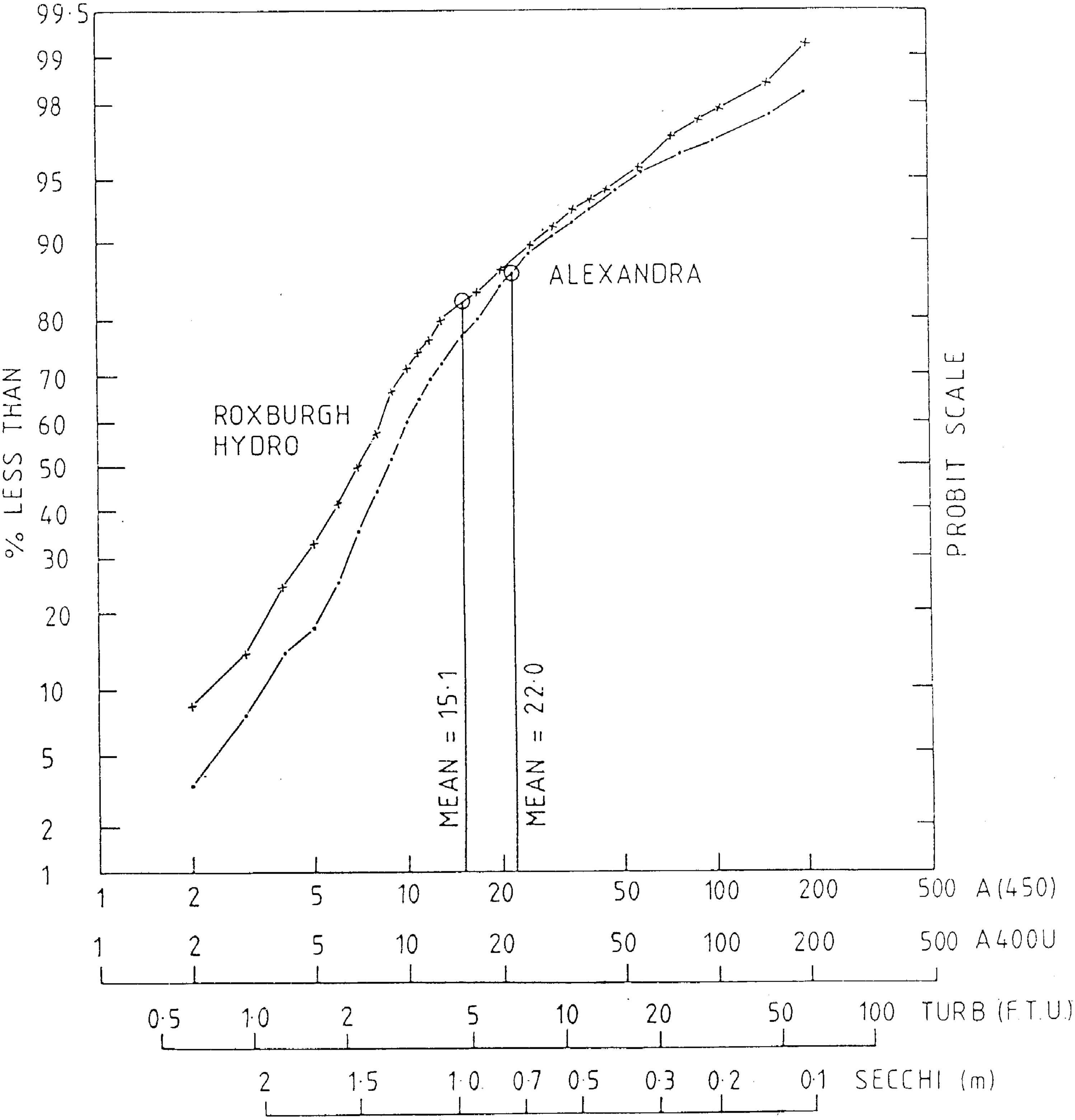
RIVER AND LOCATION	n	COND.	HCO_3	Cl	SO_4	Ca	Mg	Na	K	SiO_2	Range of Discharge $m^3.s^{-1}$
Waikato River at Lake Taupo outlet	53	118	45.3	9.1	5.8	5.9	2.5	14.3	2.1	19.9	134-278
Waikato River at Mercer	67	155	42.0	19.2	7.2	7.0	2.3	18.6	3.2	28.4	122-806
Motu River at Houpoto	24	99	36.0	5.6	8.0	10.6	1.6	5.5	0.9	13.7	10-150
Mohaka River at Willow Flat	18	99	43.7	4.4	6.0	10.1	1.5	6.9	1.0	23.8	23-152
Waimakariri River at Halkett Groyne	62	66	30.5	0.9	5.4	8.8	1.0	2.3	0.8	n.d.	54-970
Clutha River	24	68	33.4	1.0	4.0	10.0	0.8	1.5	0.6	4.9	approx 500
World Freshwater Average	-	140	58.6	7.8	11.0	15.0	4.3	6.0	2.7	13.2	-

Note :
All values as $g.m^{-3}$ except conductance (COND) which is micromhos/cm (corrected to 25 °C)
n = number of observations for which a mean value was obtained.

TABLE 7 : EFFECT OF LAKE ROXBURGH ON CLARITY OF THE CLUTHA RIVER. TURBIDITY AND SUSPENDED SEDIMENT DATA FOR THE CLUTHA RIVER AT ALEXANDRA AND AT ROXBURGH DAM (DATA OBTAINED BUT NOT REPORTED BY BIGGS AND McBRIDE, 1980).

	1979						1980								
	3/7	4/7	18/9	24/10	20/11	11/12	22/1	19/2	19/3	15/4	20/5	24/6	22/7	26/8	23/9
TURBIDITY F.T.U.															
Lake Roxburgh at Jetty	1.1	1.3	2.6	3.8	4.5	3.9	4.3	2.1	2.4	1.8	1.8	2.3	2.2	7.5	22
Clutha at Alexandra Bridge	1.5	1.7	2.7	2.7	7.6	5.1	5.7	2.5	2.5	2.2	2.3	4.1	3.0	43	34
SUSPENDED SEDIMENT $g.m^{-3}$															
Lake Roxburgh at Jetty	<1	4	8	3	7	10	9	2	4	6	6	8	5	12	31
Clutha at Alexandra Bridge	6	3	9	8	74	45	18	23	16	6	9	13	12	322	103


169°
170°
45°
46°
River Sampling Sites
Tributary Sampling Sites
Hydro Dam
Towns
Cromwell
Clyde Dam
Alexandra
Lake Roxburgh
ROXBURGH HYDRO
Roxburgh
Teviot R.
Benger Burn
Tima Burn
Talla Burn
Beaumont R.
BEAUMONT
Blackleugh Burn
Tuapeka R.
CLYDEVALE
Clutha R.
Balclutha
Boundary
Catchment
N
AREA OF MAP


% LESS THAN
PROBIT SCALE
ROXBURGH HYDRO
ALEXANDRA
MEAN = 15·1
MEAN = 22·0
99·5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
1 2 5 10 20 50 100 200 500 A(450)
1 2 5 10 20 50 100 200 500 A400U
0·5 1·0 2 5 10 20 50 100 TURB (F.T.U.)
2 1·5 1·0 0·7 0·5 0·3 0·2 0·1 SECCHI (m)