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KAWARAU RIVER:
WATER QUALITY INVESTIGATIONS

M. E. Livingston, R. D. Pridmore and R. H. S. McColl

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KAWARAU RIVER: WATER QUALITY INVESTIGATIONS

A report for Power Directorate,
Ministry of Works and Development

by

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KAWARAU RIVER: WATER QUALITY INVESTIGATIONS

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SUMMARY

This report describes the water quality characteristics of the Kawarau River and its main tributaries in the period 1983/84, and presents predictions of the effects impoundment by hydro-dams might have on river water quality.

The water quality was found to be high in terms of existing uses and it was predicted that impoundment would make little change to this. The waters are soft, low in plant nutrients, and reasonably clear except during floods when suspended solids principally from the Shotover River markedly increase water turbidity. An algal growth model indicated that with the low nutrient concentrations and low hydraulic residence times any of the proposed impoundments would not develop appreciably more planktonic algae that exists in the river at present.

INTRODUCTION

Surveys of the stream biology and water quality characteristics of the Kawarau River and tributaries were carried out by Water and Soil Directorate as part of the investigations by Power Directorate, Ministry of Works and Development (MWD) for the hydro-electric development of the Kawarau River. The present report describes the water quality studies, while the stream biology is described in a separate report prepared by Penny (1984). The engineering and environmental studies for the hydro investigations are reviewed in Anon (1985).

The objectives of the water quality study were:

1 to record the water characteristics of the present river system;

2 to identify any special water characteristics and values of the Kawarau River;

3 to predict changes in the water quality that could result from the various hydro-development proposals and any associated developments;

4 to determine whether there is potential to design any of the proposed developments in such a way as to reduce detrimental impacts to stream flora and fauna.

Background

The source of the Kawarau River is taken as the control gates on Frankton Arm of Lake Wakatipu. From here, the river flows some 55 km eastward to its confluence with the Clutha River at Cromwell. The main tributary, the Shotover River, has a major effect on the water characteristics of the Kawarau River below their confluence. Other tributaries include Rastus Burn, Arrow River, Nevis Burn, Gentle Annie, Roaring Meg and Bannock Burn. In its upper reaches the Kawarau River is essentially lakewater derived from Lake Wakatipu which is oligotrophic and clear. The Shotover River tributary introduces turbid water derived from glacial melt, and transports substantial quantities of sediment (McSaveney, 1978). In a study of the Clutha River system, Jowett and Hicks (1981) noted that most (≃ 90%) of the suspended sediment entering the lower Clutha River comes from the Kawarau River and in particular the Shotover River sub-catchment. Much of this suspended sediment is in the form of minute flakes of micaceous minerals (derived from schistose rocks) which have extremely low settling velocities and relatively high specific light scattering coefficients (ie, light scattered per unit of suspended sediment concentration) (Davies-Colley, 1985).

Water samples taken from the Kawarau River at Bannock Burn indicated that the water was low in nutrients, but had relatively high turbidity compared with the Clutha (Biggs and McBride, 1981). Preliminary water quality measurements carried out at selected tributary and mainstream sites in 1983 confirmed these findings (Table 1).

To assist in predictions of the likely water quality characteristics and appearance of possible future impoundments on the Kawarau, a water quality survey was carried out in summer (period of highest water temperatures) and winter (period of lowest flows) in 1984.

SURVEY DESIGN AND METHODS

The two main water quality issues likely to arise out of hydro-development on the Kawarau River are:

1 nutrient enrichment and consequent nuisance growths of algae and macrophytes; and

2 excessive suspended sediment, unattractive water appearance, and poor conditions for the development of flora and fauna.

TABLE 1: Water quality characteristics at four sites in the Kawarau River and in three of its tributaries, measured in a preliminary survey, 17 August 1983

	Sampling Site						
	Kawarau River				Tributaries		
	1	2	3	4	N	S	A
pH	-	-	7.4	7.5	7.3	7.6	7.6
Conductivity at 25°C (mS/m)	5.7	6.4	5.9	6.4	4.2	9.6	10.4
Turbidity (Formazin Turbidity Units [FTU])	1.2	3.6	3.9	5.9	1.1	15.0	4.3
Suspended Solids (g/m^3 SS)	0.57	23.2	27.9	43.0	5.8	121.6	31.2
Absorbance - visible @ 400 nm 1 cm light path, filtered sample (Abs x 1000)	1	2	7	10	5	5	5
Absorbance - visible @ 400 nm 1 cm light path, unfiltered sample (Abs x 1000)	1	9	10	13	11	31	16
Absorbance - ultraviolet @ 270 nm 1 cm light path, filtered sample (Abs x 1000)	6	9	16	22	34	19	22
Absorbance - ultraviolet @ 270 nm 1 cm light path, unfiltered sample (Abs x 1000)	9	22	24	30	45	62	41
Total Hardness (g/m^3 as $CaCO_3$)	24.0	27.9	28.4	28.6	-	-	-
Total Alkalinity (g/m^3 as $CaCO_3$)	23.0	26.5	26.0	25.5	17.8	38.8	44.5
Dissolved Reactive Phosphorus (mg/m^3 P)	1	1	1	2	5	1	1
Ammonia-nitrogen (mg/m^3 N)	4	4	5	7	7	7	13
Nitrate-nitrogen (mg/m^3 N)	41	40	41	43	18	41	72
Chloride (g/m^3 Cl)	0.7	0.7	0.8	0.9	1.3	0.6	0.6
Sulphate (g/m^3 SO_4)	4.1	4.7	5.1	5.3	3.7	5.2	3.8
Silica (g/m^3 Si)	1.5	1.6	1.6	1.7	3.3	1.9	2.5
Total Phosphorus (mg/m^3 P)	2	9	17	24	10	38	21
Total Dissolved Phosphorus (mg/m^3 P)	<2	2	7	3	10	3	5
Total Kjeldahl Nitrogen (mg/m^3 N)	10	30	20	20	45	20	90
Chemical Oxygen Demand (g/m^3 O_2)	<1	<1	<1	<1	2	<1	2
Sodium (g/m^3 Na)	1.05	1.03	1.08	1.23	2.09	1.11	1.36
Potassium (g/m^3 K)	0.39	0.43	0.45	0.48	0.42	0.64	0.61
Calcium (g/m^3 Ca)	8.75	10.11	10.23	10.23	5.57	15.59	15.83
Magnesium (g/m^3 Mg)	0.50	0.64	0.67	0.72	1.07	1.07	1.77

Kawarau River sites (map reference in brackets): 1 (S132: 620705); 2 (S132: 730737); 3 (S133: 759736); 4 (S133: 884695)

Nevis River site: N (S133: 876674); Shotover River site: S (S132: 638747); Arrow River site: A (above Arrowtown)

Nutrient enrichment can enhance biological productivity with benefits to the fishery, but if nutrient enrichment is excessive algal blooms and nuisance growths of macrophytes can develop. Suspended sediments can affect water appearance by changing both colour and clarity. Suspended sediments may limit the growth of algae and macrophytes by reducing light penetration. Excessive suspended sediments may also harm aquatic animals and reduce the quality of fisheries.

The water quality properties measured in this survey are given in Table 2 and the sample sites used are indicated in Figure 1. Each site was sampled four times each in summer (February-March 1984) and winter (July 1984) by staff of Project Office, MWD, Cromwell.

For each sampling two acid-washed, one-litre bottles were filled at each site. The bottles were stored in an ice chest and freighted to the Hydrology Centre, MWD, Christchurch for analysis within 24 hours of sampling. Temperature and pH were measured on site on each occasion and the state of the river level (normal, rising, falling) was recorded. Analytical methods used at the Hydrology Centre were standard (APHA, 1975).

TABLE 2: Water quality characteristics measured and site locations for the summer and winter surveys of the Kawarau River and its tributaries, 1984

Symbol	Determinand (Units)
K_{25}	Conductivity (mS/m)
DRP	Dissolved reactive phosphorus (mg/m^3 P)
NO_3N	Nitrate-nitrogen (mg/m^3 N)
NH_4N	Ammonia-nitrogen (mg/m^3 N)
Cl	Chloride (g/m^3 Cl)
TDP	Total dissolved phosphorus (mg/m^3 P)
TKN	Total Kjeldahl nitrogen (mg/m^3 N)
FTU	Turbidity (FTU)
SS	Suspended solids (g/m^3)
Af	Absorbance 270 nm (filtered)
Au	Absorbance 270 nm (unfiltered)
Time	Time
T	Temperature (°C)
pH	pH

Sampling Dates

27 February 1984	summer
5 March 1984	"
13 March 1984	"
19 March 1984	"
9 July 1984	winter
16 July 1984	"
23 July 1984	"
30 July 1984	"

Site locations and map references

Kawarau River		Tributaries		
K1	S132:620705	KS	Shotover	S132:635746
K2	S132:660729	KRb	Rastus Burn	S132:680735
K3	S132:709742	KH	Hayes Outlet	S132:672749
K4	S133:810725	KA	Arrow	S132:715772
K5	S133:884695	KN	Nevis	S133:878675
K6	S133:991656	KRm	Roaring Meg	S133:905750
K7	S133:018689	KB	Bannock Burn	S133:995658

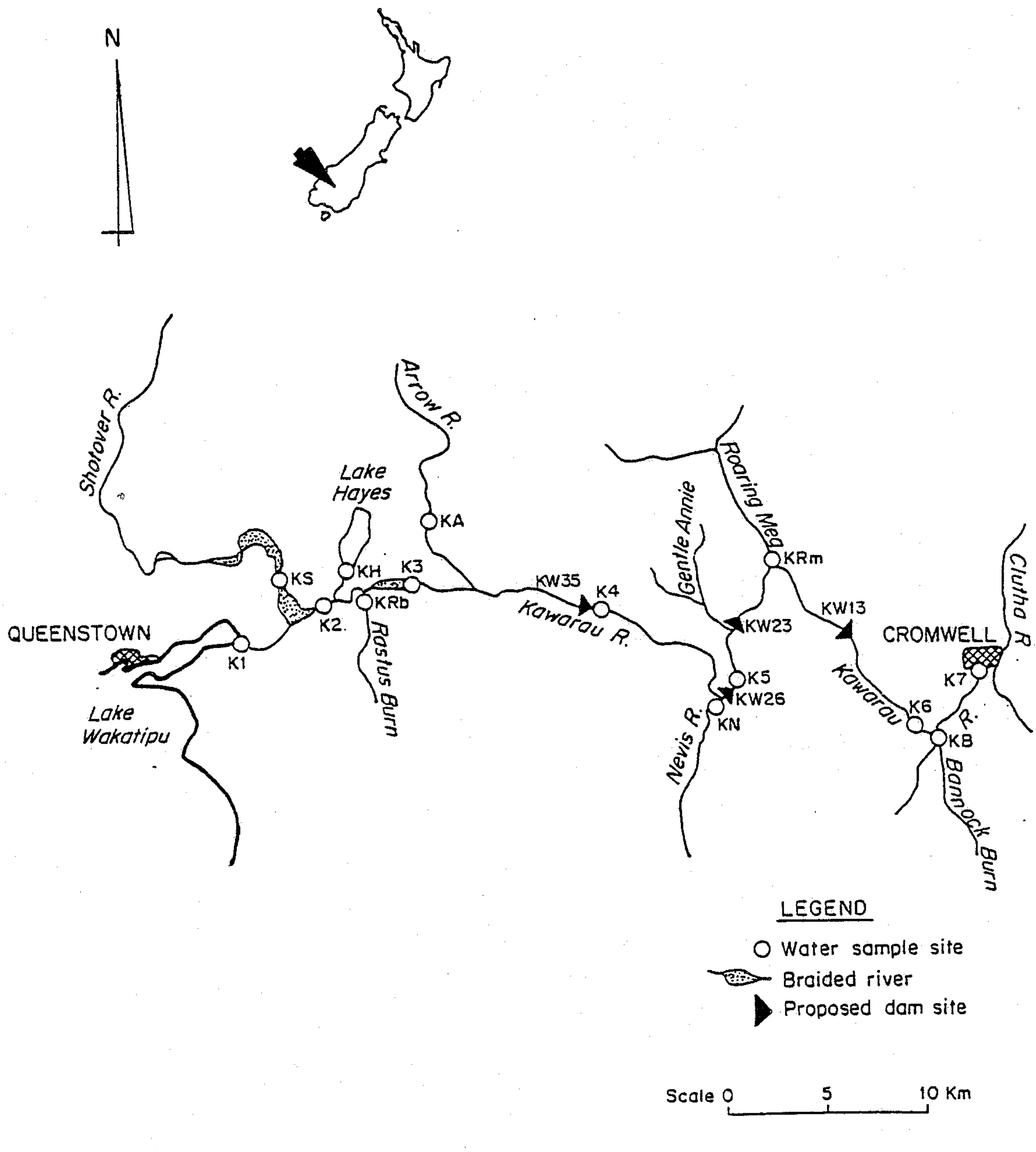

Figure 1 Water quality sampling sites, Kawarau River and tributaries, summer and winter 1984. See Table 2 for site codes and map references.

SURVEY FINDINGS

The water of the Kawarau River can be classified as a relatively soft, poorly buffered water of low ionic strength on the basis of its low total hardness (< 29 g/m^3 as $CaCO_3$), low total alkalinity (< 27 g/m^3 as $CaCO_3$) and low conductivity (< 6.5 mS/m) (Table 1). The concentrations of major ions found in the river are similar to those of other New Zealand flowing waters and are about half the "world freshwater average" (Table 3). The river's pH was about neutral (median 7.5) and did not fluctuate outside the "acceptable" and usual range of 6 to 9 for freshwaters (Table 4). The organic content of the water was low as indicated by the low levels of chemical oxygen demand (< 1 g/m^3 O_2) and the predominantly low light absorbances of filtered samples (A270F < 20) (Tables 1, 4).

Concentrations of the plant nutrients, nitrogen and phosphorus, in the Kawarau River waters were low (Table 5), and can be explained by the oligotrophic, low productivity, condition of the source, Lake Wakatipu. The nutrient concentrations are similar to those reported by Biggs and McBride (1981) for the Kawarau River at Bannock Burn between July 1979 and September 1980 and to those given by Davies-Colley (1985) for the nearby Clutha River (Table 6).

Nitrate and total kjeldahl nitrogen tended to increase below the river source (site K1) (Table 4). The Arrow River, which receives sewage inputs from Arrowtown and had the highest nitrate

TABLE 3: Comparison of solute concentrations in New Zealand rivers with the world freshwater average (after Bryers, 1985). All values as g/m^3 except conductivity which is mS/m (corrected to 25°C).

River (and location)	Conductivity	HCO_3	Cl	SO_4	Ca	Mg	Na	K	Range of Discharge (m^3/s)
Waikato River at Lake Taupo outlet	11.8	45.3	9.1	5.8	5.9	2.5	14.3	2.1	134-278
Waikato River at Mercer	15.5	42.0	19.2	7.2	7.0	2.3	18.6	3.2	122-1806
Motu River at Houpoto	9.9	36.0	5.6	8.0	10.6	1.6	5.5	0.9	10-150
Mohaka River at Willow Flat	9.9	43.7	4.4	6.0	10.1	1.5	6.9	1.0	23-152
Waimakariri River at Halkett Groyne	6.6	30.5	0.9	5.1	8.8	1.0	2.3	0.8	54-970
Clutha River*	6.8	33.4	1.0	4.0	10.0	0.8	1.5	0.6	33-4760
World freshwater average (from Livingstone, 1963)	14.0	58.6	7.8	11.0	15.0	4.3	6.0	2.7	-
Kawarau River	6.1	25.0	0.8	4.8	9.8	0.6	1.1	0.4	170-390

* Mean of results from Roxburgh Hydro, Beaumont, and Clydevale.

TABLE 4: Water quality characteristics of seven Kawarau River sites and seven tributaries, summer (February-March) 1984 and winter (July) 1984. Detection limits (<); dissolved reactive phosphate-P and nitrate-N, 1 mg/m^3; total dissolved P, 2 mg/m^3; suspended solids 1 g/m^3. See Table 2 for symbols and site location.

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au x 1000	Time	T °C	pH
27 February 1984*														
Kawarau River 1	5.4	<	7	3	0.4	2	25	0.5	<	6	11	1543	16.1	7.6
" " 2	5.3	<	7	3	0.4	4	33	0.4	1	6	10	1555	16.2	7.7
" " 3	6.0	1	9	9	0.4	6	159	1.4	24	6	16	1615	16.5	7.5
" " 4	6.0	<	15	6	0.4	5	79	2.3	20	5	17	1450	16.4	7.6
" " 5	5.7	<	11	8	0.4	6	42	2.3	51	6	17	1436	16.6	7.6
" " 6	6.3	<	16	3	0.4	3	33	2.4	43	6	21	1134	15.7	8.0
" " 7	6.1	<	14	6	0.5	5	673	3.4	31	7	27	1109	15.8	7.5
Shotover River	8.5	<	11	5	0.3	3	36	2.4	18	6	15	1715	16.0	7.5
Rastus Burn	6.7	<	7	5	0.4	3	64	0.6	<	9	15	1605	19.9	7.7
Hayes Outlet	10.6	2	6	7	1.4	10	263	4.5	4	26	44	1730	21.4	8.7
Arrow River	10.1	3	13	6	0.6	7	129	2.3	2	10	14	1625	15.0	7.8
Nevis River	3.9	1	10	5	0.6	6	872	0.9	<	13	21	1445	16.2	7.8
Roaring Meg	6.4	4	12	8	0.4	4	115	0.8	1	13	22	1150	12.2	8.1
Bannock Burn	27.7	3	5	11	7.2	8	179	8.0	16	44	61	1124	16.2	8.4

* River flows falling, Hayes Outlet normal; air temperature 24°C; fine, no cloud.

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au x 1000	Time	T °C	pH
5 March 1984*														
Kawarau River 1	5.2	<	10	5	0.5	<	38	0.4	<	7	11	1340	16.0	7.9
" " 2	6.3	<	13	5	0.4	<	69	8.4	140	10	40	1350	14.7	7.5
" " 3	5.7	<	10	4	0.6	<	192	13.0	118	10	42	1406	15.4	7.5
" " 4	6.2	<	14	5	0.6	<	69	7.8	115	8	32	1025	15.0	7.3
" " 5	5.9	<	12	5	0.5	<	52	4.9	67	8	32	1006	15.1	7.3
" " 6	6.2	<	14	4	0.6	<	57	5.0	63	7	31	0915	15.5	8.0
" " 7	6.3	<	15	4	0.6	10	52	4.5	86	8	29	0848	15.5	7.9
Shotover River	6.9	1	14	4	0.4	<	168	28.0	323	8	116	1520	12.6	7.7
Rastus Burn	4.7	<	6	6	0.4	<	90	0.5	2	16	23	1357	15.9	7.4
Hayes Outlet	11.9	1	5	6	1.2	3	209	2.2	2	25	39	1540	18.6	8.7
Arrow River	8.4	1	63	8	0.4	<	109	2.5	18	22	36	1412	13.1	7.6
Nevis River	4.4	1	7	5	0.6	4	56	1.4	4	22	31	1020	14.0	7.5
Roaring Meg	4.1	5	7	5	0.7	7	111	1.4	5	28	37	0950	12.9	7.4
Bannock Burn	20.2	2	4	5	5.7	9	149	10.0	15	37	56	0906	15.3	8.2

* River flows rising, Hayes Outlet normal; air temperature 18°C; overcast, showers.

TABLE 4 (continued)

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au x 1000	Time	T °C	pH
13 March 1984*														
Kawarau River 1	5.4	<	11	7	0.5	<	98	0.7	<	8	10	1325	15.7	7.4
" " 2	5.2	<	18	9	0.6	<	56	1.5	4	8	11	1338	15.6	7.5
" " 3	5.5	<	17	9	0.5	<	58	2.4	15	9	15	1400	15.5	7.3
" " 4	5.4	<	35	9	0.6	<	142	2.3	32	7	15	1332	14.5	7.3
" " 5	5.9	<	18	9	0.6	5	75	2.4	11	8	15	1325	15.0	7.5
" " 6	5.6	<	13	7	0.5	<	71	4.4	47	7	22	0900	14.5	7.2
" " 7	5.9	<	15	9	0.5	<	46	3.3	37	8	20	0825	14.5	7.3
Shotover River	8.1	<	15	3	0.4	2	41	8.1	59	10	31	1456	12.7	7.3
Rastus Burn	6.0	<	11	4	0.4	<	66	0.7	5	13	21	1347	16.0	7.2
Hayes Outlet	12.2	1	4	5	1.4	<	247	2.6	2	30	43	1540	19.0	8.7
Arrow River	9.9	<	80	5	0.4	3	61	1.1	16	17	21	1410	12.1	7.5
Nevis River	3.8	2	7	3	0.7	2	84	0.6	<	23	29	1129	12.1	7.9
Roaring Meg	4.8	3	6	7	0.5	4	70	0.6	<	23	32	1005	10.0	7.1
Bannock Burn	19.7	<	7	7	5.0	3	363	4.5	5	48	59	0845	12.2	7.7

* River flows above normal, tributaries normal; air temperature 20°C; fine, 1/8 cloud, light wind

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au x 1000	Time	T °C	pH
19 March 1984*														
Kawarau River 1	5.7	1	9	7	6.3	6	108	0.4	1	10	11	1230	15.5	7.7
" " 2	5.9	<	30	8	0.8	5	169	1.0	6	10	14	1245	15.0	7.5
" " 3	6.2	<	19	11	1.0	6	390	1.5	8	9	18	1305	15.0	7.4
" " 4	6.1	<	11	6	0.7	5	145	1.5	38	6	16	1100	14.2	7.5
" " 5	6.1	<	9	6	0.9	6	159	1.4	22	7	18	1045	14.0	7.2
" " 6	5.9	<	14	4	1.1	5	119	2.5	46	8	23	0907	13.9	7.5
" " 7	5.9	<	81	7	0.8	7	299	2.4	65	9	28	0945	13.9	7.5
Shotover River	9.2	<	15	9	1.1	3	183	4.6	30	15	28	1400	12.7	7.6
Rastus Burn	3.2	1	5	5	0.1	8	158	3.2	28	18	31	1255	12.5	7.5
Hayes Outlet	13.1	2	3	7	1.3	10	586	1.5	12	32	48	1415	18.4	8.4
Arrow River	10.1	2	81	5	0.7	7	260	1.1	6	16	26	1320	10.4	7.7
Nevis River	2.8	3	6	5	0.6	17	250	1.6	17	51	65	1055	9.3	7.2
Roaring Meg	4.6	4	3	9	0.3	12	362	0.8	7	22	31	1025	9.5	7.5
Bannock Burn	17.9	2	6	5	4.3	8	396	3.8	7	40	59	0935	11.4	7.9

* River flows normal; air temperature 20°C; fine, 1/8 cloud.

TABLE 4 (continued)

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au x 1000	Time	T °C	pH
9 July 1984*														
Kawarau River 1	4.6	<	16	4	0.5	3	46	0.7	1	8	9	1330	9.5	7.7
" " 2	4.9	<	17	6	0.5	9	45	0.9	6	7	9	1345	8.4	7.9
" " 3	5.1	<	18	7	0.6	<	50	1.3	5	10	14	1415	7.5	8.2
" " 4	5.1	<	22	5	0.6	4	55	1.4	7	8	12	1120	7.0	7.9
" " 5	4.9	<	21	8	0.5	24	47	1.6	26	10	17	1110	7.0	7.9
" " 6	4.6	<	24	6	0.6	10	39	1.9	14	9	13	1010	6.5	8.0
" " 7	4.9	<	26	4	0.6	3	<	0.9	11	8	17	1020	6.6	7.9
Shotover River	7.4	<	5	6	0.5	10	11	2.4	13	10	14	1525	2.3	8.0
Rastus Burn	7.4	<	<	5	0.7	3	27	0.8	1	13	15	1400	5.0	8.4
Hayes Outlet	9.4	10	22	114	1.5	18	164	0.7	4	31	38	1540	6.5	8.1
Arrow River	8.5	<	113	7	0.6	<	8	0.7	3	11	14	1430	1.9	8.0
Nevis River	3.8	<	2	5	0.9	3	20	0.5	6	17	19	1100	0.9	8.0
Roaring Meg	4.9	4	10	11	0.6	23	24	2.1	2	14	19	1610	2.0	8.2
Bannock Burn	18.2	1	19	12	4.8	5	128	1.3	3	26	26	1000	2.3	7.1

* River flows low, Shotover, Arrow and Nevis Rivers very low, Hayes Outlet normal; air temperature 10°C; fine, 1/8 cloud, calm.

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au x 1000	Time	T °C	pH
16 July 1984*														
Kawarau River 1	4.6	<	19	6	0.6	<	11	0.4	1	8	9	1200	8.8	-
" " 2	4.9	<	17	4	0.5	23	<	0.5	2	7	9	1300	8.2	-
" " 3	4.9	<	18	5	0.5	5	<	0.6	11	8	11	1345	7.4	-
" " 4	4.9	<	26	4	0.6	<	8	2.5	17	7	16	1505	7.0	-
" " 5	4.6	<	21	5	0.5	8	39	2.4	101	8	18	1510	6.7	-
" " 6	4.0	<	24	6	0.6	10	47	1.6	14	8	16	1030	6.5	-
" " 7	4.6	<	15	11	0.7	<	108	1.5	12	10	17	1045	6.7	-
Shotover River	6.3	<	12	6	0.6	<	14	1.5	4	8	15	1115	2.8	-
Rastus Burn	5.7	<	<	2	0.6	<	20	2.2	8	13	24	1335	4.5	-
Hayes Outlet	9.1	7	26	81	1.4	9	223	3.5	3	31	42	1130	5.5	-
Arrow River	8.3	<	108	3	0.7	2	17	2.7	5	10	22	1350	2.8	-
Nevis River	4.6	<	<	3	0.9	<	10	1.3	7	17	29	1500	2.0	-
Roaring Meg	6.9	3	26	6	0.7	<	68	0.9	3	14	17	1045	2.0	-
Bannock Burn	19.3	<	9	3	5.8	<	101	4.9	24	24	39	1015	2.6	-

* River flows low, Shotover, Arrow and Nevis Rivers very low, Hayes Outlet normal; air temperature 8°C; fine, snow to low levels.

TABLE 4 (continued)

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au	Time	T °C	pH
23 July 1984*														
Kawarau River 1	4.6	<	23	4	0.6	6	87	1.0	2	8	9	1245	8.5	7.2
" " 2	4.3	<	25	4	0.6	3	107	1.1	6	9	15	1315	8.0	6.8
" " 3	4.2	<	28	4	0.6	3	57	2.0	42	11	18	1330	7.4	7.2
" " 4	5.7	<	28	4	0.6	7	70	1.3	45	13	30	1050	7.2	6.8
" " 5	5.4	<	31	5	0.7	3	74	2.8	59	15	21	1100	6.5	6.8
" " 6	5.7	<	32	5	0.7	6	71	3.6	29	18	34	0945	6.9	7.2
" " 7	5.7	<	32	7	0.7	3	122	3.6	82	19	36	1000	6.9	7.2
Shotover River	7.0	<	26	5	0.6	5	93	4.9	93	20	43	1430	4.0	8.1
Rastus Burn	4.8	4	25	5	0.7	8	165	23.0	103	22	84	1300	4.9	7.6
Hayes Outlet	11.3	11	33	44	1.6	14	261	1.9	5	30	39	1445	6.4	7.6
Arrow River	6.5	3	91	9	0.7	7	103	2.5	23	22	40	1345	4.0	7.2
Nevis River	3.8	3	17	3	1.2	7	198	2.3	14	46	64	1045	3.0	6.8
Roaring Meg	3.8	7	35	6	0.6	13	47	2.6	9	42	51	1030	3.7	6.9
Bannock Burn	18.3	6	61	7	5.7	8	234	6.5	29	62	87	0930	4.0	7.9

* River flows normal; air temperature 10°C; partly cloudy, little wind.

	K_{25} mS/m	DRP mg/m^3	NO_3N mg/m^3	NH_4N mg/m^3	Cl g/m^3	TDP mg/m^3	TKN mg/m^3	FTU	SS g/m^3	Af x 1000	Au	Time	T °C	pH
30 July 1984*														
Kawarau River 1	3.8	<	22	6	0.6	3	120	0.6	<	7	11	1315	9.0	7.6
" " 2	3.5	<	20	6	0.5	6	112	1.0	33	8	15	1340	8.4	7.8
" " 3	4.8	<	23	8	0.5	4	155	1.3	14	9	18	1400	8.0	8.0
" " 4	4.3	<	28	6	0.6	<	87	1.7	10	7	20	1030	7.2	7.4
" " 5	4.3	1	32	6	0.6	6	82	1.7	15	11	22	1045	7.2	6.9
" " 6	4.3	<	23	5	0.6	<	7	1.3	13	10	18	0945	6.9	7.3
" " 7	4.3	<	31	5	0.6	2	60	2.9	15	9	23	0900	6.9	6.9
Shotover River	6.5	<	21	7	0.5	<	64	16.0	197	17	56	1500	5.5	8.2
Rastus Burn	7.5	1	10	8	0.7	<	50	24.0	85	18	104	1340	8.5	8.2
Hayes Outlet	10.8	9	41	52	1.6	11	218	1.0	5	31	41	1125	7.0	8.0
Arrow River	6.5	2	82	10	0.9	3	71	2.2	17	10	30	1420	5.5	8.1
Nevis River	4.1	2	12	6	1.0	5	75	4.2	8	37	54	1025	3.5	7.9
Roaring Meg	4.3	6	36	4	0.6	5	36	1.5	9	21	34	1000	3.9	7.5
Bannock Burn	17.2	2	42	4	5.6	3	155	3.8	4	35	51	0930	4.0	7.8

* River flows very low, Roaring Meg and Bannock Burn low, Rastus Burn and Hayes outlet normal; air temperature 10.5°C; fine, partly cloudy.

TABLE 5: Summary statistics for nutrient data collected during the February-March 1984 and July 1984 surveys of the Kawarau River. Median and interquartile values are for the combined data set. All values are in units of mg/m^3.

Determinand	Median	Interquartile Range	Number of Observations
Total dissolved phosphorus (TDP)	3.6	<2 to 6.0	56
Dissolved reactive phosphorus (DRP)	<1	<1 to <1	56
Nitrate (NO_3-N)	18	14 to 24	56
Ammonium (NH_4-N)	6	4 to 7	56
Total Kjeldahl nitrogen (TKN)	69	46 to 108	56

TABLE 6: Comparison of plant nutrient concentrations in the Kawarau and Clutha Rivers. All values are in units of mg/m^3.

River	Ammonium (NH_4-N)	Nitrate (NO_3-N)	Total Kjeldahl Nitrogen (TKN)	Total Dissolved Phosphorus (TDP)	Dissolved Reactive Phosphorus (DRP)	Source
Kawarau (1984)	6	18	69	3.6	<1	This study. Table 4
Kawarau (1979-1980)	7	26	85	-	1	Biggs and McBride (1981)
Clutha (1982-1984)	5	40	60	3.0	2	Davies-Colley

concentrations of the tributaries, appeared to cause a small increase in the nitrate concentration of the Kawarau River between sites K3 and K4 on several sampling occasions. Phosphorus concentrations showed no trend downstream. The Lake Hayes Outlet tributary (KH) which flows from a part of the catchment with agricultural use had relatively high concentrations of nitrogen and phosphorus in winter but did not cause observable increases in the nitrogen and phosphorus concentrations in the Kawarau River (Table 4). In total, Rastus Burn, Hayes Outlet, Roaring Meg and Bannock Burn contribute only 2% of the mean flow in the Kawarau River. The Shotover, Arrow and Nevis Rivers contribute 18%, 1.5% and 4.5% respectively (Anon 1985). The chemical concentrations of the smaller tributaries are thus considerably diluted on entering the main river.

The high ratio of dissolved inorganic nitrogen:phosphorus compounds in the river waters ($NH_4 + NO_3 - N:DRP = > 12$) found at most sites on most occasions (based on data from Table 4) suggests that phosphorus is more likely to limit phytoplankton growth rate than nitrogen (cf. Forsberg et al., 1980).

Water clarity in the Kawarau River was reasonably high (FTU, interquartile range 1.0-2.5, n = 56, Table 4), except during flood events when increased suspended solid loads, principally from the Shotover River increased the river's turbidity (Figure 2). Sampling did not include a major flood event; the results for 5 March 1984 when river flows were rising include the highest suspended sediment value recorded in this study for the Shotover

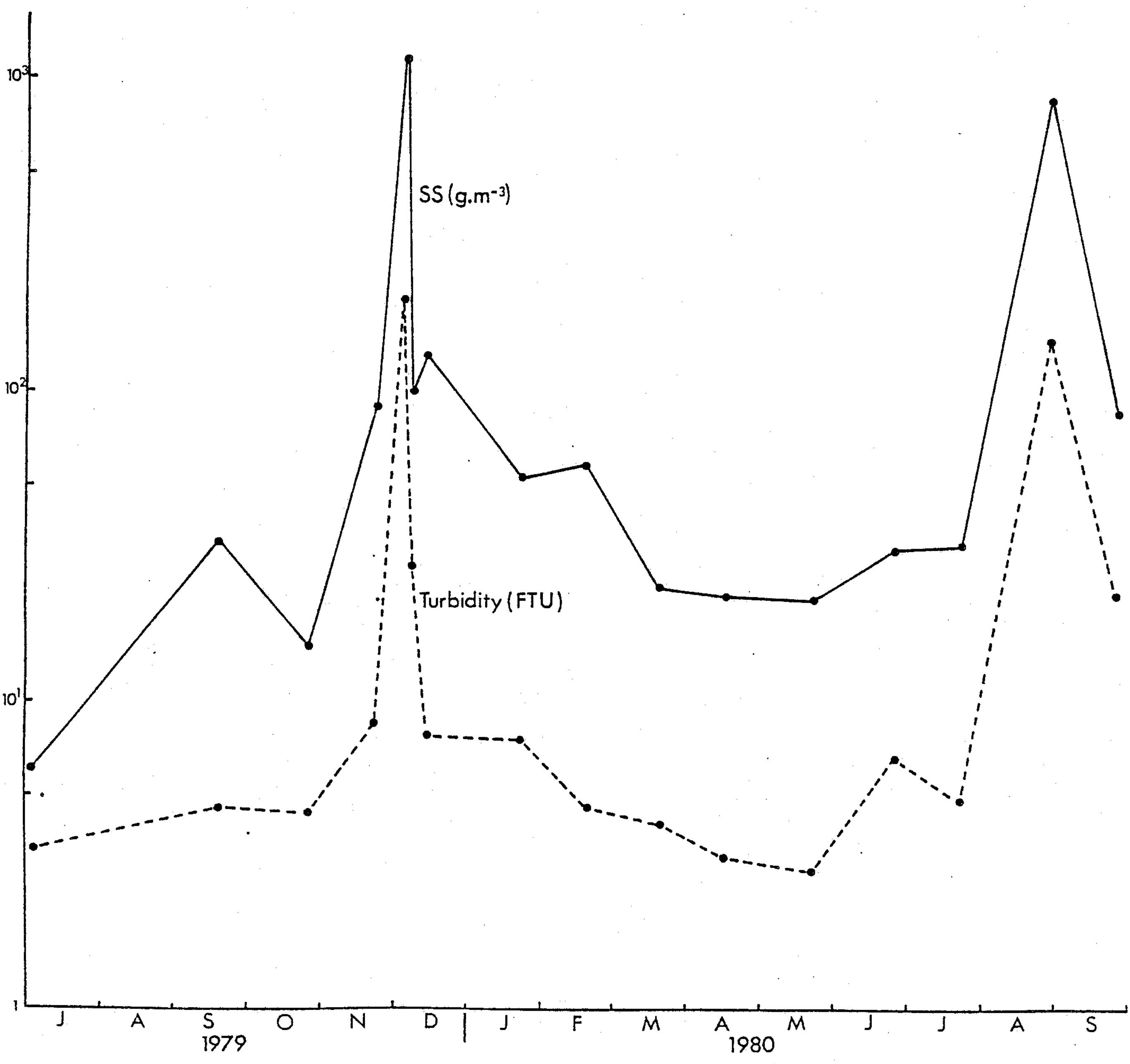

Figure 2 Fluctuations in turbidity and suspended solid concentration (SS) in the Kawarau River at Bannock Burn. Data from Biggs and McBride (1981).

River (323 g/m^3). At an annual suspended sediment yield of 1.12 x 10^6 t (Hicks 1980, July 1967-July 1977) and a mean flow of 38 m^3/s, mean annual suspended sediment concentration in the Shotover River would be several times higher than this at around 940 g/m^3. Downstream increases in the turbidity and light absorbance (at 270 nm) of the Kawarau River were observed on most sampling occasions; these increases were usually coupled with increases in suspended solids concentration (Table 4). The increases in the upper river were attributable to inputs from the Shotover River but those increases observed frequently between sites K4 and K5 could not attribute to a tributary input and may have been caused by channel erosion. There was no downstream increase in the light absorbance of filtered water samples (Table 4).

PREDICTED WATER CHARACTERISTICS OF PROPOSED IMPOUNDMENTS

Because the residence time of water is less than 0.5 day in each of the impoundments proposed for the Kawarau River (Table 7), the fine sediment suspended in the water column is not expected to settle out and the turbidity of the water should remain much the same as at present. This conclusion is supported by observations made on Lake Roxburgh (Table 8), a hydro dam on the nearby Clutha River with similar suspended sediment characteristics and a water residence time of 1.7 days (see Davies-Colley, 1985). The predominant suspended sediment levels in the proposed impoundments are expected to be too low to significantly interfere with any

TABLE 7: Hydraulic residence times of some proposed Kawarau impoundments

Damsite Location	Hydraulic Residence Times
KW 13	6-7 h
KW 23	8-9 h
KW 26	8-10 h
KW 35	3-4 h

TABLE 8: Effect of Lake Roxburgh on clarity of the Clutha River (from Davies-Colley, 1985)

	1979 (day/month)					
	3/7	4/7	18/9	24/10	20/11	11/12
Turbidity (FTU) at Alexandra Bridge (up-river of Lake Roxburgh)	1.5	1.7	2.7	2.7	7.6	5.1
Turbidity (FTU) at Lake Roxburgh jetty	1.1	1.3	2.6	3.8	4.5	3.9

	1980 (day/month)								
	22/1	19/2	19/3	15/4	20/5	24/6	22/7	26/8	23/9
Turbidity (FTU) at Alexandra Bridge (up-river of Lake Roxburgh)	5.7	2.5	2.5	2.2	2.3	4.1	3.0	43.0	34.0
Turbidity (FTU) at Lake Roxburgh jetty	4.3	2.1	2.4	1.8	1.8	2.3	2.2	7.5	22.0

fishery that might develop. There is no evidence that suspended solids concentrations less than 25 g/m^3 harm fisheries and good fisheries can normally be maintained at concentrations in the range 25-80 g/m^3 (Alabaster and Lloyd 1980).

Impoundment of the Kawarau River is also unlikely to affect phytoplankton abundance. This can be examined using a model that describes algal growth in relation to nutrient supply and residence time of the water in the impoundment. Assuming that phytoplankton growth will be limited by phosphorus, the model of Pridmore and McBride (1984) can be used to predict changes in phytoplankton abundance (as chlorophyll a) in the river. The following data were used in the model: concentration of biologically available phosphorus, 10 mg/m^3; the total hydraulic retention time for all five impoundments, 2 days; maximal specific phytoplankon growth rate, 0.80/day; initial chlorophyll a concentration of impoundment, 2 mg/m^3; chlorophyll a concentration of inflow, 2 mg/m^3. These data were chosen to give the "worst case" likely phytoplankton response for the river system. The model predicts that chlorophyll a will not exceed 4 mg/m^3 even if all five impoundments were built in the Kawarau River. This chlorophyll a concentration is typical of mesotrophic to oligotrophic lakes (McColl 1972) and will not deleteriously affect any of the existing or proposed water uses for the Kawarau River.

The proposed impoundments, because of their low residence time and the rocky and infertile characteristics of the land to be inundated, would probably equilibrate to the new water conditions quickly and would have water characteristics not appreciably different from the present characteristics of the river. Inputs of coarser solids from the tributary rivers would settle out and form deltas or deposits on river terraces, but this would not appreciably reduce the concentrations of fine sediments in the water column or the turbidity.

DEVELOPMENT CONSIDERATIONS

Care would have to be taken during the construction phase of any development to prevent excess inputs to the river of suspended solids, nutrients, or potentially toxic materials, and to ensure downstream water quality and aquatic life were adequately protected.

There are possibilities for manipulating water quality in some of the proposed impoundments by diversion of some of the tributary inputs. For example, the Nevis River could be diverted into the residual river below KW23. Significant improvements in the water colour and clarity would be achieved if it was possible to reduce sediment input from the Shotover catchment. McSaveney (1978) discusses ways this might be possible.

The removal of topsoil from areas that could be inundated would reduce the degree of nutrient enrichment in the early stages of filling and establishment of the impoundments, and could reduce the suitability of the edges of the impoundments for macrophyte growth. However, water residence times of the impoundments would be so short that such enrichment would probably be short lived and unlikely to cause appreciable increases in algal growth in the impoundments. It is not recommended that topsoil removal be carried out solely for water quality reasons.

CONCLUSIONS

The data collected in this study and taken from other reports demonstrate that the Kawarau River is of high water quality in terms of its existing uses. However, the Kawarau River is not identified as having any special or unique water quality characteristics. The water quality characteristics in the proposed impoundments, once established, would be similar to those of the present river and the water quality would be high in terms of likely future uses. Hydro-generating operations of the proposed stations would not be expected to cause significant alterations of water quality characteristics from present.

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