Hydrology of small catchments in the Warra LTER Site: objectives and preliminary analysis

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Abstract

A major hydrology and water quality program has been established at the Warra Long-Term Ecological Research (LTER) Site. Weirs have been constructed on three streams, Warra Creek, Swanson Creek and King Creek, with a further 13 streams within the Warra Site sampled fortnightly.

The three objectives of the study are to (a) characterise the variability of water quality in a pristine stream, (b) determine the impact of logging on stream hydrology and (c) obtain an overview of the water quality within the Warra LTER area. Warra Creek, with a catchment of 442 ha, is to be retained as a pristine (control) catchment. Both Swanson Creek (84 ha) and King Creek (48 ha) catchments have been partially logged and further logging is planned.

Initial data on water quality and quantity are presented. The three streams with weirs carry water that is coloured with organic matter. Although base flow turbidity for Warra Creek is low (< 1 ntu), average turbidity is high at 11.5 ntu. Storm events in the area are generally associated with cold changes, resulting in drops in stream water temperature. Storm profiles are characterised by a rapid increase in stream flow followed by a gradual return to base levels. Turbidity is highest during initial storm flow, with a seasonal difference occurring in flow and turbidity.

Streams in the Warra LTER Site vary in their catchment geology and water chemistry. Work is under way to characterise the water colour and to determine the chemistry of the water.

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Introduction

Measurement of the quality and quantity of water flowing from forested catchments has been the subject of many studies in Australia and overseas (e.g.Vertessy 1999; Croke 1999). Forested catchments provide much of the water used for rural and domestic purposes in Tasmania and catchment health is of major interest to the public generally and authorities for water management (Otley 2001). In a catchment of defined geology and vegetation, water characteristics will vary with climatic conditions and natural disturbances such as fire. Changes also occur with land use, such as harvesting for timber and subsequent reforestation (Mackay and Cornish 1982; Mackay and Robinson 1987; Bren 1987). A code of practice in place in Tasmania for forest operations aims to protect water quality and flow on a catchment basis (Forest Practices Board 2000). The effectiveness of these prescriptions has been the subject of two large hydrology studies in northern Tasmania (Sustainable Development Advisory Council 1996; W. Neilsen, pers. comm.).

Detailed data on water quality and quantity flowing from undisturbed forested catchments allow analysis of natural

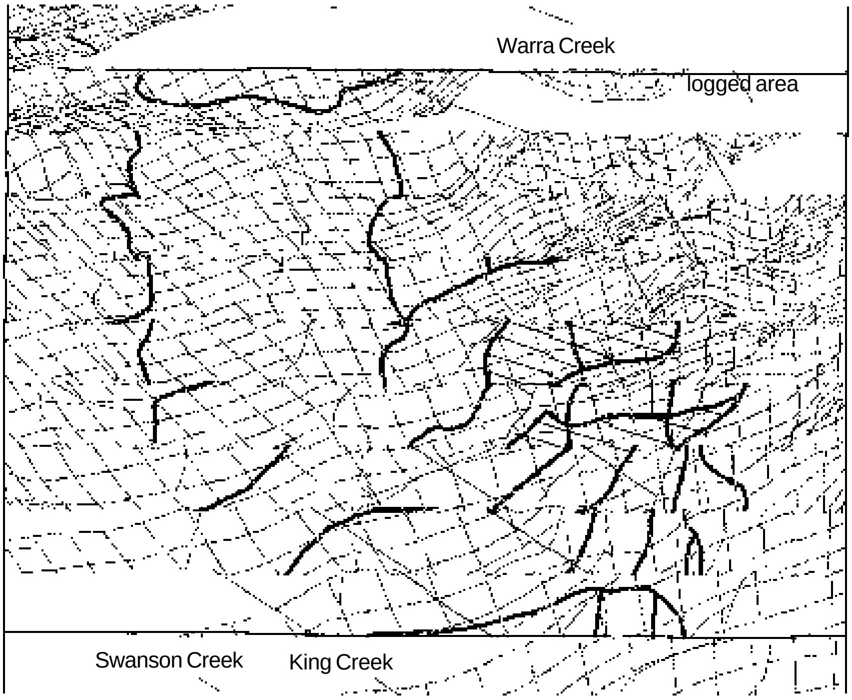

Figure 1. Landscape positioning of the three research catchments showing the area cut over in 1997.

variation and provide a benchmark for comparison with catchments elsewhere. Such data also provide information relevant to the study of biological systems within the catchment, such as stream biodiversity and evaluation of the effects of disturbance.

A major hydrology research project has been established within the Warra LTER Site (Ringrose and Meyer 2001). Weirs have been constructed on three of the streams (Warra Creek, Swanson Creek and King Creek) for continuous data collection, and a further 13 streams within the Warra LTER Site are sampled fortnightly. The overall hydrology project comprises three discrete sub-projects, which are interrelated but operate over varying time frames. The details of these three projects are given below.

1. Characterisation of a pristine stream

The major aim of this sub-project is to provide reference data on the flow and physical characteristics of a small, undisturbed stream (Warra Creek), draining a forested catchment within the Warra LTER Site. Stream flow and water quality data are collected using in-stream probes and field data loggers.

2. Determination of the effects of commercial logging on stream hydrology

This sub-project is intended as a multiple catchment study aimed at determining the hydrologic effects of forest logging, under the Tasmanian Forest Practices Code, on stream flow and water quality. It is an extension of the preceding project and aims to compare the hydrologic behaviour of the Warra Creek catchment, as the undisturbed control, to that of the proposed treated catchments of both Swanson and King Creeks.

3. Broadscale water sampling of the Warra LTER Site

Broadscale water sampling provides information on the physical water quality of the major rivers and streams within the

Table 1. Weirs established at the Warra LTER Site.

Weir	Purpose and condition	Catchment area (ha)	Geology
Warra	Control weir, for long-term characterisation	442	Dolerite
Swanson	Future logging; partially logged 1997 (24%)	84	Dolerite
King	Future logging; partially logged 1997 (47%)	48	Dolerite (80%) Sandstone (20%)

Warra LTER Site. This sub-project aims to determine whether the intensively studied sites mentioned above represent the broader environment of the Warra area. This database of water quality information will also serve as a reference point for future studies in accordance with the aims of the LTER concept. Sixteen sites in the Warra area, including the three weir catchments, are systematically sampled on a fortnightly basis.

This paper outlines the pre-treatment water quantity and quality data that have been collected to date from the Warra LTER Site.

Methods

Site description

The Warra Site is diverse, with altitudes ranging from 37–1260 m and various geological substrates. However, much of the Site is underlain by Jurassic dolerite. Other geologies include Permian sedimentary rocks, with massive sandstones and interbedded fossiliferous siltstones present as rafts showing contact metamorphism and as unaltered fault blocks within the dolerite. Precambrian orthoquartzites and siliceous metasediments occur in the western section and on the eastern side (between the ridge of Glovers Bluff and the Weld River). Cambrian age serpentinite, quartzites, siliceous glacial and riverine boulders also occur (Corbett 1997).

To minimise site differences, the three catchments on which weirs have been constructed are located adjacent to one another (Figures 1, 2). General catchment characteristics are listed in Table 1. A comparison stream of differing geology (Crystal Creek; Figure 2) is located separately for intensive study of site effects on water quality.

Warra Creek.—The Warra Creek catchment has an area above Warra Road of 442 ha. No forest operations have occurred in the past and none is planned in the future as this catchment will be used as the control in sub-project 2. The catchment drains from the eastern edge of Mount Frederick (altitude 600–750 m) in the World Heritage Area. The forest ranges from Photo-Interpretation type E4 to E2 (Stone 1998) throughout the catchment, with predominantly E3 in the upper catchment (i.e. mature eucalypts in the height range of 15–34 m) with an understorey of rainforest species. At lower altitudes, 350–600 m, the forest is mostly E2 (i.e. mature eucalypts in the height range of 41–55 m). In addition to the difference in altitude, the species change also indicates a change in geology from Triassic sandstone and Permian mudstone in the higher areas, to Jurassic dolerite in the lower catchment.

Swanson Creek.—Swanson Creek catchment has an area of 84 ha (Figure 1), draining from an altitude of 550 m and joins Warra Creek just below the road junction. It has some limited forestry activity within it, with the top 20 ha harvested in 1997 and burnt in 1998 as part of the coupe Warra 011B. The remaining 64 ha, comprising E3 forest grading down to E2, is planned for logging in the future. The geology of this catchment is Jurassic dolerite.

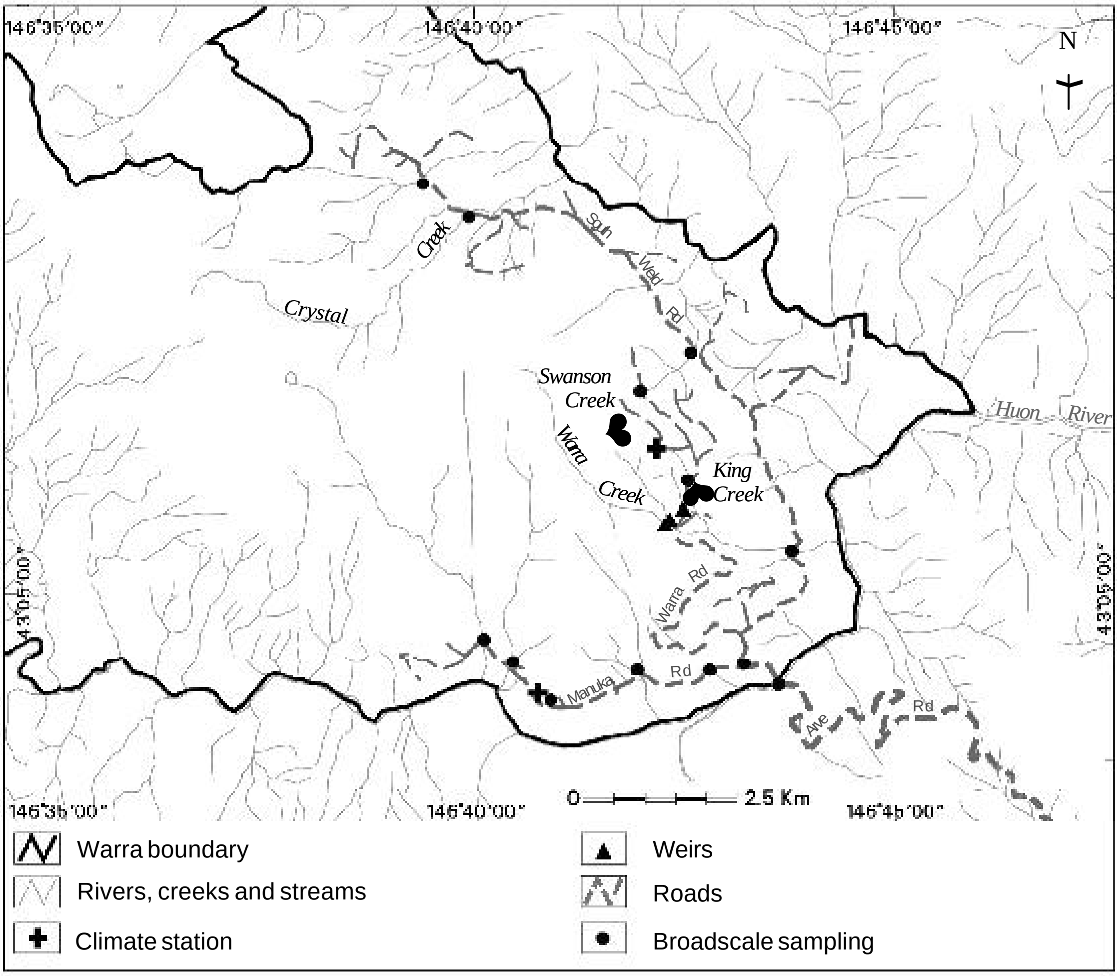

Figure 2. Location of hydrology sampling sites at the Warra LTER Site.

King Creek.—The King Creek catchment has an area above Warra Road of 48 ha, draining from an altitude of 480 m (Figure 1). It also has already had the top portion, a rather flat basin of 22 ha with an altitude range of only 20 m, harvested and burnt as part of the coupe Warra 011B. The remaining 26 ha comprises E1 and E2 forest (i.e. mature forest in the height range of 41–76 m). This area is planned for logging in the future. Since the catchment is less than 50 ha, this stream is presently treated as a Class 4 site. This means that a formal streamside reserve will not be required, and trees can be felled away from the stream but machinery will not be allowed closer than 10 m to the stream (Forest Practices Code 2000).

Water quantity measurements

Since July 1998, the streamflow of Warra, Swanson and King Creeks has been measured continuously at the weirs. Each weir consists of a small stilling pond impoundment behind a concrete wall. As water flows down the creek it is forced to pool behind the concrete wall and thus passes through a calibrated 120° sharp-edged, stainless steel 'V'-notch blade, before returning to the creek.

A continuous record of the water height in the pond is obtained from a float-activated Unidata Shaft Water Level Instrument. The float moves inside a 'stilling well' on a

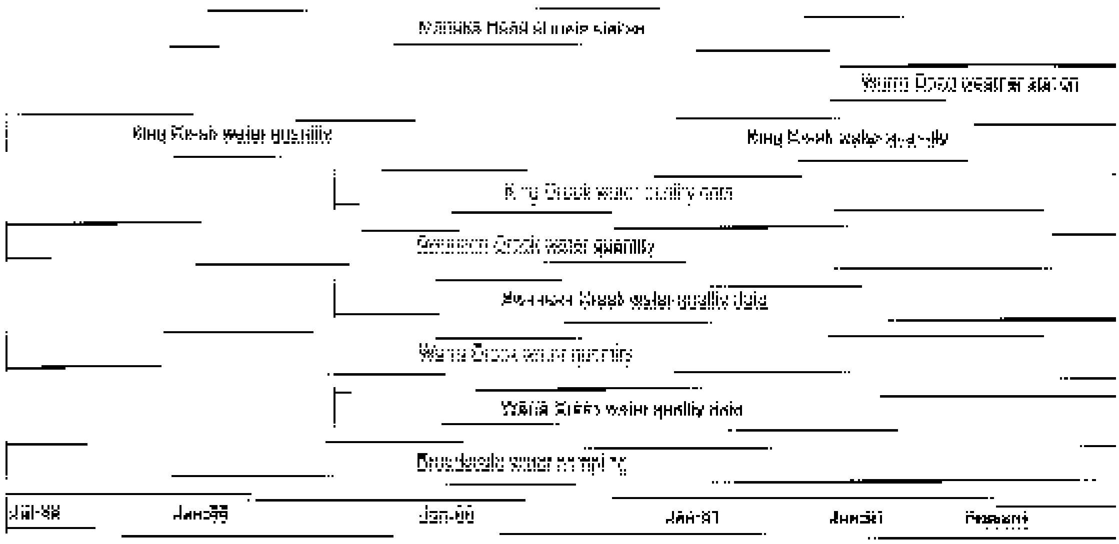

Figure 3. Diagrammatic history of monitoring of catchments.

pulley system, and as water rises or falls the float rises or falls along with it. A Unidata Starlog Datalogger encoder records this information at 15-minute intervals.

Water quality at the weir sites

Physical water quality measured through the use of in-stream probes commenced in May 1999 (Figure 3). These probes are located within the pond water behind the weirs. Turbidity is measured through a Mindata Turbidity sensor which uses an infrared optical backscattering technique, with a range of 0–100 ntu. A Mindata Conductivity probe measures conductivity within the range of 0–1000 ?s/cm and temperature from 0–50°. Both probes are linked to a Mindata data logger and record values every 15 minutes. Grab samples are also being collected to characterise base flow chemistry and recently installed Gamet automatic water samplers provide samples for detailed chemical analysis of storm events.

Water quality in Warra streams

Since July 1998, all 16 sites in the Warra area have had water samples collected at fortnightly intervals. Water temperatures and stage heights are measured in the field, and turbidity, conductivity and pH are measured in the laboratory the following day.

Climate information

Two weather stations have been installed at the Warra LTER Site. The first consists of a Unidata system, located on Manuka Road since the commencement of the project (Figure 2). The second, an Environdata Weathermaster 2000 climate station, was installed in October 2001 above the Swanson and King catchments, at the top of Warra Road (Figure 2). Both climate stations meet Australian meteorological standards (i.e. they are surrounded by a cleared diameter of two and a half times the height of the nearest vegetation). The following parameters are measured: rainfall (through a tipping bucket system and rain-gauge), ambient temperature, relative humidity and global solar radiation. The Weathermaster 2000 also measures wind speed and direction. All measurements are recorded with data loggers at up to 15-minute intervals.

Table 2. Monthly rainfall (mm) recorded at the Warra LTER Site, 1999–2001.

	1999	2000	2001	Mean
January		52	48	50
February		58	23	41
March		56	48	52
April	106	96	122	108
May	87	160	66	104
June	64	101	58	74
July	168	113		140
August	189	118		154
September	59	142		100
October	76	213		144
November	126	24		75
December	63	129		96
Total				1138

Table 3. Absolute monthly maximum and minimum temperatures (°C) recorded at the Warra LTER Site over the period 1998–1999.

	Max.	Min.
January	18.5	6.6
February	18.9	0.0
March	27.7	3.3
April	17.9	0.8
May	16.4	0.2
June	12.4	-1.6
July	12.1	-1.6
August	13.0	-0.7
September	24.6	-1.6
October	22.8	2.3
November	28.6	0.8
December	32.5	2.9

Results and discussion

Rainfall, air temperature, water level, turbidity, conductivity and water temperature have been measured from July 1998 to the present. Gaps occur in the data due to malfunctioning sensors, data loggers and computer software, but because of the large number of storm events in this area the existing data provide a very good picture of the flow and water quality dynamics in the catchment streams.

Climate

The rainfall (Table 2) and number of storms show a strong winter bias, with highest rainfall occurring during July and August. High maximum temperatures are recorded in summer and lower minimum temperatures occur in winter; however, low minimum temperatures can occur in any month (Table 3).

Water flow and quality at the weir sites

Although the three weirs are on streams of different sizes and volume of flow is different, the pattern of flow for the three weirs is similar (Figure 4). Base flow levels and total sediment load in the streams at Warra are much higher in winter and spring than in summer and autumn. Base flow in winter is about twice the height of the summer levels. Initial calculations indicate a low ratio of flow to precipitation for these catchments. Flow varies from 1% to 19%, averaging around 10%, which is similar to other Australian data on runoff coefficients (Croke and Jackeman 2001). This indicates high transpiration rates for these forests, although the runoff coefficients need to be verified with further data collection.

The three catchments yield water that is coloured with organic matter (yet to be characterised). Turbidity levels vary between base levels and storm events, and also between the streams. Mean base levels at Warra Creek are less than 1 ntu, while in storm events, levels commonly reached around 20 ntu. In Swanson Creek, the base level mean is slightly higher but still less than 2 ntu, while storm events reached similar levels to those in Warra Creek of 20 ntu. The mean base level turbidity in King Creek is similar to that in Swanson Creek but turbidity in storm events reached 40 ntu. During base flow, which accounts for the majority of the time, turbidity is low. Elevated turbidity levels accompanied by large volumes of flow occur during storm events, resulting in an overall weighted mean turbidity for Warra Creek and King

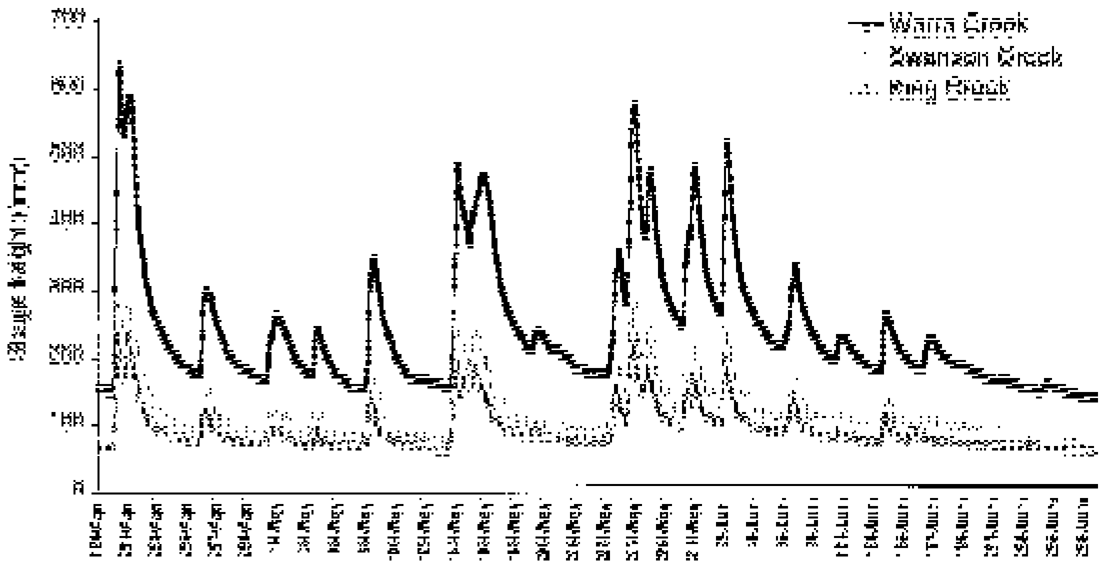

Figure 4. Comparison of flow at the three weirs over a number of storms, April to June 1999.

Creek of 11.5 ntu, and 7.2 ntu in Swanson Creek. These levels are considered high when compared with the recommended drinking water standard of 5 ntu (NHMRC 1996). However, the percentage of time that turbidity in Warra, Swanson and King Creeks is below this standard (5 ntu) is 70%, 77% and 67% respectively.

Although the average turbidity levels and profile of flow (Figure 4) for Warra and King Creeks are similar, the proportions of total flow related to turbidity levels between the streams differ. Warra Creek has a greater proportion of flow at higher turbidity (22+ ntu) while King Creek has a higher proportion of flow at medium turbidity (3–20 ntu) (Figure 5). Swanson Creek shows a similar profile to Warra Creek but at lower turbidity levels. Turbidity is also related to characteristics of storm events rather than flow as such, and high flow rates late in a storm event may be associated with lower turbidity readings (Figure 8). The difference in the turbidity distribution between Warra Creek and King Creek is likely to be related to the size and profile of the stream. Warra Creek is longer with a low rate of rise in the lower reaches while King is shorter and steeper (Figure 1).

Conductivity in the three streams frequently ranges between 30–60 ?s/cm. Conductivity generally drops with storm events and increases again on return to base flow levels.

Water temperature varies from a base of 5°C in winter to 12°C in summer. The diurnal variation is less during winter. Water temperature declines during storms, the extent of the decline being related to the air temperature at the time of precipitation. Water temperature can drop by as much as 4°C over a storm event.

Seasonal storm profiles

Storms are characterised by a lag phase in discharge at commencement of rain. This lag phase varies with season and the moisture status of the catchment. The lag is greater in the summer and autumn, when the soils are drier, and less in the winter and spring, when soils are wet (Figure 6).

Flow levels tend to increase rapidly with a storm and fall away slowly to seasonal base levels. Conductivity and temperature generally follow similar trends for a particular storm event. As flow level increases with the increase in rain, water

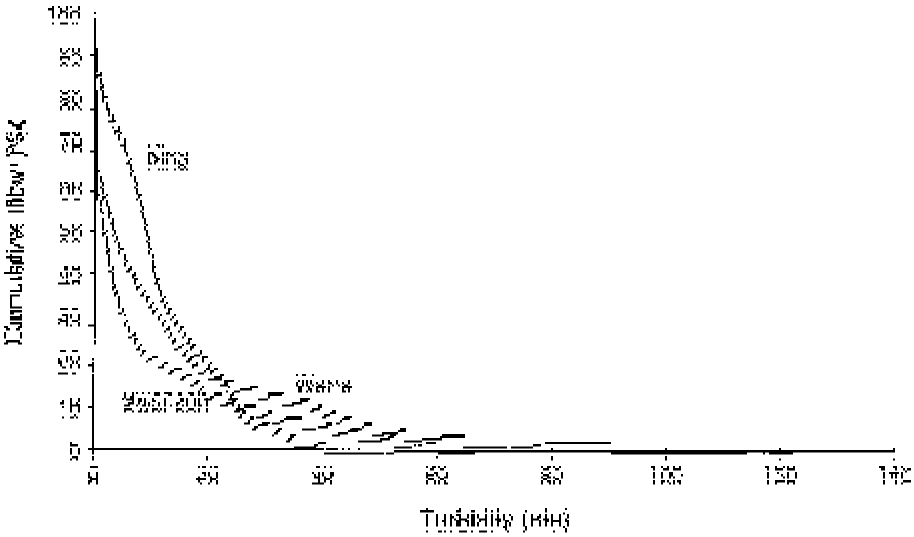

Figure 5. Turbidity profile of the water flow over the weirs on three streams at Warra.

temperature drops quickly. The water temperature will then slowly climb back to its previous base level (Figure 7). In contrast, turbidity levels increase rapidly at the beginning of the storm event and then tail off. Turbidity profiles vary with the season, tailing off quickly in the summer and autumn but maintaining elevated levels for longer in winter and spring due to greater soil saturation and greater subsequent runoff. A higher base level of turbidity also exists with repeated storms in winter for the same reason.

Multiple storm events are accompanied by large fluctuations in air temperature and stream flow. Coldest air temperatures reflect the largest drop in water temperature (Figure 8). A good relationship exists between flow in Warra Creek and flow in Swanson Creek and King Creek (Figure 9). There are, however, variations in specific storm events which require further investigation.

Water characteristics of streams within the Warra LTER Site—broadscale sampling

Water samples were collected from 16 streams (Figure 2), including the three weir sites, in the Warra LTER Site on a fortnightly basis in 1999 and 2000. These streams cover a range of conditions and stream characteristics, including eight of the streams where a proportion of the catchments has been logged (Table 4). These samples collected also cover a series of flow rates ranging from base level flow to major storm events.

The pH of the streams sampled within the Warra area was similar, with average readings ranging from 5.3 to 6.4. These readings indicate that the rivers are quite acidic, and this is consistent with other streams located on the south-west coast of Tasmania (Fuller 1993; Buckney and Tyler 1973).

Water in the streams at Warra, like many of the streams in western Tasmania, are generally coloured from naturally leaching organic compounds (Fuller 1993). Within the Warra area, 14 of the sampled streams are coloured to some extent, even at base flow. Two streams, Crystal and Isabella Creeks, are clear at base flow but are coloured at peak flow (Table 5).

A comparison of water chemistry at the Warra Creek weir site and Crystal Creek during base flow conditions indicate lower turbidity, apparent colour, nitrogen and iron in Crystal Creek, but higher pH, conductivity,

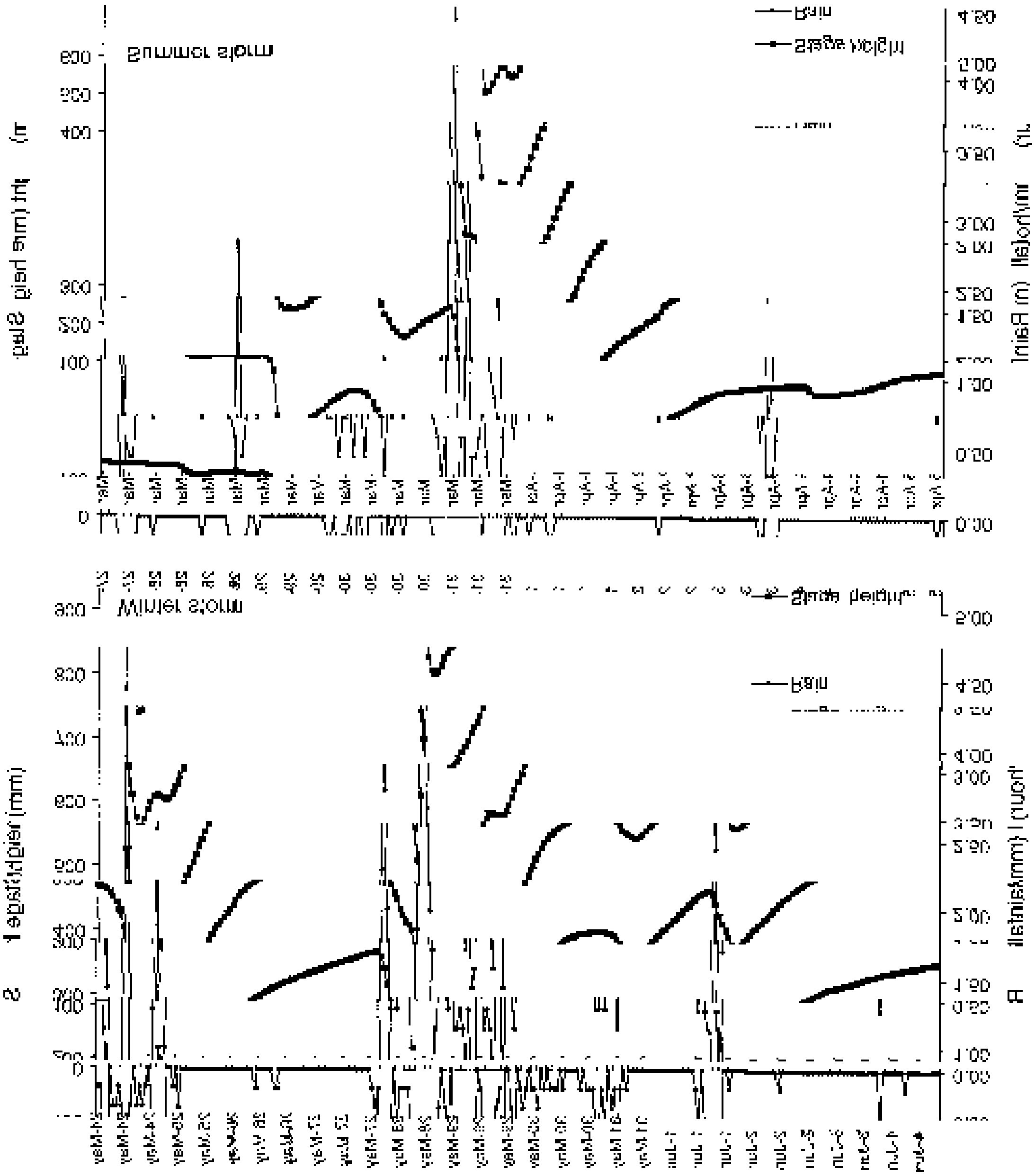

Figure 6. Comparison of summer and winter storms at Warra Creek in the year 2000.

calcium and magnesium levels (Table 5). However, during storm events, both calcium and magnesium levels fell considerably in Crystal Creek, while nitrogen, iron and turbidity rose to levels similar to those seen at Warra Creek.

Such patterns in the levels of magnesium, calcium and iron can be attributed to the differing geologies of these catchments. These cations are derived principally from rock weathering, ground-water and leaching and are thus significant components during base flow (Chapman 1996). The greater proportion of carbonates and limestone within the catchment of Crystal Creek consequently results in higher levels of these cations during base flow compared

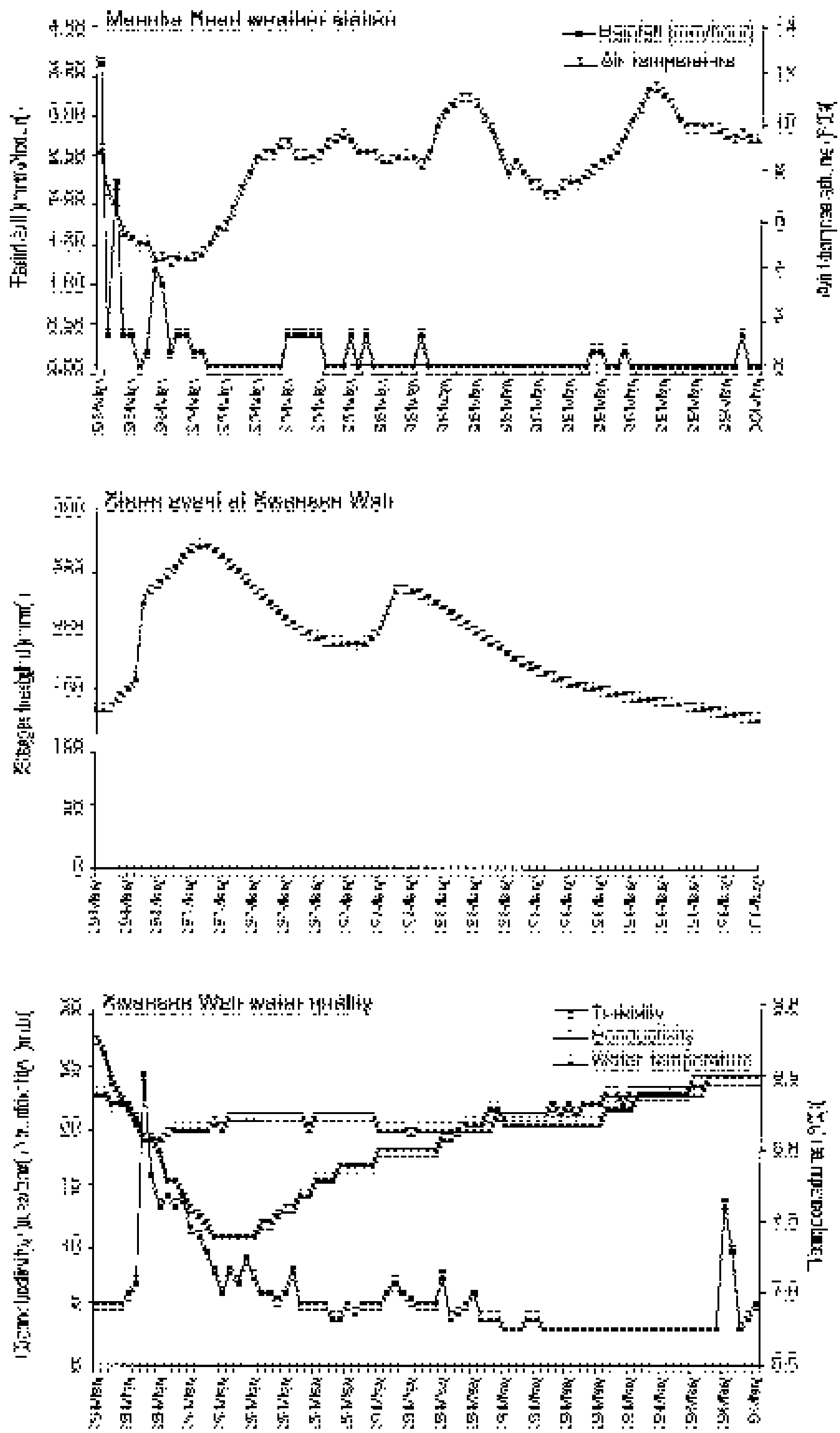

Figure 7. Rainfall, air temperature, flow, turbidity, conductivity and water temperature for a storm event in Swanson catchment in 1999.

Table 4. Mean water quality data (unweighted means) for the 16 stream sites in the Warra LTER Site where broadscale sampling was conducted over three years. (Turb. = turbidity, cond. = conductivity, temp. = temperature)

Site	Turb. (ntu)	Cond. (?s/cm)	pH	Temp. (°C)	Stage height (mm)	Comments
Warra Weir	1.8	47.4	5.3	8.2	255	Pristine forested catchment
Swanson Weir	2.6	57.3	5.6	8.5	129	Partial logging of catchment
King Weir	4.4	58.5	5.8	9.0	140	Partial logging of catchment
Tomalah Creek	1.0	54.0	6.1	7.7	210	Partial logging of catchment*
Kroanna Creek	1.8	53.2	5.8	7.9	64	Partial logging of catchment
Johns Creek	4.8	91.6	6.2	8.6	289	Partial logging of catchment
Laurel Creek	4.5	69.1	6.2	8.7	144	Pristine forested catchment
Leighs Creek	7.7	107.3	6.4	9.1	132	Partial logging of catchment
Isabella Creek	1.0	47.8	6.4	7.9	79	Clear stream*—partial logging
Crystal Creek	1.5	51.4	6.3	7.9	226	Clear stream*—partial logging
Glovers 1 Creek	3.4	58.7	6.2	8.9	198	Partial logging of catchment
Warra 1 Creek	2.0	55.1	6.0	8.9	294	Partial logging of catchment
Glovers 2 Creek	4.6	60.1	5.7	9.9		Partial logging of catchment
Bren Creek	10.9	73.7	5.9	8.8		Partial logging of catchment
Tahune Creek	5.7	79.4	5.9	9.5	109	Partial logging of catchment
Huon River	3.4	73.0	5.9	9.9	861	Partial logging of catchment

* No organic colour evident.

Table 5. Preliminary chemical characteristics of water from two sites for four selected flow levels (summer and winter base flows and storm flows).*

		Warra Weir		Crystal Creek	
		base flow	storm peak	base flow	storm peak
pH		5.3	4.11	6.04	5.72
Conductivity	?s/cm	43.5	50.0	59.2	55.0
Turbidity	ntu	0.6	8.2	0.25	9.2
Apparent Colour	CU	66.0	272.0	4.0	142.0
Nitrogen (total)	mg/L	0.158	0.642	0.085	0.451
Iron (total)	mg/L	0.366	0.743	0.092	0.990
Calcium (total)	mg/L	0.74	1.17	3.08	1.71
Magnesium (total)	mg/L	0.84	1.27	2.31	1.30

* Details of the turbidity, conductivity, pH, temperature and stage height from the sample streams are given in Table 4. The range of mean turbidity is from 1 ntu to 10.9 ntu. Most streams generally run below 5 ntu while the two clear streams generally run below 2 ntu, for most samples. High flow samples have higher turbidity, with 45 ntu being recorded for Bren Creek. The same storm at Crystal Creek recorded 6 ntu.

to Warra Creek with its predominantly dolerite geology.

During periods of high flow, the stream water contains not only ground-water discharge but also surface and subsurface runoff. Subsurface runoff is water that circulates within the upper soil layers. It leaches dissolved organic carbon and nutrients. Surface runoff is usually turbid, carrying larger amounts of total suspended solids, including particulate organic carbon (Chapman 1996). The decrease in calcium and magnesium levels at Crystal Creek can be attributed to a dilution effect caused by the increased volumes of water coming out

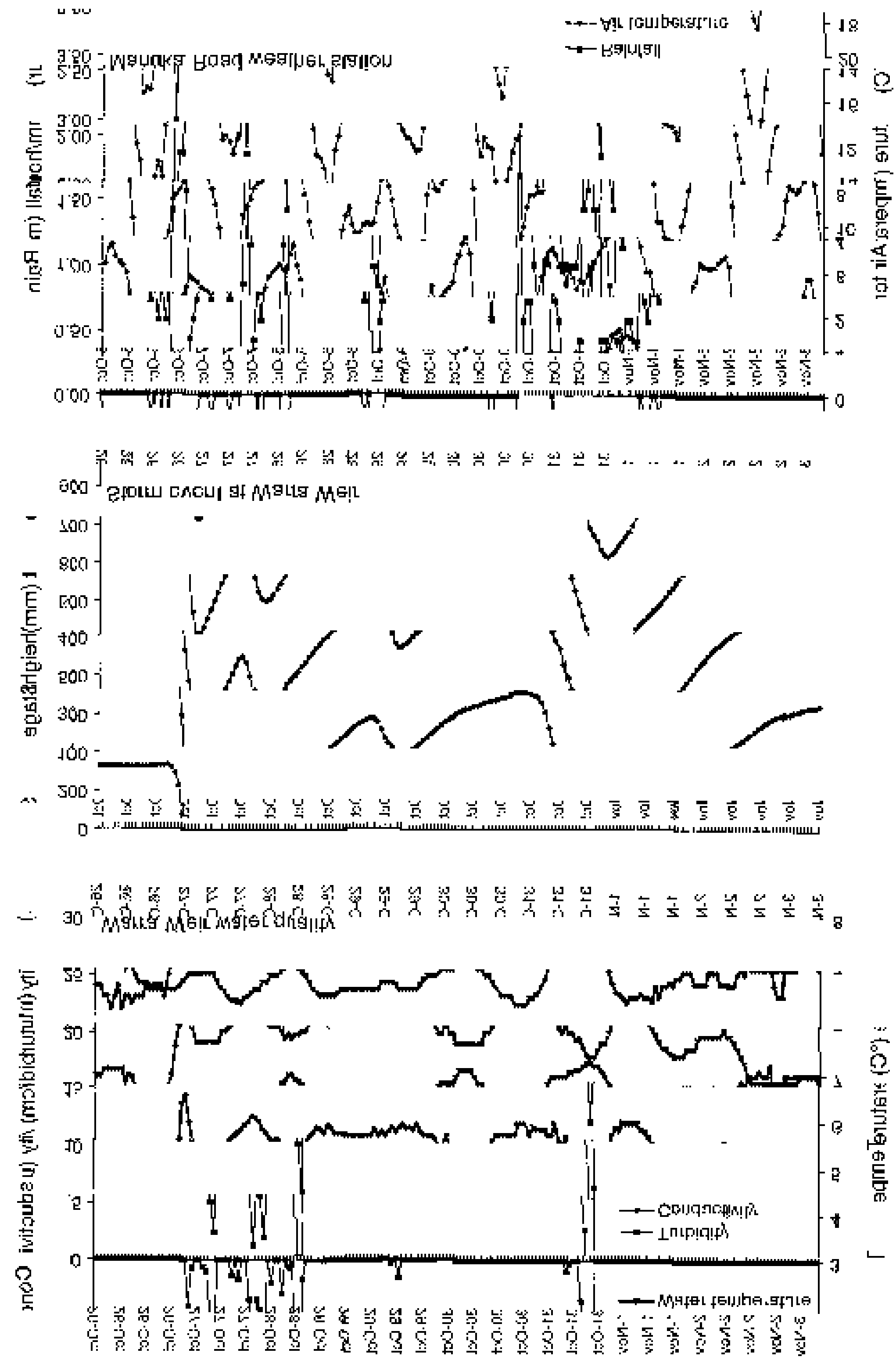

Figure 8. Rainfall, air temperature, flow, turbidity, conductivity and water temperature for a sequence of storm events in the Warra catchment in 1999.

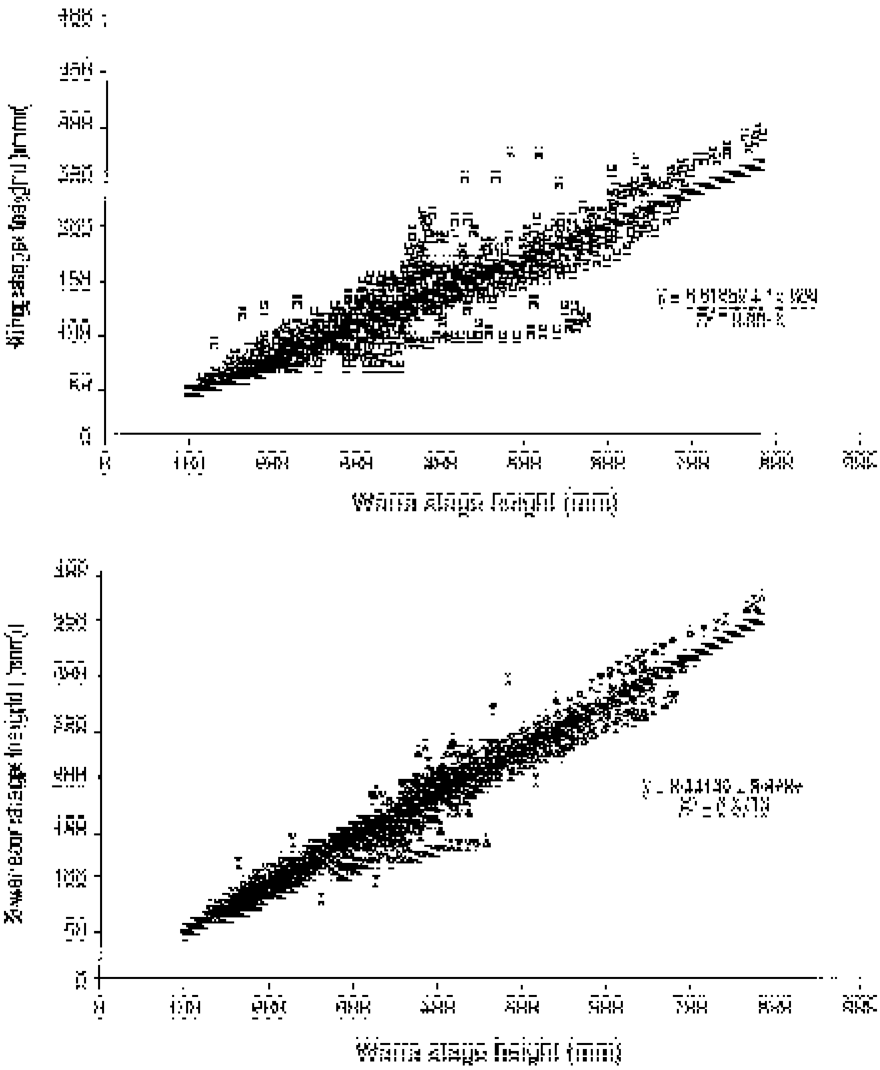

Figure 9. Relationship of stage height for Swanson Creek and King Creek with Warra Creek for 1999.

of the catchment. Parameters such as turbidity, colour, nitrogen and iron generally increased as surface and subsurface water created an impact on the water quality.

Further research

Detailed information on water budgets will be derived when additional seasonal information has been obtained. Seasonal storm profiles from the weir sites will be characterised using automatic water samplers. Storm profiles will also be obtained for Crystal Creek, a stream with characteristics different from those where the weirs have been established.

It has been noted that high turbidity levels occur during storm events even within catchments which have not been logged. This warrants further investigation of the water quality within the catchments to determine the source of the turbidity and colour, particularly that resulting from organic sources.

Further stream water chemistry will be determined for base flow and high flow (early storm flow) for the 16 sites within the Warra LTER area (Table 5, Figure 2).

Acknowledgements

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