Technical Report

Investigations and
Monitoring Group

Ashley River:
Flow management regime

Environment
Canterbury
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EXECUTIVE SUMMARY

This report aims to synthesise knowledge about the hydrology and instream values of the Ashley River and its tributaries, as a basis for public debate about management of the flow regime. It draws on hydrological data from, principally, flow recorders on the Ashley at Gorge, and Okuku at Fox Creek, and brings together the results of research and investigations in the Ashley.

The hydrological regime of the Ashley and Okuku reflects their location in the foothills of Canterbury, and shows considerable variability. Discharge differences reflect their catchment areas (472 km^2 and 222 km^2 respectively). The mean flow of the Ashley is 10.9 m^3/s, with a range from 1.14 m^3/s to 876 m^3/s. Highest flows are in winter and spring, with the highest mean monthly flow in September (17 m^3/s) and the lowest in March (4.96 m^3/s). The annual number of distinct flood events > 30 m^3/s averages 10, ranging from 3 to 16. They can occur throughout the year, but are most likely during July to December. They are not evenly spaced, and the flow may never exceed 30 m^3/s for up to 11 months. The annual pattern of low flows reflects that of mean monthly flows; the annual 7-day low flow ranges from 1.2 m^3/s to 6.6 m^3/s.

The mean flow of the Okuku is 4.57 m^3/s, with a range from 0.2 m^3/s to 333 m^3/s. Annual flood peaks range from 47 m^3/s to 333 m^3/s; flood peaks range from 23% to 85% (average 55%) of the equivalent peak in the Ashley. Annual 7-day low flows range from 0.24 m^3/s to 2.08 m^3/s; low flows are only 25-30% of those in the Ashley. There are no data for any other of the Ashley's tributaries, except for Taranaki Creek, which is a spring-fed stream in the lower catchment whose catchment area is indeterminate. Many tributaries are ephemeral, and the Ashley River itself ceases to flow in the vicinity of Rangiora when flow at the Gorge drops below about 2.5 m^3/s.

Water quality in the Ashley and its tributaries generally is high, and there is no evidence that their instream values are significantly affected by changes in chemical and bacteriological water quality that could be caused by management of the flow regime. Other matters, in particular the control of point source, non-point source, and directly introduced contaminants are of considerably greater significance. Water temperatures during summer low flows can approach those that are lethal to salmonids, and in some sub-habitats, such as disconnected pools, temperature can exceed lethal levels. On the other hand, flow through the gravel riverbed can cool the water in the channel, particularly in spring-fed side channels and pools in the main channel, so that there are refugia for fish that are temperature-sensitive.

Periodic bed resurveys indicate that gravel removal from the Ashley exceeds replenishment. However, while there has been degradation by up to 0.9 m (1960-1997) between the Makerikiri River and the railway bridge, there has been aggradation by up to 0.7 m between Rangiora and the coast. These changes are most likely to affect instream values that are related to the gravel bars in the river bed, rather than those related to the low flow channel. Because sediment is transported principally during large floods, management of the flow regime is unlikely to affect it.

Instream values of the Ashley can be defined in terms of the Resource Management Act as related to life-supporting capacity, natural character, amenity values, trout and salmon habitat, and mahinga kai (the last two largely are covered by the others). The report focuses on the ways in which these values are related to flow, and modification of the flow regime by human activity.

Hydrological impacts on life-supporting capacity with respect to terrestrial plants and animals in the Ashley River are caused principally by flood flows large enough to wash over gravel surfaces and remove colonising vegetation. Low flows are of limited significance, largely in terms of changes in the number of branch channels in braided reaches of the river. However, hydrology is probably of minor importance, relative to flood and river control, the introduction and control of exotic species, and other human activities.

Life-supporting capacity with respect to bird life is related to hydrologic regime principally through flood events, at any time of year, that provide vegetation-free gravel bars for nesting, and the medium to low flows that provide feeding areas during the nesting/breeding period, especially in riffles and side braids. Flood events are not materially affected by management of the flow regime. The critical period for low flows is August through to January/ February, before the river has fallen to its lowest, mid- to late-summer levels. Reductions in flow due to abstraction may increase predators' access to nesting birds, although this effect probably is small. Flow reductions also reduce the area of streambed that is suitable for food production and for feeding by wading birds. Observations suggest optimum flow levels for food production of around 2.5 m^3/s.

The aquatic vegetation (periphyton) of the Ashley is adjusted to the frequency of large flows (>30 m^3/s) able to remove it, and to the durations of low flows during which biomass is able to re-establish. The range of species is similar to that in other Canterbury Plains rivers, and is unlikely to be modified by management of the hydrological regime. Periphyton biomass increases with the duration of stable low flows, and may be increased by flow abstraction.

The invertebrate fauna of the Ashley is similar to that in other Canterbury Plains rivers. The benthos of the Ashley already reflects a naturally unstable flow regime, and is persistent and resilient to disturbance. Aside from the ability of some species to take refuge in stagnant ponds or even within moist gravel, recolonisation by downstream drift is rapid. It is unlikely that a reduction in low flows by abstraction – even to the point of increasing the extent or duration of total de-watering of the riverbed – has other than a temporary effect on macroinvertebrate species diversity or abundance in the Ashley.

Fish fauna in the Ashley are affected by the hydrological regime in a way similar to that for macroinvertebrates, in part because macroinvertebrates provide the food for many fish. There is the additional constraint of passage depth for migratory species. The fish communities are resilient to the naturally high levels of disturbance by floods, and are able to recolonise the riverbed after periods of low flow and de-watering. Declining flow – either naturally or exacerbated by abstraction – has a negative effect on the fish in the river, to the extent that many thousands of salmonids (and no doubt native species) would die during late summer low flows, as a result of habitat loss. Flow reductions below 2-4 m^3/s are likely to cause accelerating loss of habitat, concentrating the fish in smaller areas and with access to declining food sources.

Natural character includes many aspects of the river, including several that reflect human activity, such as introduction of exotic vegetation. One of the most important elements is the flow regime that is responsible for the overall dimensions and appearance of the Ashley, and that provides a basis for the ecosystems that are characteristic of the river. The particular sequence and statistics of flows – floods, low flows, and variations through the year – can be regarded as crucial to defining the river's character. The natural character of the river at the commonly occurring low flows is one of extensive areas of gravel crossed by one or a few wandering channels. Flow abstraction undoubtedly affects attributes such as the relative areas of gravel and water, but it is uncertain to what extent the effects can be discerned.

Amenity values commonly are considered in terms of scenic quality, recreational fisheries, and other types of recreation. The Ashley and its tributaries would be regarded by the general public as scenically unattractive, because of the open, featureless landscape of the lower Ashley fan, the large areas of bare gravel and weedy vegetation, the barely moving water, and the many signs of human modification of the river. During the frequently-occurring low to moderate flows, variations in discharge are likely to have only a limited influence on perception of scenic value. As a result, modification of the flow regime of the river is unlikely to have a significant effect on the scenic quality of the Ashley, even in the reach that is subject to periodic de-watering. The river mouth and estuary are very popular for recreational fishing; the lower catchment tributaries have limited use for recreational fishing, principally whitebaiting and eel fishing. The quality of the estuarine/ wetland fisheries in the river mouth/estuary and lower tributaries is controlled principally by human influences such as land drainage and water quality degradation, and natural estuarine/marine processes such as tidal circulation. Management of the flow regime in the main river or tributaries is unlikely to have a significant influence on recreational fishing in these areas, separately from influences on the fishery resource itself. Use of the middle/lower Ashley River for boating is limited, and for the tributaries is non-existent. Most use is for family picnicking, camping, sightseeing, trail-biking and off-road vehicle driving. These activities are enhanced by but not dependent on the presence of water, and do not have specific flow requirements. Even in the case of swimming, a disconnected pool fed by seepage can be acceptable or even preferred, even if there is no flow along the riverbed as a whole. The principal requirement is the appearance of high water quality, which may decline during continuous periods of low flow.

The flow-related requirements of instream values can be used to summarise the desirable characteristics of a managed flow regime, which in brief are:

1. Maintain the frequency and magnitude of freshes and floods (> 30 m^3/s) at all times of year, to remove vegetation that has colonised gravel bars, limit nuisance growths of periphyton, and provide for salmonid migration if flows naturally fall below 2.5 m^3/s.
2. Maintain flows above 2.5 m^3/s at all times (when available), to maintain preferred habitat for food-production (macroinvertebrates) required by birds (August to January/February), optimum habitat for as many fish species as possible (year round), quality of angling, minimal passage depth for upstream migration of salmonids (November to March), flowing water throughout the length of the river for amenity (recreational) purposes (school holidays, weekends, evenings, particularly Christmas to Easter).
3. Maintain the annual pattern of flows, to maintain the natural character of the river as defined by hydrologic regime.
4. Avoid holding flows at the minimum value for extended periods, by sharing flows between instream and out-of-stream users above that value.
5. Maintain physical, bacteriological and chemical water quality above the standards specified for bathing, particularly below the Makerikeri River confluence.

Based on the above and as a starting point for discussion, a water management rule might be proposed as:

a) No abstractions are permitted when natural flow, measured at the Gorge, falls below 2.5 m^3/s.
b) Above a flow of 2.5 m^3/s, abstraction of 50% of the additional flow is permitted.

This rule appears to achieve the purposes of the Resource Management Act more closely than the current Ashley management plan. The above flow-related requirements for the main river are consistent with the aim of maintaining the "instream" values of the Ashley estuary. These values are affected to a limited extent by the hydrologic regime of the main river, with large flood events having the greatest impact on the morphology, ecosystems and human use of the estuary. The lack of information on the hydrology or instream values of the Ashley's tributaries make it impracticable to propose an appropriate flow regime for them. However, the rationale for maintenance flows in the lower tributaries appears to be appropriate.

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1. Introduction

A flow management regime was established in 1989 for the Ashley River and its lower tributaries by the *Ashley River (Rakihuri) catchment, land and water management plan* (NCCB&RWB, 1989). Its provisions were incorporated into the *Transitional Regional Plan* (Canterbury Regional Council, 1991); Environment Canterbury must commence a review of these provisions by October 2001.

This report aims to provide an up-to-date synthesis of knowledge about the hydrology and instream values of the Ashley River and its tributaries, as a basis for public debate about management of the flow regime. It was required to critically review:

- The existing hydrological data for the Ashley River and its tributaries;
- The flow patterns in the Ashley River (below the Gorge) and its major upstream tributaries (Glentui, Garry, Okuku and Makerikeri Rivers), and the relationship between river flow and the frequency, duration and extent of riverbed drying;
- The flows in downstream tributaries (Saltwater Creek, Taranaki Creek, Waikuku Stream, Little Ashley);
- The specific values that are affected by river flows, their flow requirements, and the most important reach for each value;
- The flow range and/or optimum flow for each value, in terms of the *Regional Policy Statement* (Chapter 9, Objective 1), including any seasonal requirements;
- The flow needed to cleanse the bed of periphyton and/or fine sediment;
- The value, in terms of flow variability, of maintaining a sharing regime for all water above the minimum flow;
- Information gaps.

Particular attention to the following matters was required:

- The need for the managed flow regime to vary through the year;
- Changes to water quality parameters during low flows;
- The need for a managed flow regime on the larger upstream tributaries;
- The need for an upper limit on abstractions to maintain freshes that will rejuvenate the riverbed;
- Other factors, such as aggradation or groundwater interactions, which might affect instream values.

Earlier *Technical Reports* (Mosley, 1999a and b) have examined the nature of the natural character and amenity values of rivers and lakes, and the relationship of flow variation and abstraction regime to those and other instream values. The present report aims to apply those principles to the specific case of the Ashley River. It considers those parts of the river whose flow regime is subject to modification by flow abstraction, i.e. the main river downstream from Ashley Gorge, and tributaries from which water is abstracted directly or via groundwater withdrawals.

The Council's (1991, section 5) *Environment Manual* provides a summary of the Ashley's natural environment and ecological values (Appendix 1).

2. The hydrology of the Ashley River system

2.1 Hydrological data

The principal source of river flow data in the Ashley catchment is the recording station at Ashley Gorge (site 66204; catchment area of

472 km^2). The station has been open since 1938, but data that are confidently usable for analysis of the hydrological regime, particularly for instream flow analysis, are available only since 1987.

Data are available also for the Okuku River (site 66213; catchment area of 222 km^2),commencing in February 1989. The Okuku is the principal tributary of the Ashley River. The data have not yet been audited, so that the analysis herein may need to be revised. Otherwise, surface water data are available only for the spring-fed Taranaki Creek, since 1996 (site 66216; catchment area undefined).

Analysis in this report uses only data series for Ashley at Gorge, for 1987-1999, and Okuku at Fox Creek, for 1989-1999.

2.2 Flow patterns in the Ashley River and major tributaries

The hydrological regime of the Ashley reflects its location in the foothills of Canterbury, with its headwaters reaching as far inland as the Puketeraki Range. There is a small accumulation of snowpack along the top of the Range during winter, but in general river flows vary in response to a series of rainfall events that can happen at any time of year, and the annual cycle of evapotranspiration.

The mean flow of the Ashley at Gorge is 10.9 m^3/s, with annual means ranging between 6.01 m^3/s in 1998 and 14.6 m^3/s in 1992 (Appendix 2, Table 1). The median flow is 7.12 m^3/s, with absolute recorded minimum and maximum flows of 1.14 m^3/s and 876 m^3/s respectively (Appendix 2, Table 2). The pattern of flows shows a tendency for highest flows in winter and spring, with the highest mean monthly flow in September (17.0 m^3/s) and the lowest in March (4.96 m^3/s) (Figure 2.1, Appendix 2, Table 3).

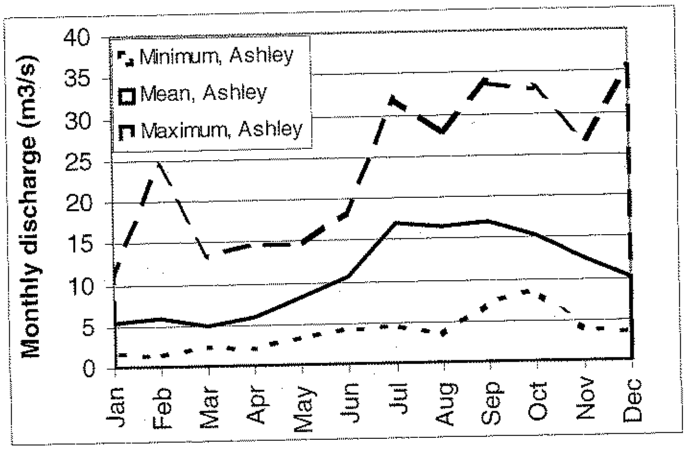

Figure 2.1. Annual flow regime for the Ashley River at Gorge.

Freshes can occur throughout the year, but the largest have had a strong tendency to be in the months of July to December (Appendix 2, Figure 2). There is a wide range in annual flood peaks, from 113 m^3/s in 1996 to 876 m^3/s in 1993 (Appendix 2, Table 1). Examination of the flow hydrograph during low flows (<12 m^3/s: Appendix 2, Figure 3) reveals that there are numerous "freshets" a few days apart. Many of these may increase flow by only a few m^3/s, and fail to do more than produce a "blip" on the hydrograph. Nevertheless, the combined effect is that the river is in an almost constant state of recession, and flows rarely are constant.

The number of distinct flood events in any one year that exceed 30 m^3/s (an index of the flow needed to "flush" the riverbed of silt and periphyton) also varies significantly (Figure 2.2). The average is 10, with a range from 3 to 16. These floods are by no means evenly spaced; sometimes, they are separated by only a few days, while at other times many months can go by with no flows above 30 m^3/s (e.g. over 11 months from August 1997 to July 1998).

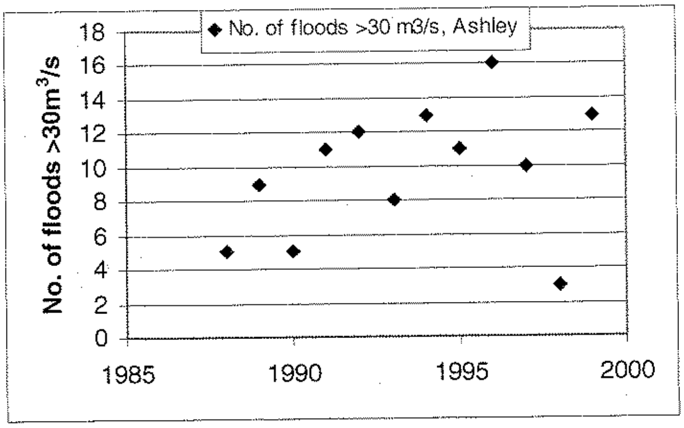

Figure 2.2. Number of floods exceeding 30 m^3/s each year in the Ashley, 1988-1999.

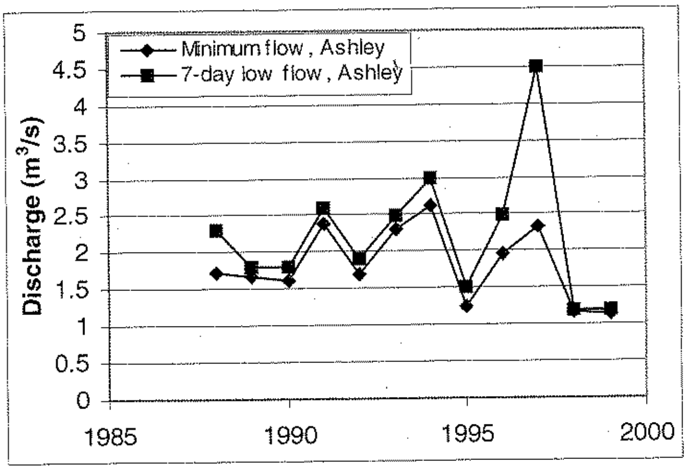

Figure 2.3. Low flows in the Ashley River at Gorge, 1988-1999.

There is considerable year-to-year variability in flows, as the over-plotted flow duration curves (Appendix 2, Figure 1) and comparison of annual hydrographs (Appendix 2, Figure 2) shows. Hence, for example, a flow of 10 m^3/s can be exceeded anywhere between 17% and 44% in different years.

The annual pattern of low flows reflects that of mean monthly flows, with the minimum 7-day low flow reaching its lowest value – an average of 2.8 m^3/s, ranging between 1.2 m^3/s and 6.6 m^3/s – in February/March. Again, there is considerable year-to-year variability (Figure 2.3).

Long periods of steady, baseflow conditions are common, interspersed with occasional freshes. Even in a year where there are many freshes, as in 1996, few of them may exceed 40 m^3/s, barely sufficient to initiate bedload transport (Appendix 2, Figure 2).

The Okuku River has a similar regime to the Ashley, but flows are lower (Figures 2.4 and 2.5). Appendix 2, Tables 6 to 9 present flow statistics for the Okuku in the same format as for the Ashley (Tables 1 to 4). The mean flow for the Okuku is 4.57 m^3/s, with annual means ranging between 2.24 m^3/s in 1998 and 5.93 m^3/s in 1992 (Appendix 2, Table 6). The median flow is 2.4 m^3/s, with absolute recorded minimum and maximum flows of 0.2 m^3/s and 333 m^3/s respectively (Appendix 2, Table 7). The highest mean monthly flow is in July (8.68 m^3/s), and the lowest in March (1.95 m^3/s).

Flood hydrology is similar to that for the Ashley (see above), and floods generally occur at the same time. There is a wide range in annual flood peaks, from 47 m^3/s in 1998 to 333 m^3/s in 1993 (Appendix 2, Table 1). Flood peaks range from 23% to 85% (average 55%) of the equivalent peak in the Ashley; the catchment area of the Okuku at Fox Creek is 47% that of the Ashley at Gorge.

The annual pattern of low flows also is similar to that of the Ashley. It reflects that of mean monthly flows, with the minimum 7-day low flow reaching its lowest value – an average of 0.78 m^3/s, ranging between 0.24 m^3/s and 2.08 m^3/s – in February/

March. Again, there is considerable year-to-year variability (Figure 2.6). Low flows in the Okuku are only around 25-30% of those in the Ashley.

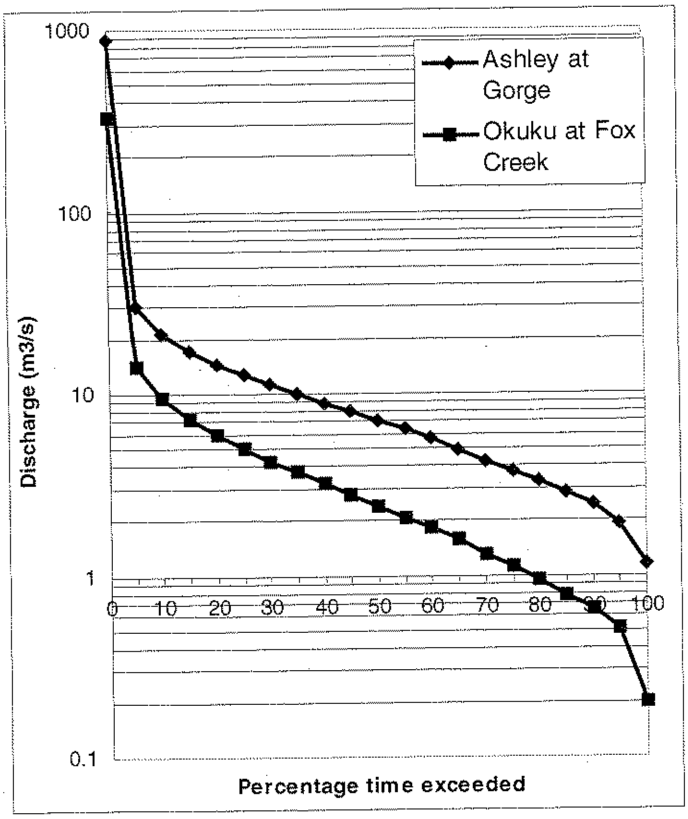

Figure 2.4. Flow duration curves for the Ashley and Okuku Rivers.

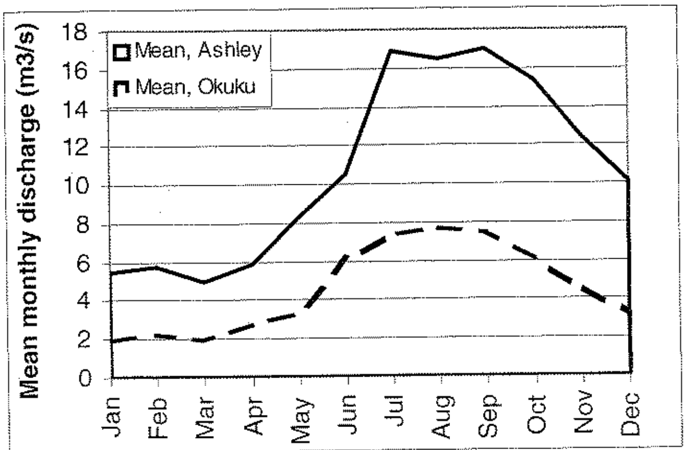

Figure 2.5. Annual flow regimes of the Ashley and Okuku Rivers.

2.3 Flow patterns in the lower tributaries

The only tributary for which there are flow data is Taranaki Creek. This is a spring-fed stream whose catchment area cannot be defined, but whose hydrological behaviour probably is modified heavily by land use, irrigation and so forth. For water resources assessment purposes, the Taranaki Creek record is of little interest.

2.4 Management of the flow regime

The natural flow regime of the Ashley River is modified principally by resource consents to abstract water directly from the river, its tributaries, and from groundwater (some wells are hydraulically connected to the river or its tributaries and effectively extract surface water).

The *Ashley River (Rakihuri) and catchment land and water management plan* (NCCB&RWB, 1989) and *Transitional Regional Plan* provide for a maximum amount of water to be allocated from the Ashley River of 1.5 m^3/s at flows below 6 m^3/s at the Gorge. There are no data on how much water is actually abstracted at any one time, but it is likely that the maximum instantaneous take is around 1 m^3/s (NCCB&RWB, 1989). Minimum flows at the Gorge, below which abstractions must cease, are set as:

May to November:	4.0 m^3/s
December:	3.0 m^3/s
January and April:	2.0 m^3/s
February and March:	1.5 m^3/s

One m^3/s above the minimum flow is available for abstraction, and above that level only 50% of the flow is available for abstraction.

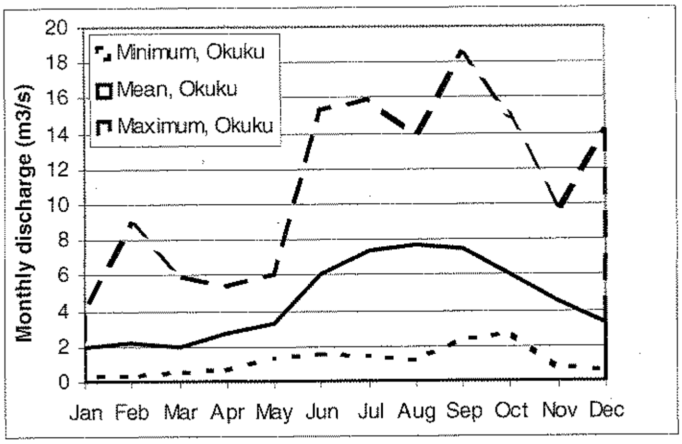

Figure 2.6. Annual flow regime for the Okuku River at Fox Creek.

The number of days for which flow falls below the flows specified above varies from year to year, from only 1 day in 1996 to 149 days in 1998 (Appendix 2, Table 5 and Figure 3). During the period of record, the months in which flow has declined below the minimum flow most frequently were January and May, and least frequently in September and October.

Minimum flows, below which abstractions must cease, are set for four of the Ashley's tributaries:

Waikuku Stream, Beach Rd: $0.151\ m^3/s$
Little Ashley, SH 1: $0.03\ m^3/s$
Taranaki Creek, Kaiapohia Monument: $0.12\ m^3/s$
Saltwater Ck, Toppings Rd: $0.1\ m^3/s$

Opportunities for further development of the water resource, in particular by damming the Gorge for hydro-electricity generation and flow regulation, have been investigated but appear unlikely to proceed in the foreseeable future. A proposal to divert water from the Waimakariri River into the Ashley catchment to augment low flows and enhance groundwater recharge was considered, but is not being proceeded with.

2.5 Water quality

2.5.1 *Chemical and bacteriological water quality*

The chemical and bacteriological water quality of the Ashley River and its middle tributaries is high (Bowden, 1982; NCCB&RWB, 1989), and recent measurements confirm that this is the case (Malcolm Main, Environment Canterbury, pers. comm., 2000). The high densities of salmonid and native fish in the river and the significant levels of use for water-contact recreation show that water quality at present does not impair the river's suitability for aquatic ecosystem maintenance or human recreation. There are few threats to chemical and bacteriological water quality in the Ashley from non-point source contamination from agriculture, given the well-drained nature of most of the catchment. Point-source discharges such as those from dairy sheds and gravel extraction plants (which are controlled effectively via the resource consent process), accidental or uncontrollable inputs such as spray drift, illegal disposal of pesticide containers, defecation by livestock and birds directly into the river, or accidental spillages are the principal risks to water quality.

The chemical and bacteriological quality of water entering the lower spring-fed tributaries is high, where the springs are fed by aquifers that are recharged from the river. Water returning to these watercourses from shallow unconfined aquifers can have higher levels of nutrients and micro-organisms, introduced by agriculture and domestic waste disposal (Sanders, 1997). The spring-fed tributaries also are affected adversely by non-point source runoff from agricultural land, and there is always the risk of accidental or illegal point source discharges from dairy sheds, stock races, industrial sites, etc. As a result, faecal coliform levels periodically exceed those permissible for contact recreation and shellfish gathering in the Ashley estuary (NCCB&RWB, 1989). (High bird populations in the estuary may also contribute to this effect.) Nutrient concentrations in the tributaries may be elevated to levels at which there is excessive growth of aquatic plants, with negative effects on other aquatic biota and birds.

There are few data to show how chemical and bacteriological water quality in the Ashley is related to discharge. Biggs and Close (1989) concluded that there was no relationship between nutrient concentrations and discharge in the main river at the Gorge, and that concentrations were relatively low at all times. Non-point source contaminants are likely to reach the Ashley system principally during heavy rainfall, and therefore will be diluted and removed during the course of the event. Point-source contaminants and contaminants introduced directly to the water (e.g. by stock defecation and birds) will have the greatest impact on receiving water quality at low flows, when dilution is least. Any reduction in the flow that is available for dilution will reduce quality further (abstraction of water with high levels of contaminants will of course make no difference to contaminant levels of the residual flow). In this respect, the varying amount of water in the Ashley estuary during the tidal cycle may be a more significant control on water quality there, than abstraction of relatively small quantities of water from the tributaries.

In summary, there is no evidence, nor any reason to expect, that the instream values of the Ashley River, the estuary, or its tributaries are significantly affected by any changes in chemical or bacteriological water quality that could be caused by management of the flow regime. Other matters, in particular the control of point source, non-point source, and directly introduced contaminants, are of considerably greater significance.

2.5.2 Physical water quality

Some determinands of physical water quality in the Ashley River are less favourable than for chemical and bacteriological quality. Suspended sediment concentrations are elevated during flood flows, in common with other rivers, but there is no evidence that concentrations have ever been so high that they have had other than temporary impacts on instream values – Canterbury braided river ecosystems are adapted to this phenomenon. During very low flows in summer, the taste and smell of the water can become tainted by dead and decaying periphyton; there is no evidence that this has had any biological or human health impact, but contact recreation can become less attractive. Dissolved oxygen and Biological Oxygen Demand are considered to be acceptable.

The attribute of physical water quality that is of particular significance for instream values in the Ashley River is water temperature. Temperatures greater than 23-25°C are potentially lethal to salmonids. The temperature tolerances of native fish present in the river are higher (generally over 30°C: Richardson *et al*., 1994), while tolerances of the more temperature-sensitive macro-invertebrate species are similar to salmonids, with *Deleatidium* having an upper lethal temperature tolerance in the range 22.6-26.8°C (Quinn *et al*., 1994). Periodic temperature observations at the SH1 bridge indicate that temperatures do reach 23-25°C in January and February (Bowden, 1982, Table 20). Mosley (1983) measured water temperature in numerous branch channels in a reach of the Ashley upstream of the Okuku confluence, during cloudless periods in February and December 1982. The data revealed that the main channel attained a maximum of 24.3°C and a night-time minimum of 15.6°C (Figure 2.7). There was a range of daily maxima from 20.5°C to 29°C at different locations, depending on the type of channel sampled. The coolest sites were channels fed by seepage through the gravels, and the warmest sites included disconnected pools with little or no flow of water through them. The highest water temperature recorded by Mosley was 34.9°C, in a disconnected pond in December 1982. Overall, Mosley concluded that during summer low flows, 60-70% of the Ashley's water area could reach daily maximum temperatures of 22-24°C, but that much of the remainder could be cooler by several degrees, and might provide refugia for at least some temperature-sensitive fish. In addition, the data indicate that the main channel (which accounted for >80% of the flow) exceeded 23°C for only a short time (< 1 hour), although minor braids and pools could exceed that figure for up to 6-7 hours.

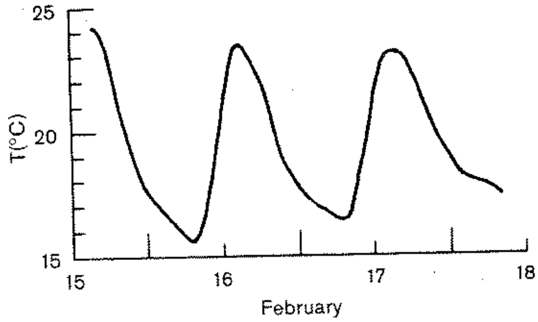

Figure 2.7. Water temperature in the Ashley main channel during 4 days in February 1982 (from Mosley, 1983).

Mosley (1983) showed empirically that smaller channels have a greater downstream rate of temperature increase than large channels. This implies that a reduction in flow by abstraction might further increase maximum temperatures above those occurring under a natural regime. His data indicated that reducing discharge from 2 m^3/s to 1 m^3/s could increase the rate of downstream temperature increase from 1.3°C/km to 2.0°C/km. However, under-flow through the gravels would become a larger portion of total flow, thus moderating the increase. The high temperatures theoretically achievable are not in fact observed in the Ashley, which is considered to be due to the significance of under-flow (especially below Rangiora) and the frequent cool easterly winds to which the river is exposed.

Although Ashley water temperature at low flows during summer is likely to be increased somewhat by flow abstraction, the effect is not considered to be significant. Any increases are moderated by the increasing proportion of flow contributed by cool underflow returning from the gravel, the availability of refugia in cooler braids (up to 40% of the total water surface area), and by the short time (< 1 hour) for which sub-lethal temperatures are actually reached in the main channel.

2.6 Sediment transport and aggradation

A major issue in the Ashley is the relationship between instream values and sediment load, particularly from the perspective of aggradation and the need for gravel extraction as a component of river and flood control.

Sediment transport occurs largely during freshes and floods. Observations in New Zealand gravel-bedded rivers indicate that the overall size of a natural channel is controlled by floods that recur every few years on average, while the detailed morphology of the bars and low flow channels is maintained by flood events that recur on average once every few months or so. Events of a moderate size and frequency may not mobilise sediment and remove vegetation over the entire river bed at any one time, but, as Mosley and Tindale (1984) observed in the Ashley River above the Okuku confluence, over a period of years they can rework the whole riverbed. For the Ashley, the flood flows responsible for the overall dimensions of the channel would be upwards of 300 m^3/s, the best estimate of the mean annual flood (Pearson, 1995). Flows responsible for reshaping bars and channels are those on the order of a few tens of cubic metres per second upwards; obviously, the larger the event, the more extensive will be the reshaping. These flows are well beyond the range of discharges affected by permitted abstraction of water from the Ashley.

Nevertheless, sediment transport and river bed levels are affected by human activity, particularly by channel constriction at bridge crossings, flood and river control activities, and gravel extraction for commercial and river control purposes.

Under natural conditions, the Ashley would have been free periodically to change its path across its fan, spreading gravel over a wide area and therefore aggrading the fan relatively slowly. With the channel constrained to a single course, any aggradational tendency is focussed along that course. Recent analysis indicates that rivers that are naturally aggrading may well aggrade more, as a result of channel constriction, rather than flush gravel through to the sea, as is conventionally believed. (This latter effect is observed in the Ashley, and informal evidence indicates that gravel is now reaching the estuary, whereas formerly the estuary was characterised by sand and mud banks (Rob Gerard, Environment Canterbury, pers. comm., 2000).

Approximately 70,000 m^3 of gravel are removed each year for roading and construction (NCCB&RWB, 1989), mostly in the reach between the Makerikeri River and the railway bridge. Cross-section surveys indicate degradation of the bed in that reach by up to 0.9 m over the period 1960-1997, and aggradation by up to 0.7 m between Rangiora and the coast (Figure 2.8). By multiplying depth of aggradation or degradation, average bed width, and distance between cross-sections, the approximate volume of sediment deposited or removed can be estimated. It appears that over the period 1960/2 to 1997, there was average removal of sediment of 68,000 m^3/km of channel, at an annual rate of 38,000 $m^3/year$, which indicates that gravel extraction may exceed sediment transport rates.

Degradation will tend to lower the whole riverbed, with deep scouring of pools along the base of the banks until a point where increased bank instability and erosion compensate. Aggradation will tend to modify the elevation and profile of the gravel bars (often referred to as "beaches") that are dry at low flow, rather than of the low flow channels. Observations in many gravel-bedded rivers in New Zealand provide little evidence that the dimensions and form of low flow channels – particularly the pools that are ecologically and recreationally significant – change as a result of overall aggradation of the riverbed. It is unlikely that the floor elevations and depths of pools in aggrading reaches of the Ashley, relative to average bed level or the groundwater table, have changed sufficiently to affect their habitat and recreational value (Figure 2.9).

In summary, aggradation and degradation of the riverbed, whether natural or associated with gravel extraction, are more likely to have an effect on "instream" values that are related to the gravel bars (e.g. recreational vehicles, nesting birds, landscape), than on those that are related to the low flow channel (e.g. instream habitat, swimming, angling). No foreseeable management of the Ashley River's flow regime is likely to have a significant effect on this aspect of the river system, since sediment transport occurs entirely at discharges well beyond those affected by flow management.

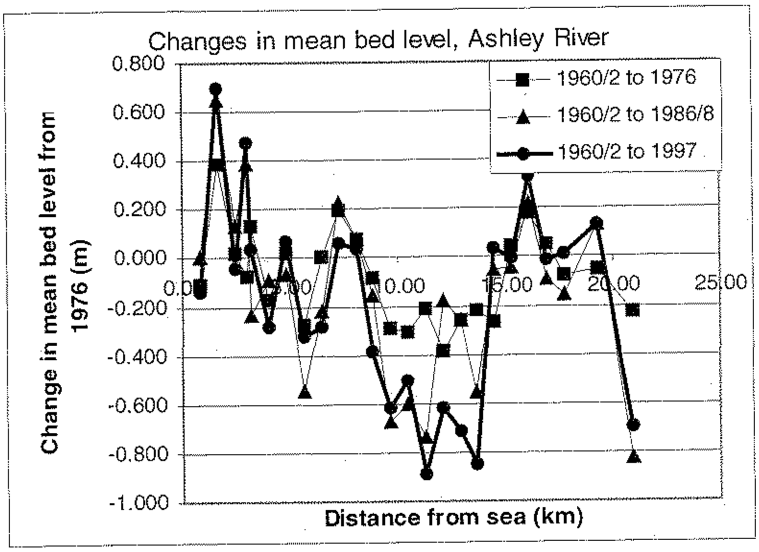

Figure 2.8. Changes in mean bed level, Ashley River, 1960-1997 (data from Rob Connell, Environment Canterbury, 2000).

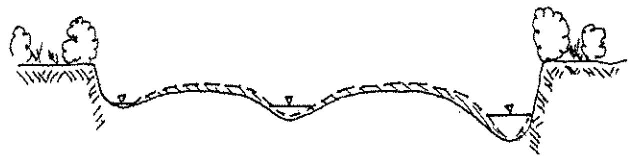

Figure 2.9. Effect of aggradation on cross-sectional elevations.

3. The instream values of the Ashley River and its tributaries

The *Regional Policy Statement* (Chapter 9, Objective 1) refers to several values of a river that are likely to be affected by management of its flow regime:

- Life-supporting capacity of the water, including its associated aquatic ecosystems, significant habitats of indigenous fauna and areas of significant indigenous vegetation;
- Provision of mahinga kai for Tangata Whenua;
- Natural character;
- Significant habitat of trout and salmon;
- Amenity values.

The way in which these attributes vary with discharge, particularly at low flows, is considered in the following sub-sections. Mosley (1999b) reviewed the general relationships between instream values and flow regime, with particular reference to Canterbury conditions. Although maintenance flows for the Ashley are presently defined in terms of minimum flows, water resources specialists increasingly recognise that it may be necessary to define a full range of flows (what might be called a "designer regime") to conserve all aspects of a river's biophysical environment. Mosley (1999b, Table 1) summarised the hydrological processes and controls relevant to the various aspects of the river environment, and the effects of flow abstraction. This summary is reproduced herein as Appendix 3, and the reader is referred to the full report for a background to the present study.

3.1 Life-supporting capacity

The Ashley River and its tributaries support a variety of life forms, including terrestrial plants and animals, birds, aquatic plants, aquatic macroinvertebrates, and fish. Their requirements in terms of a flow regime may be quite different, and in several cases are conflicting.

3.1.1 *Terrestrial plants and animals*

For much of their length, the Ashley River and its tributaries flow through developed pasture, and their banks and berms are covered by exotic vegetation. This includes introduced grasses and other low vegetation, shrubs (gorse, broom), trees (predominantly willows and poplars, planted for river control), and a variety of other species such as lupin and Old Man's Beard. Many of the dominant plants are noxious weeds.

The nature and extent of terrestrial plants along the main river and its tributaries is controlled largely by:

- human activity (agriculture, river control, direct and indirect introduction of species), and
- fluvial processes during periodic high flows, when branch channels migrate and gravel bars are reshaped, bank lines may be cut back or built up, and vegetation is removed from eroded bars.

The riverbeds are subject to invasion by terrestrial plants during periods when flows are insufficient to rework the gravel surface. Such invasion is regarded as undesirable for river control purposes, amenity values, and riverbed bird habitat. However, flood flows large enough to wash over and rework vegetated gravel surfaces and reshape the network of braids occur on average only a few times each decade (Mosley, 1999b). They are not affected materially by any past or foreseeable discharge modifications in the Ashley River system.

Low flows have little effect on terrestrial plants, because they do not modify the ground surface on which the plants are growing. Neither do modifications to low flows caused by abstraction, except through the minor effect of creating slightly more ground surface that plants can colonise.

Only in the area of the river mouth and estuary do plant communities not consist predominantly of exotic species. Here, where an old sand dune system, mudflats, sand/gravel banks, and tidal channels are significant features of the river environment, is an extensive area of salt marsh and estuarine vegetation. The Ashley has the largest estuary in Canterbury with largely intact natural vegetation, and it is included in the SSWI and WERI databases as a wetland of international significance.

Around the estuary and river mouth, plant communities owe more to natural geomorphic and ecological processes than in the main river and tributaries. In particular, the character of the estuary reflects tidal inflows and outflows, changes to the river mouth caused predominantly by coastal processes, and flood events. Low river flows are of little significance, and in this locality tidal flows are much larger than any reduction of river flow due to abstraction.

Terrestrial animals – possums, cats, mustelids, rodents, roaming livestock, etc – found along the Ashley River and its tributaries are rarely referred to in discussions of river management. In general, their numbers are unrelated to fluvial processes or river discharges. The principal concern is the possible effect of flow regime management on the ability of predator species and livestock to gain access to areas used by riverbed birds for nesting and feeding. A reduction of the frequency and/or magnitude of flood flows may facilitate the activities of predators, by permitting more extensive vegetation colonisation, which will provide better cover for predators, and force birds that nest on bare gravels into smaller areas. However, as already noted, management of the Ashley's flow regime is unlikely to have any material effect on vegetation colonisation or clearance. On the other hand, predators can range more widely across the riverbed, and any reduction in flow – particularly if it reduces the number of channel braids and facilitates access to former islands – will increase this ability.

Data for the Ashley River and other Canterbury braided rivers indicate that the number of braids, and therefore the number of islands surrounded by water, does decline as discharge declines. At a cross-section near Rangiora airfield, a series of gaugings showed that the number of braids declined from 7 at a discharge of 25 m^3/s to 2 at discharges below about 3 m^3/s (Figure 3.1).

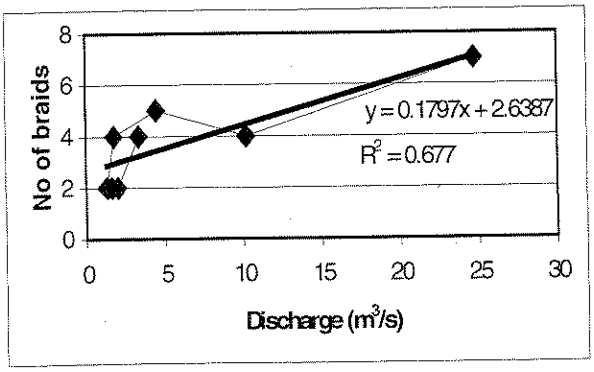

Figure 3.1: Number of braids in the Ashley near Rangiora Airfield, as a function of discharge (data from NCCB&RWB, 1982)

A more extensive study by Mosley (1983) showed a tendency for the number of braids in four Canterbury Rivers, including the Ashley, to decline from an average of 5 at 20 m^3/s to an average of 2 at 1 m^3/s (Figure 3.2). There is considerable variability in this relationship, and it should be noted that the definition of a braid could include a spring-fed channel that might not in fact create an island wholly surrounded by water. The data indicate that flow abstractions at low flow in the Ashley River may reduce the number of braids at the average rate of about 0.2 braids per 1 m^3/s of flow reduction – arguably a minor effect, given that permitted abstractions from the river total 1.5 m^3/s.

In summary, hydrological impacts on life-supporting capacity with respect to terrestrial plants and animals in the Ashley River are caused principally by flood flows large enough to wash over gravel surfaces and remove colonising vegetation. Low flows are of limited significance, largely in terms of changes in the number of branch channels in braided reaches of the river. However, flow hydrology is probably of minor importance, relative to flood and river control, the introduction and control of exotic species, and other human activities.

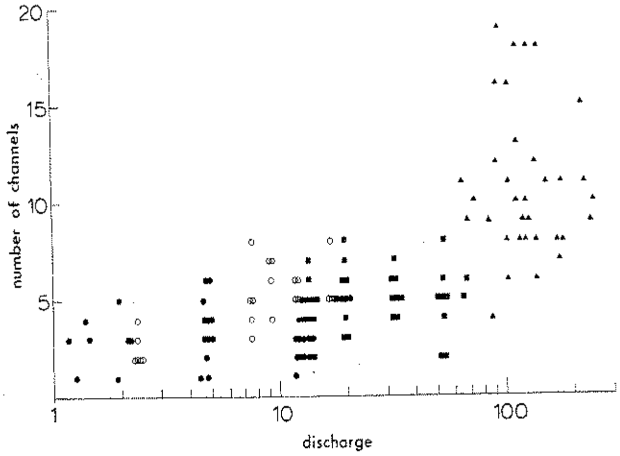

Figure 3.2. Number of braids as a function of discharge, Canterbury rivers (from Mosley, 1983). Ashley data are marked by solid circles, and are in the range 1-20 m^3/s.

3.1.2 Birds

The Ashley riverbed is considered by Department of Conservation (O'Donnell and Moore, 1983) to be of outstanding value for birdlife. The estuary is considered to be one of the most important bird habitats on the east coast of the South Island, because of the diversity of species that utilise it and its role as a sanctuary for migratory waders (Bowden, 1982). It has particular significance for overwintering waders, during June to August. The wetlands associated with the lower tributaries are of local importance for waterbirds. About 80 different bird species (>45 wetland species and >15 migratory species) have been observed in and adjacent to the estuary.

The value of the estuary, river mouth, and wetlands as habitat for waterbirds is affected by a range of factors and processes, such as land use modification and drainage, nutrient enrichment by intensive agriculture in the catchments of the lower tributaries and wetlands, human use of the area for recreation, and the natural hydrologic and geomorphic processes characteristic of a river mouth and estuary. The regime of low to medium flows in the river is relatively unimportant in comparison, although large flood events have a significant impact on sediment movement into and the morphology of the estuary and river mouth.

The hydrology of the lower tributaries ultimately is related to aquifer hydrology, but is much modified by drainage. The tributaries are fed by groundwater originating from seepage into the Ashley River bed further upstream, flowing down-fan, and returning to the surface as it approaches base level (sea level). The Council's investigations (Sanders, 1997) indicate that nearby groundwater wells draw a high proportion of their yield from the surface water bodies, so there is a potential – as yet incompletely defined – for groundwater abstraction to have a negative impact on waterbird habitat provided by the lower tributaries and wetlands.

The most valuable reach on the main river is between the Okuku confluence and Rangiora (Bonnett *et al.*, 1982), which incidentally is the reach that is subject to de-watering during low flow periods. The main river is particularly important for the threatened wrybill plover and banded dotterel, and other waterbirds – black-fronted tern, South Island pied oystercatcher, pied stilt, black-billed gull – also nest, feed and rear their young in this area, principally during the period late August to January/February (Tony Crocker, Ornithological Society of New Zealand, pers. comm., 1999). The main habitat types are (Moore, 1981):

a. Gravel bars.
Vegetation-free gravel bars are prime nesting areas for wrybill plover, black-fronted tern, and black-billed gull, and provide feeding areas for some waders.

b. Aquatic habitat.
Riffles and seepage channels provide feeding areas for wrybill plover and banded dotterel; pools and backwaters provide feeding areas for pied stilt, South Island pied oystercatcher, white-faced heron, and spur-winged plover, as well as loafing areas for waterfowl; runs are little used by waders, mainly shag, black-billed gull, and black-fronted tern.

c. Berms.
The vegetated berms are mainly inhabited by introduced passerines, and adaptable native birds like fantail, grey warbler, and kingfisher.

As already noted, the extent of bare gravel bars suitable for nesting is related principally to the frequency of floods large enough to cause migration of braids and to wash over and rework the bars. Management of the flow regime, particularly at low flows, is unlikely to have any effect on the extent of bare gravel. Indeed, the Ashley-Rakahuri Rivercare Group has assessed the threats to indigenous bird species on the Ashley River (Environment Canterbury file NO2C/224), and has concluded that flow regime management is only one of five groupings of threats, and a poorly defined one at that. The main impact of human activity on this aspect of habitat will be through disturbance (particularly recreational visits), predation by introduced species, invasion by introduced weeds, and gravel extraction.

The principal impact of management of the Ashley's flow regime is on the area of aquatic habitat usable for feeding. As noted in the preceding sub-section, the number of braids at a cross-section declines with declining flow, at an average rate of about 0.2 braids per 1 m^3/s reduction in flow (at a given flow the number of braids can vary substantially along the channel; recall also that resource consents to abstract from the river total 1.5 m^3/s). The wetted area (or water surface width per metre of channel) in run, riffle and pool sub-habitats all decline with discharge (Mosley, 1983, Table 4), although the statistical relationships between pool and riffle areas and discharge are rather weak, in the range of flows (<20 m^3/s) that Mosley studied. This implies that management of low flow regime might, at a given cross-section, have limited effect on the aquatic habitats – riffles and side pools – of greatest value for waterbird feeding.

On the other hand, Hughey (unpublished evidence to a hearing on the proposed Waimakariri River RRP) demonstrated a strong relationship between discharge and the weighted usable area (estimated using the IFIM methodology) on two sample cross-sections in the Ashley, for feeding wrybill (Figure 3.3). Hughey's estimates indicate a loss of up to 1.5 m^2 of feeding habitat per metre of channel, for each 1 m^3/s reduction in flow, below 20 m^3/s.

While Hughey's data indicate that weighted usable area declines linearly with discharge, a more extensive study in the Ashley indicates that the weighted usable area available for food production (i.e. habitat suitable for macroinvertebrates) actually peaks at approximately 2 to 2.5 m^3/s (Mosley and Jowett, 1985). It declines thereafter by about 5%, to a discharge of 1.5 m^3/s (the lowest flow for which data were obtained).

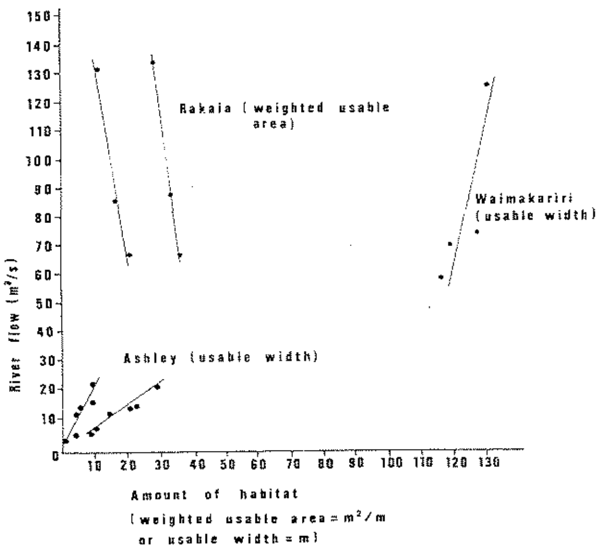

Figure 3.3. Weighted Usable Area for riverbed birds as a function of discharge (from Hughey, unpublished data).

In the extreme, modification of the flow regime by flow abstraction can result in de-watering of the riverbed. The smaller tributaries of the Ashley, the Glentui, Garry, and Makerikeri, cease to flow on many occasions, in the vicinity of their confluences, even in the absence of abstractions. Even the Ashley periodically ceases to flow in the reach from the Okuku confluence almost to SH 1 in the late summer, when discharge at Ashley Gorge falls below about 2.5 m^3/s (Figure 3.4). This de-watering is due to losses to groundwater through this reach; Appendix 6 provides fuller information, derived from vertical aerial photographs, of the consequences of losses to groundwater for channel morphology at low flows. A set of aerial photographs taken (January 1974) at a flow of 4.45 m^3/s shows that the river had become a series of disconnected pools through a 2 km reach downstream from the railway bridge. The concurrent gaugings in Figure 3.4 therefore do not conclusively demonstrate that a flow of 2.5 m^3/s is sufficient to maintain continuous flow.

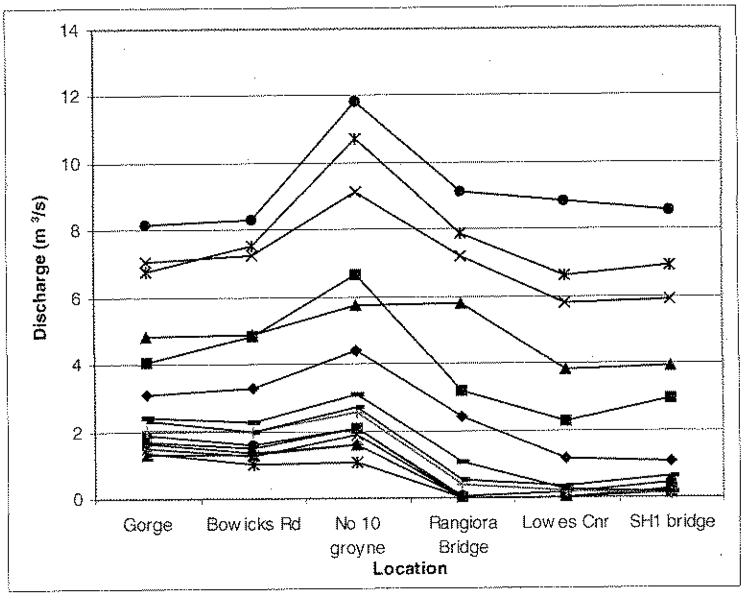

Figure 3.4. Discharge along the Ashley on different occasions. The riverbed is dry between Rangiora Bridge and Lowes Corner when flow at the Gorge is below about 2.5 m^3/s.

Abstraction of water from the river or hydraulically connected wells can be expected to increase the frequency, duration, and/or extent of de-watering. This will have an obvious effect on the amount of aquatic habitat available for feeding, if de-watering occurs during the prime nesting, rearing and feeding period (late August to January/ February). It should be noted, however, that the most highly valued area for riverbed birds is that which is subject to natural de-watering, and that the nesting and breeding season is largely over before Ashley flows fall to the level (<2.5 m^3/s at the Gorge) at which de-watering occurs.

In summary, the life-supporting capacity of the Ashley River with respect to bird life is related to hydrologic regime principally through flood events, at any time of year, that provide vegetation-free gravel bars for nesting, and the medium to low flows that provide feeding areas during the nesting/breeding period, especially in riffles and side braids. Flood events are not materially affected by management of the flow regime. The critical period for low flows is August through to January/ February, before the river has fallen to its lowest, mid- to late-summer levels. Reductions in flow due to abstraction may increase predators' access to nesting birds, although this effect probably is small. Flow reductions also reduce the area of streambed that is suitable for food production and for feeding by wading birds. There is some uncertainty about this, since observations in the Ashley suggest that optimum flow levels for food production may actually be around 2.5 m^3/s.

3.1.3 Aquatic plants

Aquatic plants, together with plant material falling into the channel from riparian vegetation, provide the basis of the aquatic food chain. In the Ashley, periphyton coating the stones on the riverbed are the predominant form of plant life; the discharge regime is too unstable for higher plants to become established and thrive, except in limited areas of spring-fed braids and backwaters. The species of aquatic plants in the Ashley system are found in many other gravel-bedded rivers in New Zealand.

Extensive research in New Zealand rivers, including the Ashley and its tributaries, shows that periphyton biomass is related to nutrient concentrations and hydrological-disturbance regime (Biggs, 1995; Biggs and Close, 1989). The critical aspect of the hydrological regime is the frequency of flood (disturbance) events large enough to mobilise the riverbed and/or slough off periphyton growths. Various indices of such events, including the flow at which mean flow velocity exceeds 1 m/s, the flow >3 times the median, or the flow which is >6 times greater than the preceding base flow, have been used. Working in the Okuku River, Biggs and Stokseth (1996) observed that significant periphyton colonisation commenced about 50 days after a flood, and accrual at an exponentially increasing rate continued for a further 30 days until sloughing of the mature community commenced (Figure 3.5).

Biggs and Close (1989) concluded that maximum periphyton biomass was achieved in the Ashley after extended periods of low flow, between floods, in late summer and winter. They observed also that declines in biomass coincided almost invariably with floods. Scrimgeour and Winterbourn's (1989) observations in the Ashley River, just upstream of the Makerikeri confluence are similar, with maximum algal biomass being measured after a period of stable flows and reductions in biomass being clearly related to the incidence of floods. Periphyton biomass in the Ashley probably is limited by phosphorus concentrations.

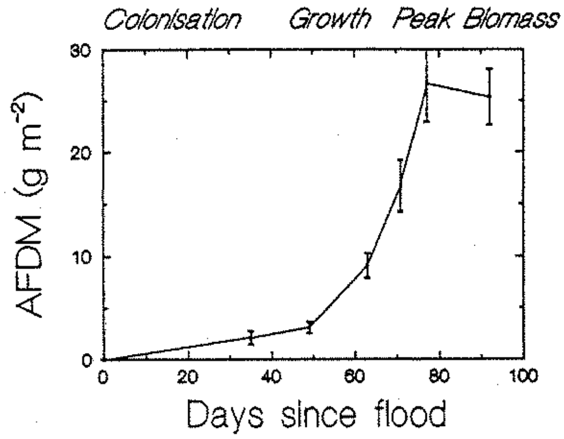

Figure 3.5. Accrual of periphyton (Ash Free Dry Matter AFDM) following a flood (from Biggs and Stokseth, 1996).

The effect of managing the flow regime of a river on periphyton growth will be mediated principally through modifications to the frequency of flows large enough to disturb the bed, and to the duration of low flows during which accrual occurs. In the Ashley, flows greater than about 30 m^3/s are regarded (Scrimgeour and Winterbourn, 1989) as a significant threshold at which bed mobilisation occurs, although Mosley (1983) found that another proposed threshold for bed mobilisation, a mean velocity of 1 m/s, is reached at only 15-20 m^3/s. Freshes exceeding 30 m^3/s occur several times a year on average, and this flow is exceeded more than 10% of the time in most years. Any modification to the flow regime that affects the frequency with which these quite small flood flows are exceeded could affect the frequency of flushing and the length of time available for accrual.

An indication of the possible effect on periphyton of modifying low flows is provided by Biggs and Close (1989). Data for nine rivers indicate that periphyton biomass increases exponentially as the discharge on the day of sampling declines (Figure 3.6). The relationship suggests that further reducing low flows by abstraction may increase periphyton biomass per unit area of wetted area (noting that wetted area declines as discharge declines), although the exact form of the relationship is not known. Of course, total dewatering, as periodically happens in the Ashley below the Okuku confluence, will result in dessication of the periphyton cover.

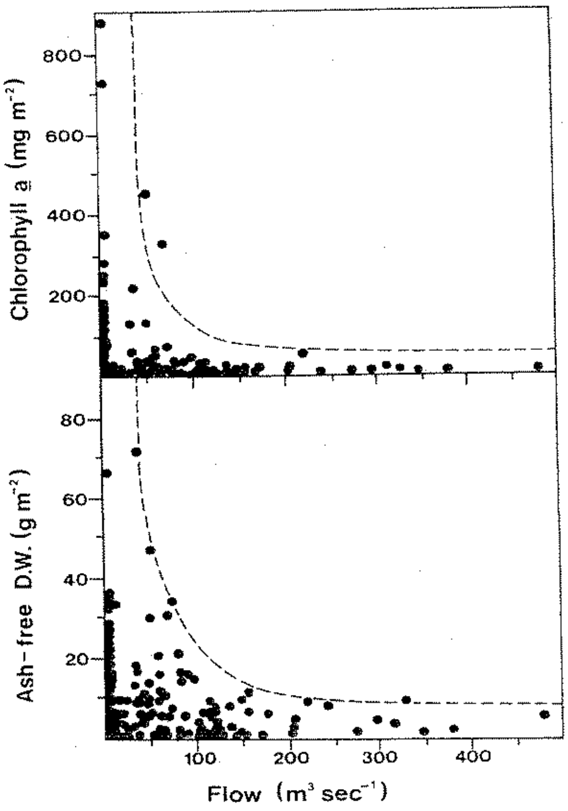

Figure 3.6. Periphyton biomass as a function of discharge at time of sampling (from Biggs and Close, 1989).

In summary, the aquatic vegetation (periphyton) of the Ashley is adjusted to the frequency of large flows (>30 m^3/s) able to remove it, and to the durations of low flows during which biomass is able to re-establish. The range of species is similar to that in other Canterbury Plains rivers, and is unlikely to be modified by management of the hydrological regime. Periphyton biomass increases with the duration of stable low flows, and may be increased by flow abstraction. It is a matter of opinion what quantity of periphyton is desirable, and therefore whether management of the flow regime should aim for a particular biomass.

3.1.4 Aquatic macroinvertebrates

Scrimgeour *et al.* (1988) observed at least 56 species of aquatic macroinvertebrates in the Ashley River, at densities as high as 18,600/m^2. They found that the macroinvertebrate fauna was dominated by larvae of *Deleatidium*, *Hydora*, and Chironomidae. The list of species is similar to that in the Rakaia River (Sagar, 1986); Sagar concluded that low species diversity is likely to characterise unstable, braided rivers like these. He suggested that disturbance by frequent high flows tends to produce a faunal community in which those species that require stable substrates and stable algal covers on which to browse are absent.

Research in the Ashley and other braided rivers indicates that, as with periphyton, aquatic macro-invertebrate densities are closely related to the occurrence of flows able to disturb the bed, and the duration of low flows during which aquatic fauna can re-establish (Sagar, 1986; Scrimgeour and Winterbourn, 1989). Flows greater than about 30 m^3/s in the Ashley and 400 m^3/s in the Rakaia (in both cases, about twice the mean annual discharge) were considered to be responsible for significant reductions in species diversity and standing crop.

Scrimgeour *et al.* (1988) found that invertebrate density was highest (almost 20,000/m^2) after long periods of low flow (Figure 3.7). Their observations, and those by Sagar in the Rakaia, demonstrate progressive increases in species diversity and standing crop during stable flows following disturbance. Recolonisation may be achieved by a variety of mechanisms, including downstream drift, aerial sources, upstream migration, and upward movement of animals from within the substrate. Sagar considered that downstream drift was dominant in the Rakaia, while Scrimgeour *et al* (1988) noted the importance of isolated pools in the Ashley riverbed that, after reconnection to the channel system during a flood, provided sources of colonists. Modification of the Roding River (Nelson) flow regime by abstraction, to the extent of causing periodic total de-watering, has not affected community composition, even after 60 years. Recolonisation from the upper catchment maintains the benthic community (John Stark, Cawthron, pers. comm., 1998), and would do so in the Ashley.

The diversity and standing crop of aquatic macroinvertebrates are likely to respond to management of the flow regime in a way similar to that suggested above for periphyton. Reduction of the frequency and magnitude of flows greater than about 30 m^3/s will provide longer periods of low flow during which colonisation and growth in standing crop can proceed. (Sagar believed that fluctuating summer flows increased rates of colonisation in the Rakaia, presumably by enhancing downstream drift. It may be that a modification of flow regime that reduces the number of flow events peaking at >30m^3/s while maintaining the pattern of flow variability could benefit macro-invertebrate communities). The objective of maximising invertebrate diversity and standing crop might prove to be inconsistent with an objective of minimising nuisance growths of periphyton.

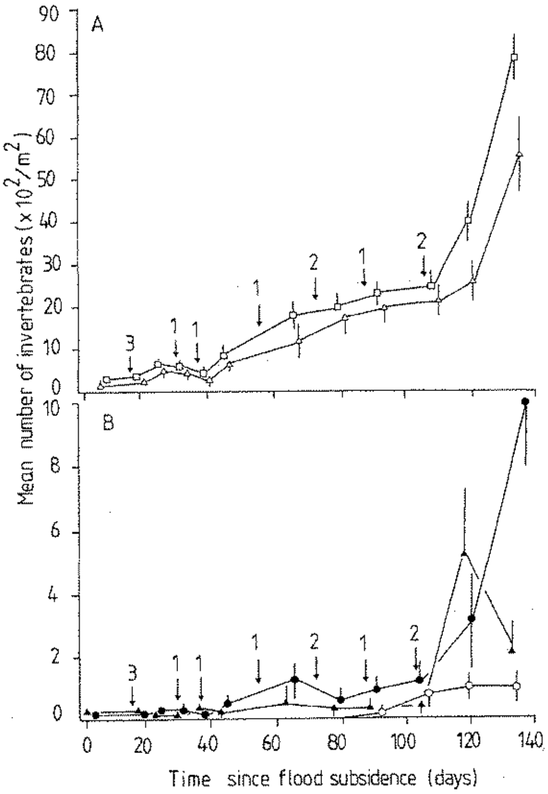

Figure 3.7. Invertebrate density as a function of time since a flood event (from Scrimgeour *et al.*, 1988).

In summary, the invertebrate fauna of the Ashley is similar to that in other Canterbury Plains rivers. The benthos of the Ashley already reflects a naturally unstable flow regime, and is persistent and resilient to disturbance. Aside from the ability of some species to take refuge in stagnant ponds or even within moist gravel, recolonisation by downstream drift is rapid. It is unlikely that a reduction in low flows by abstraction – even to the point of increasing the extent or duration of total de-watering of the riverbed

– has other than a temporary effect on macroinvertebrate species diversity or abundance in the Ashley.

3.1.5 Fish

Twenty-one fish species inhabit the Ashley River system; fifteen are migratory. Many species are present in relatively high numbers and at high densities (Bonnett *et al.*, 1982). Glova *et al.* (1985) concluded that the most common species in riffles in the Ashley were torrentfish, longfinned eel, blue-gilled bully, and upland bully. Brown trout and quinnat salmon are present, and both migratory and resident fish provide the basis for a river fishery (see below). Spawning fish migrate towards the middle and upper reaches of the Ashley, Okuku, Garry and Glentui Rivers during November-March, with spawning taking place in late autumn-winter.

Comparison of fish populations in riffles in the Ashley, Hurunui and Rakaia Rivers indicated a mean abundance (5.95 fish/m^2) in the Ashley that was ten times that in the Hurunui and over twenty times that in the Rakaia, apparently as a result of fewer floods during the period preceding sampling (Glova *et al.*, 1985).

The lower tributaries and Ashley-Saltwater Creek estuarine wetlands provide a nationally important breeding and rearing habitat for several fish species, including eel, the Canterbury mudfish, and whitebait. Whitebait (inanga and possibly small numbers of koaro) provide a regionally important fishery during the spring (August-November) in-migration. Kahawai, yellow-eyed mullet and black flounder are found in the estuary, and provide a popular recreational fishery.

The fishery potential of the Ashley and its tributaries is constrained by summer low flows, particularly when the bed is completely de-watered in the middle reach of the main river and the lower reaches of the upper tributaries. Low or zero flow may result in habitat loss, reduced cover, reduced drift food availability, elevated water temperatures, siltation and packing of substrates, and impeded fish migration. The high numbers and densities of fish observed by Glova *et al.* (1985) in the main river may be interpreted as evidence of compression of the fish into a reduced area of habitat (Bonnett *et al.*, 1982). In past years, salvage operations have rescued up to 8,000 salmonids in any one year, with dozens of dead fish being observed in disconnected pools in the riverbed (Bonnett *et al.*, 1982).

Several studies have investigated the relationship of available habitat to discharge in the Ashley and similar Canterbury rivers. Generally, usable habitat area declines with declining discharge for all species and life stages, but not all species have the same habitat preferences, so it is not possible to affirm a single discharge as the optimum or minimum acceptable. For instance, Mosley and Jowett (1985) found that the optimum flow for blue-gilled bully would be about 1.5 m^3/s, the minimum for adult brown trout would be 2.5 m^3/s, and the minimum for long-finned eel would be about 4 m^3/s (Figure 3.8). Mosley (1983) calculated that the usable habitat for eight species in the Ashley would in all cases decline increasingly rapidly with declining discharge. However, the variability about the regression relationships is in most cases so great that estimates of the effect of a reduction in discharge have a large degree of uncertainty.

As already noted, it appears that fish densities are greater than might be expected during low flows – that is, usable areas calculated using habitat preference curves are not accurate because fish are forced into habitat that they do not prefer, but can tolerate (up to a point).

It is clear that complete de-watering of the riverbed – whether as a result of natural flow variation or exacerbated by flow abstraction – will have a catastrophic effect on the fish present in the river at the time, if they are trapped in disconnected pools that eventually dry up. At the same time, it is also clear that re-colonisation of even a completely de-watered riverbed occurs once flow is re-established, albeit more slowly than after disturbance by a major flood (Fowles, 1972).

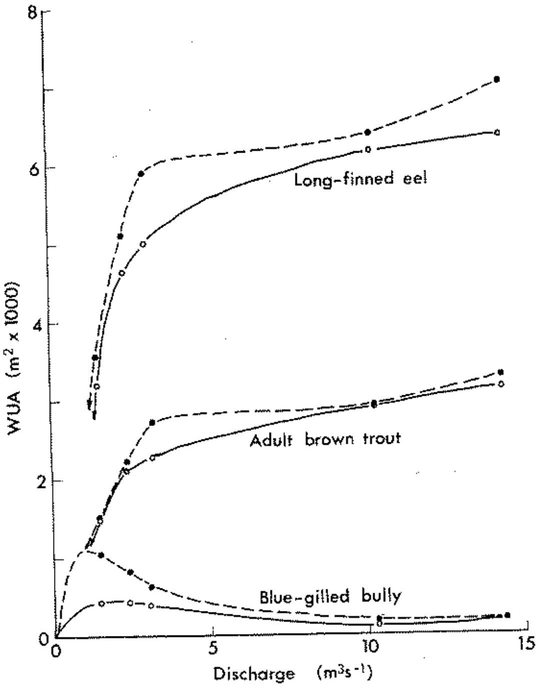

Figure 3.8. Usable habitat (WUA) for three species in the Ashley as a function of discharge (from Mosley and Jowett, 1985). Dashed lines are computer-simulated WUA, and solid lines are based on measurements.

High water temperature is a potentially limiting factor for fish populations in shallow braided rivers like the Ashley (section 2.5.2). Water temperatures of 23°C have frequently been measured in the Ashley, and temperature can reach as high as 35°C in summer, particularly in disconnected pools. Moreover, rates of temperature change can approach 1°C per hour, which may introduce another source of stress if the fish are unable to find cool refugia. A reduction in flow will, in general, enable an increase in water temperature at a rate on the order of 0.1°C per 1 m^3/s reduction (Hockey *et al.*, 1982), as heat is transferred to a reduced mass of water. Nevertheless, as discussed in section 2.5.2, observations in the Ashley River show that temperatures are very variable from place to place, because of the effects of cool underflow through the substrate. While 60-70% of the total water surface area of the river (accounted for mainly by the main channel and largest braids) may reach a maximum temperature of 22-24°C on a summer's day, 30-40 % may be cooler by up to several degrees. This area comprises small channels partially or wholly maintained by seepage from the gravels, or in which regular exchange of flow between surface and subsurface occurs at riffles. Such waters may provide refugia for at least some fish that would otherwise be exposed to sub-lethal temperatures.

The potential effect of flow reduction on movement of the Ashley's 15 migratory fish species is of concern, particularly the salmonids, which are migrating upstream during the period of summer low flows. A rule of thumb is that migrating quinnat salmon require a minimum depth of 0.25 m to avoid loss of condition by abrasion, although they are able to swim upstream for short distances in water significantly shallower than that. Large trout require about 0. 18 m, and small trout about 0.12 m. Mosley (1982) concluded that a flow of at least 38 m^3/s would be required to provide a minimum passage depth of 0.25 m in Canterbury braided rivers (including the Ashley), that is, a small fresh. However, upstream-migrating salmonids can move at lower water depths and discharges, and Bonnett *et al.* (1982) consider that a minimum flow of only 3-4 m^3/s at Ashley Gorge is sufficient to allow continuous passage for all but the largest fish. In any case, migrating salmonids are able to achieve upstream progress during freshes, with periods of resting in pools in between, so that the frequency of freshes is at least as significant as the minimum discharge to which the river drops. However, during November-March, the number of freshes > 30 m^3/s in the Ashley averages only 2 (range from 0 to 5; Appendix 2, Figure 2). This frequency is unlikely to facilitate upstream migration, especially since the smallest number of freshes occurs in the driest years.

Flood events may be significant for fish populations in other ways (Hayes, 1995). The effect of floods on aquatic flora and fauna has already been referred to above; reduction of standing crop during floods must obviously have an impact on food availability for fish. More directly, Hayes (1995) has pointed to two major effects of floods on brown trout in the gravel-bedded Kakanui River: losses of eggs and alevins from spawning areas, and downstream displacement of emergent fry. These effects are very variable in the river system, and also depend on whether floods occur at critical stages in the life cycle of the fish. On the basis of his field observations, he concluded that "floods with a 4-year return period coinciding with fry emergence periods have a dominant influence" on trout density, and more generally that variability in juvenile trout density "appears to be largely density (i.e. habitat) independent, associated with flood events". The floods that can cause these effects are well beyond the range of discharges modified by flow abstraction.

In the lower tributaries and associated wetlands, the issues are rather different. Flood control, land drainage, land use change, and invasion of exotic vegetation have severely reduced the area of wetland suitable for species such as short-finned eel, whitebait and mudfish. Reduction of flows in the spring-fed streams and wetlands due to ground- and surface water abstraction, as well as livestock disturbance and declining water quality associated with intensive agriculture, may exacerbate these effects in the remnant wetlands and streams. A number of measures have been taken to provide "maintenance flows" and to manage water quality (NCCB&RWB, 1989). However, the present level of knowledge on the fishery, its relationship to discharge and water quality, and the consequences of flow modification is limited. The effectiveness of these management measures only can be surmised.

In summary, fish fauna in the Ashley are affected by the hydrological regime in a way similar to that for macroinvertebrates, in part because macroinvertebrates provide the food source for many fish. There is the additional constraint of passage depth for migratory species, which may be a serious one, since freshes are infrequent during the period of migration. The fish communities are resilient to the naturally high levels of disturbance by floods, and are able to recolonise the riverbed after periods of low flow and de-watering. Declining flow – either naturally or exacerbated by abstraction – has a negative effect on the fish in the river, to the extent that many thousands of salmonids (and no doubt native species) would die during late summer low flows, as a result of habitat loss. Flow reductions below 2-4 m^3/s are likely to cause accelerating loss of habitat, concentrating the remaining fish in smaller areas and with access to declining food sources.

3.2 Mahinga kai

The estuary, lower tributaries and wetlands – notably Taerutu and Tutaepatu – have been important sources of mahinga kai and kai moana – eels, whitebait, freshwater crayfish, and shellfish as well as other resources such as flax and mud for dyes – for the Kaiapoi Ngai Tahu (Canterbury Regional Council, 199?). These resources have been much depleted by the loss of habitat, land drainage and "reclamation", sedimentation and declining water quality, as noted in preceding sections. Flow reduction by abstraction provides an additional source of stress on the resource.

Mahinga kai is related to life-supporting capacity, whose relationship with discharge has been considered in section 3.1.5.

3.3 Natural character

The term "natural character" is not defined in the Resource Management Act, but Mosley (1999a) has analysed case law and resource management literature to develop the following definition:

> The natural character of a locality might be defined as deriving from those observable elements, attributes, and patterns in the environment that were produced by naturally occurring biological and physical processes, and those processes themselves. It excludes any that were produced by human agency. The elements, attributes, patterns, and processes that are viewed as contributors to natural character, and the importance attached to each, may depend on the observer, and may vary from place to place.

The analysis indicates that natural character can be regarded as a component of amenity value, and that there is a considerable overlap with ecological and fish/wildlife habitat values. This section therefore addresses only aspects of natural character that are not considered in other sections.

The natural character of the Ashley River derives from its wide gravel bed, wandering braided channels, its aquatic biota and birdlife, and the frequently dense exotic shrubland (willows, gorse, broom, etc) along the berms and on islands in the channel. The definition of natural character established by reference to case law includes "processes", the hydrologic regime of the Ashley (its pattern of flows over the year, the occurrence of flood events, even the periodic de-watering of the middle section of the river due to very low natural flows). Hydrologic regime therefore must be regarded as an element of natural character, and perhaps an element that is crucial to defining the character of this particular river.

The Ashley is by no means pristine, but in terms of case law has significant natural character because of the importance of natural geomorphological and ecological processes (e.g river braiding, vegetation succession) in the creation of its overall appearance. Artificial features such as groynes, rockwork, vehicle tracks, and gravel extraction points detract at some places from natural character, although to a relatively limited extent.

Overall, the visual character of the Ashley River and its margins is created largely by a combination of geomorphic processes during floods that are large enough to reform the riverbed and banks, and river control measures. The low flow regime has little influence on the overall appearance of the river, since low flows accommodate themselves to the contours of the riverbed that are created during floods.

The number and sizes of braids, riffles and pools, the wetted area, the nature of the water surface, and the quantity of flowing water are important elements of natural character. As reviewed in section 3.1, they are sensitive to changes in discharge, and therefore to any human modification of discharge. However, it is uncertain to what extent these attributes respond to discharge modification in a way that is discernible to even an expert onlooker, except in the extreme case that the riverbed becomes dry over a greater length of channel than would otherwise be the case. Indeed, they show such a level of spatial and temporal variability that statistically significant measurements of their response to changing discharge are extremely demanding of resources (Mosley, 1983).

In summary, natural character includes many aspects of the river, including several that reflect human activity, such as introduction of exotic vegetation. One of the most important elements is the flow regime that is responsible for the overall dimensions and appearance of the Ashley, and that provides a basis for the ecosystems that are characteristic of the river. The particular sequence and statistics of flows – floods, low flows, and variations through the year – can be regarded as crucial to defining the river's character. The natural character of the river at the commonly occurring low flows is one of extensive areas of gravel crossed by one or a few wandering channels. Flow abstraction undoubtedly affects attributes such as the relative areas of gravel and water, but it is uncertain to what extent the effects can be discerned.

3.4 Trout and salmon habitat

Trout and salmon habitat is an aspect of "life-supporting capacity", and its relationship with discharge has been considered in section 3.1.5.

3.5 Amenity values

Amenity values are defined in the Resource Management Act as "those natural or physical qualities and characteristics of an area that contribute to people's appreciation of its pleasantness, aesthetic coherence, and cultural and recreational attributes". Amenity values commonly are considered in terms of scenic quality, recreational fisheries, and other types of recreation.

3.5.1 Scenic quality

The *New Zealand recreational river survey* (Egarr and Egarr, 1981, p. 119) classified the lower Ashley (below the Gorge) as having an "uninspiring" scenic value. The Glentui, Makerikeri, and Garry Rivers were classified as having "moderate" scenic value, the Okuku (focussing on the gorges, however) as "picturesque", and Saltwater Creek as "uninspiring". Using the methodology of Egarr *et al.* (1979), the river and its lower and middle tributaries would rank as "dull" to "ordinary" over much of their length, perhaps approaching "interesting" in the upper reaches where downlands and foothills are visible.

In comparison with the New Zealand rivers studied by Mosley (1989), the Ashley and its tributaries would be regarded by the general public as scenically unattractive. The open, featureless landscape of the lower Ashley fan, the large areas of bare gravel and weedy vegetation, the barely moving water, and the many signs of human modification of the river would generate a score (on a 0-9 scale) on the order of 3.5-4.0, similar to that of the lower Waimakariri (NCCB&RWB, 1986, section 17). The ranking would increase upstream, as riparian vegetation becomes an increasingly important component of the scene and as downlands and foothills provide variety in the overall scene.

Public perception of the scenic value of New Zealand rivers is influenced by discharge to a limited extent, principally through the presence of moving water (rapids and riffles). Water colour also can be significant, with muddy water reducing the scenic value of a river relative to those with clear water. During the low to moderate flows that are observed in the Ashley for much of the time, variations in discharge are likely to have only a limited influence on perception of scenic value. The width of flowing water during even moderate flows is in most places much less than the overall width of the gravel bed, which averages 350 m in the lower 20 km of the river. For example, a halving of flow, say from 8 m^3/s to 4 m^3/s, would produce a decrease in average water surface width from about 40 m to about 30 m, which would have little effect on the overall appearance of the river. As a result, modification of the flow regime of the river is unlikely to have a significant effect on the scenic quality of the Ashley, even in the reach that is subject to periodic de-watering.

3.5.2 Recreational fisheries

In a 1979 angling survey, the Ashley River fishery ranked fourth equal in popularity with the Hurunui River, below the Waimakariri, Rakaia and Selwyn (Bonnett *et al.*, 1982). Its usage was comparable with other well-known angling rivers such as the Motueka, Pomahaka and Southland Waiau.

The Ashley trout and salmon fishery was ranked as only average in terms of angling quality; the Okuku was rated slightly higher, while other tributaries were not considered to provide significant fisheries. The Ashley's popularity derives principally from its close proximity to Christchurch and other North Canterbury population centres, and to its suitability for family visits for general recreation, of which angling is just one aspect.

The relationship between the river fishery resource and flows has been considered in a preceding section (3.1.5). Angling has a number of requirements in addition to those that relate to the fishery resource (Appendix 4). In general, the water-related requirements will be met to a decreasing extent as flow in the river declines, and water is concentrated into a declining number of fishable pools. However, no data – particularly on the number and dimensions of pools – are available that allow either an optimum or a minimum flow for angling in the Ashley to be set. In practice, fish habitat preferences and associated discharges can be taken to meet flow-related angling requirements also. For adult brown trout, Mosley and Jowett (1985) found that usable habitat was relatively constant until a flow of about 2.5 m^3/s, at which it started to decline rapidly.

The river mouth and estuary are very popular for recreational fishing – whitebaiting, netting, shellfish gathering, angling for sea-run salmonids and kahawai, bait fishing. The lower catchment tributaries have limited use for recreational fishing, principally whitebaiting and eel fishing at certain times of year. The quality of the estuarine/ wetland fisheries in the river mouth/estuary and lower tributaries is controlled principally by human influences such as land drainage and water quality degradation, and natural estuarine/marine processes such as tidal circulation (Section 3.1.5). Angling in the area is largely unrelated to river flows, except that large floods with turbid water would tend to curtail angling. Management of the flow regime in the main river or tributaries is not considered likely to have a significant influence on the many forms of recreational fishing in these areas, separately from influences on the fishery resource itself.

3.5.3 Other recreation

Egarr and Egarr (1981) consider the Ashley and its tributaries as of low to insignificant recreational value, but in fact the Ashley is one of the most heavily used rivers in Canterbury (NCCB&RWB, 1989). Users come from Christchurch, or live in the near vicinity of the river, e.g. in Rangiora. The most intensively used areas are at the Gorge, the reach adjacent to Rangiora, and the lower river and estuary. An informal survey by students of Ashgrove Primary School revealed that their families use the Ashley for nearly thirty activities, with picnicking, swimming, mountain biking and 4WD driving as the most popular (Appendix 5).

Use of the middle/lower Ashley River for boating is limited, and for the tributaries is non-existent. Even though jetboating and kayaking are possible during moderate flows, there are better rivers nearby (including the Ashley and Okuku Gorges). Most use is for family picnicking, camping, sightseeing and "on-looking" (Bowden, 1982). It is likely that trail-biking and off-road vehicle driving have become much more important in recent years. These activities are enhanced by the presence of water, but are not dependent on it, except that an important element of family visits to a river is swimming. The pools in the Ashley have value particularly for families with young children, and the river is regarded as safer than the Waimakariri.

Water-enhanced activities in the Ashley do not have specific flow requirements. The simple presence of water seems to be more significant than the actual flow, although the satisfaction derived by users is likely to be greater if there is flowing water present in the riverbed. (Activities that use the riverbed for travel have no flow requirements at all, of course). Even in the case of swimming, the principal water-based activity in the Ashley, a disconnected pool fed by seepage can be acceptable or even preferred, even if there is no flow along the riverbed as a whole. The principal requirement is the appearance of high water quality (sight, smell, taste), which may decline during continuous periods of low flow, as periphyton die and decay.

It is difficult to define a managed flow regime that meets the requirements of recreational users of the Ashley (cf. Mosley (1983), who identified "habitat" preferences for water-related recreation, in terms of width, depth, velocity, and substrate). On the principle that some water is desirable at all places along the river, concurrent gaugings down the river (Figure 3.4) indicate that at least 3 m^3/s at the Okuku confluence or 2.5 m^3/s at Ashley Gorge (if available) should be maintained to ensure flow throughout the section that is subject to natural de-watering.

The estuary of the Ashley River is heavily used for recreation, although few data are available to establish levels of use. In addition to recreational fishing, the same activities observed along the river (picnicking, swimming, trail-bike riding, etc) are engaged in. These are not particularly constrained by the river flow regime (except for the effect of high flows and turbidity during floods), and tidal flows are of greater significance. The lower tributaries have limited recreational value or use, because of their small size and degree of human modification.

4. The desirable flow regime for instream values in the Ashley River

Section 3 has reviewed the wide range of instream values characteristic of the Ashley River, and their response to discharge. Flow requirements vary widely, with some instream values having little relationship to discharge. Tables 1 and 2 in Appendix 7 summarise the conclusions of section 3.

The discussion has focused entirely on the Ashley, since there is very little information about instream values in the tributaries, or their relationship to discharge. The general principles discussed in section 3 presumably apply to the tributaries in the upper and middle catchment, except that all but the Okuku are ephemeral (i.e. they periodically cease to flow). Comments regarding the effects of de-watering in the Ashley have particular relevance, therefore.

Some assumptions have been necessary regarding the likely objectives of setting a flow regime for the Ashley, and are implicit in the column "Specific requirements for flow management" in Table 1 of Appendix 7. Some of the likely objectives have inconsistent flow requirements. Thus, for example, to minimise periphyton growth requires that the periods of stable low flow, during which accrual occurs, are brief and separated by frequent freshes; to maximise the standing crop of macroinvertebrates is favoured by long periods of stable flow, on the other hand. The choice of a managed flow regime therefore needs to achieve balance and compromise, and to be based on an assessment of the relative importance to the community of each instream value. The present report therefore presents only a preliminary proposal for managing the flow regime in the Ashley, as input to the process of consultation that will be necessary to establish the community's views on priorities. It does not attempt to make any proposals for the tributaries, because there simply are insufficient data on which to base an analysis.

4.1 Desirable characteristics of a managed flow regime

Table 1, Appendix 7, can be used to synthesise the flows in the Ashley River that will maintain flow-related instream values to the greatest possible extent. The following items are referenced to the flow recorder at the Gorge. (The Okuku River adds water to the Ashley, but its proportional contribution is greatest during high flows. It ceases to make a significant contribution when flows at the Gorge decline to around 2.5 m^3/s (Figure 3.4), which happens to be a critical figure for maintenance of natural character and amenity values.)

6. Maintain the frequency and magnitude of freshes and floods (> 30 m^3/s) at all times of year, to remove vegetation that has colonised gravel bars, limit nuisance growths of periphyton, and provide for salmonid migration if flows naturally fall below 2.5 m^3/s (at which

continuous upstream movement becomes increasingly difficult or damaging).

7. Maintain flows above 2.5 m^3/s at all times (when available), to maintain:

    - preferred habitat for food-production (macroinvertebrates) required by birds (August to January/February),
    - optimum habitat for as many fish species as possible (year round),
    - quality of angling,
    - minimal passage depth for upstream migration of salmonids (November to March). (The value of 2.5 m^3/s is less than that specified by fishery scientists, but the occurrence of periodic freshets would periodically raise water levels and permit upstream movement).
    - flowing water throughout the length of the river for amenity (recreational) purposes (school holidays, weekends, evenings, particularly Christmas to Easter).

    Maintenance of these flows will also help to maintain water temperature in the main channel below lethal levels.

8. Maintain the annual pattern of flows, to maintain the natural character of the river as defined by hydrologic regime.

9. Avoid holding flows at the minimum value for extended periods, by sharing flows between instream and out-of-stream users above that value.

10. Maintain physical, bacteriological and chemical water quality above the standards specified for bathing, particularly below the Makerikeri River confluence.

If the preceding items were adopted, it should not be necessary to set a permissible total abstraction, as is presently the case.

4.2 Proposal for a managed flow regime for the Ashley

The items in Section 4.1 can be used to develop an appropriate water management rule. These items are based on an analysis of the attributes of a flow regime managed in such a way as to achieve the purposes of the Resource Management Act, particularly with regard to Sections 6 and 7. Community debate will be necessary to balance instream and out-of-stream uses of the resource.

In practice, item 1 in Section 4.1, relating to maintenance of flood flows >30 m^3/s, can be neglected. Present abstractions have a minor impact on such flood events. In the future, it is conceivable that major abstractions for groundwater recharge or to fill off-stream storage might have an impact on high flows, but an appropriate sharing rule to address item 4 also could address this issue.

Taken together, items 2 to 4 imply a significant change from the existing rule. It appears that ecological requirements largely can be met by item 2, specifying a year-round minimum flow of 2.5 m^3/s (when naturally available; flows actually are below this value for 20% of the time on average). Items 3 and 4 essentially address amenity requirements (natural character and appearance of the river), by aiming to maintain patterns of flow variability.

Item 3 might be achieved by setting a minimum flow in each month of the average or the minimum recorded 7-day low flow for that month (see Appendix 2, Table 4). However, this might be somewhat difficult to administer, and the particular values of mean or minimum 7-day low flow (or some multiple thereof) have no theoretical justification (and would change if calculated for a different period of hydrological record). Figures 4.1. and 4.2 compare a year-round 2.5 m^3/s with the current minimum flows and the mean and minimum monthly 7-day low flows. It (2.5 m^3/s) is well below the mean monthly 7-day low flow during winter (Figure 4.1), but is of the same order of magnitude as the minimum monthly 7-day low flow year-round except September and October (Figure 4.2). The current monthly minimum flow series reflects to an extent the variation of baseflows through the year, but it has barely more logic than a constant minimum flow. A sharing rule (item 4) in association with a single minimum flow would address item 3.

Item 4 might be achieved by setting a 1:1 sharing rule for flows in excess of the minimum, as at present. A 1:1 sharing regime commonly is regarded as equitable, although there is no particular theoretical justification for that ratio. It would also have the effect of mirroring the annual cycle of flows (item 3), and maintaining flood events (though flood peaks potentially could be reduced by half, and a sharing rule of 2:1 for "river:abstraction" might be more prudent).

As a starting point for discussion, a water management rule might be proposed as:

c) No abstractions are permitted when natural flow, measured at the Gorge, falls below 2.5 m^3/s.

d) Above a flow of 2.5 m^3/s, abstraction of 50% of the additional flow is permitted.

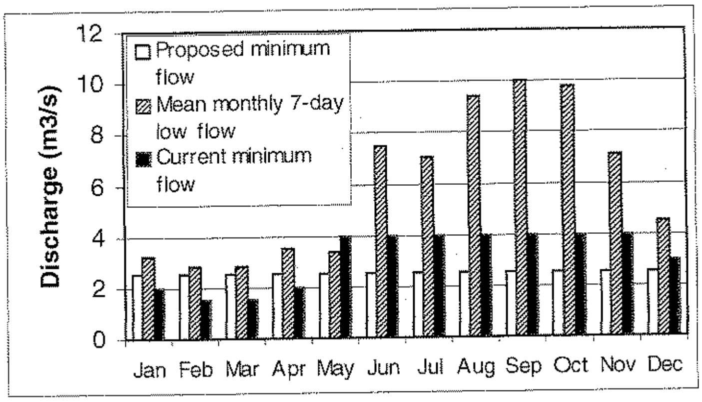

Figure 4.1. Comparison of current minimum flow series, 2.5 m^3/s, and the series of mean monthly 7-day low flows for the period 1984-1999.

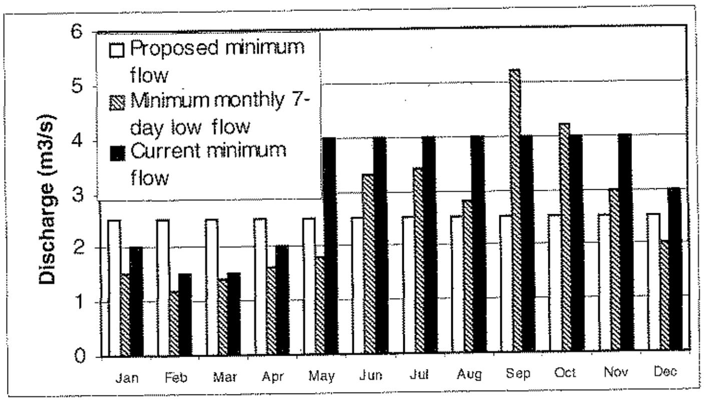

Figure 4.2. Comparison of current minimum flow series, 2.5 m^3/s, and the series of minimum monthly 7-day low flows for the period 1984-1999.

4.3 Appropriateness of the proposed rule and the Ashley management plan for achieving the purposes of the Resource Management Act

The flow management rule proposed in Section 4.2 aims to preserve the natural character and maintain the amenity values of the main Ashley River. It addresses their flow-related aspects, particularly with regard to mitigating the impact of flow abstraction.

In terms of Section 32 of the Resource Management Act, a rule of the type proposed in Section 4.2 above appears to be necessary to achieve the purposes of the Act, particularly those defined in Sections 5 to 7 of the Act. Section 3 of this report demonstrates that many aspects of natural character and amenity values are flow-related, and specifically are related to low flow conditions. To avoid, remedy or mitigate the adverse effects of flow abstraction requires a management instrument that maintains flows that are, at the very least, above those at which natural character and amenity values are impaired to an unacceptable extent. There is no obvious, practicable, and more appropriate alternative to the type of rule proposed in Section 4.2 as a means of achieving this purpose.

The policies and implementation methods adopted in the Ashley management plan (NCCB&RWB, 1989, section 2.1.4) went some way to meeting the requirements considered in Section 4.1. Item 5 (related to water quality) is fully addressed therein. (The 1989 policies also take account of out-of-stream uses, which the present report was not required to do).

For practical purposes, item 1 (Section 4.1) is presently met by Policy One (i) (total flow allocation not to exceed 1.5 m^3/s). However, this policy is unnecessarily strict for *this* purpose, since the 1.5 m^3/s limit on flow allocation is only 5% of the "threshold" 30 m^3/s flood flow that is estimated (with a significant degree of uncertainty) to be required for channel flushing. In addition, Policy One (i) does not directly address the desired environmental outcomes, and specifies a total flow allocation that is difficult to justify in terms of environmental effects. It is not considered necessary to maintain the existing Policy One (i), since its intent would be met if the rule proposed in Section 4.2 was implemented.

Item 2 (Section 4.1) is partly addressed by the existing Policy One (i) and (ii), but the minimum flows specified therein for January-April (1.5 and 2.0 m^3/s) appear to be too low to conserve ecological values. The minimum flow proposed in Section 4.2 above is based on a review of instream flow needs, which consistently indicates that a flow of 2.5 m^3/s is desirable to meet ecological requirements. (For some purposes, notably upstream migration of salmonids, a flow of 3-4 m^3/s would be desirable, but the periodic occurrence of freshes reduces the need to specify a higher minimum flow). The flows specified by Policy One (ii) were not set by reference to environmental outcomes; the Policy does not maintain the flows required in January to April, but it is unnecessarily strict in other months.

The 1:1 sharing regime of Policy One (ii) (c)) in effect addresses the environmental outcomes dealt with in items 3 and 4, Section 4.1. The proposed rule (b) in Section 4.2 includes the same provision. In practice, because flows during winter are at most times considerably greater than current abstraction rates, this rule may be required only periodically, or in the event that major abstractions are proposed, to fill off-stream storage. However, under these circumstances, a 1:1 share might not achieve fully the aim of item 1.

4.4 Flow requirements for the Ashley River estuary

The flow-related requirements listed in Section 4.1 for the main river are consistent with the aim of maintaining the "instream" values of the Ashley estuary. These values are affected to a limited extent by the hydrologic regime of the main river, with large flood events having the greatest impact on the morphology, ecosystems and human use of the estuary.

4.5 Flow requirements for the upper tributaries of the Ashley River

There is little information on the hydrologic regimes or instream values of the upper tributaries other than the Okuku, the relationship between hydrology and instream values, or the effect of current management of the flow regimes. It is therefore impracticable to make recommendations for flow regimes suitable for maintaining instream values.

4.6 Flow requirements for the lower tributaries of the Ashley River

There is limited information on the hydrological regimes of the lower, spring-fed tributaries, and on the current status and trend of instream values. There is virtually no information on the relationship between their hydrology and instream values. It is therefore not possible to provide specific recommendations for flows in the lower tributaries. The "rationale for maintenance flows" provided by the Ashley management plan (NCCB&RWB, 1989, Section 3) appears appropriate in the circumstances.

5. Recommendations for additional investigations

The Ashley River is one of the best studied rivers in New Zealand, particularly from the perspective of its geomorphology and aquatic ecosystems. Nevertheless, this report has found a number of areas in which information is lacking:

- The flow and other requirements of recreational users, and the locations, types, and levels of use.
- The ecological values of the Ashley's tributaries, particularly the ephemeral upper tributaries and the lower spring-fed tributaries, and their flow-related requirements.
- The flows needed in the main river for unimpeded upstream migration of salmonids.

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APPENDIX 1

ASHLEY RIVER AND SALTWATER CREEK
(from Canterbury Regional Council, 1991)

5 Ashley River and Saltwater Creek

DESCRIPTION:

A "foothills" river, rain fed, with origins in Puketeraki Range. Catchment a mixture of native forest (Mts Grey, Thomas, Richardson areas), exotic forest, native grasslands, extensive and developed pasture and urban areas. Near the coast the river passes through old sand-dune system. Ashley-Saltwater Estuary and Lagoon is an extensive area of salt marsh and mudflats.

Upper reaches and tributaries - small steep streams, with clean water, gravel beds; lower down winds through narrow Gorge then across Plains (as braided river) to estuary. Willows dominate banks on lower stretches, broom and lupins in bed.

Lees Valley (including Duck Creek tributary) formerly large wetland. Small streams on plains (eg Taranaki Ck) contain potential habitat for native fish, but affected by agriculture and clearance of weeds.

Important species:

Wrybill plover, banded dotterel, black-fronted tern, SI pied oystercatcher, pied stilt and black-billed gull nesting areas on braided riverbed and upstream of Gorge. Significant numbers of most of these. Only site in New Zealand where red-capped dotterel has bred. Trout fishery and good breeding success. Whitebait population significant.

At rivermouth large number of species and of individuals recorded, due to combination of wetland, dune and estuary. Australasian bittern, black stilt, marsh crake and pied shag recorded.

Important plants are those associated with salt and brackish water reaches.

Important habitats:

Braided riverbeds, bush covered upper catchment, gravel beds, coastal lagoon, estuary, vegetated drainage channels

IMPORTANT SITES:

Few legally protected natural areas given signifcance of species present. Unusual joint protection for wrybill breeding area, given through former North Canterbury Catchment Board, Rangiora District Council and Department of Conservation under covenant - needs maintenance through changes in local authorities.

The whole river is important for river birds, including estuary/lagoon and has been rated *outstanding* for wildlife. This includes upper tributaries, where conditions can affect downstream values. Upper reaches important for trout spawning - Okuku, Garry, Glentui and Lees Valley creeks, also main stream sometimes.

A number of sites of value to the tangata whenua are located close to streams around Woodend and Waikuku; there is a midden/oven site on the north side of the estuary, close to the river.

THREATS:

recreation - too many people, vehicles on riverbed, fire, animals attack birds
overfishing - loss of whitebait breeding population
agriculture - pollution, erosion, trampling by stock, loss fish breeding habitat, wetland loss
weeds - loss open shingle braids, loss bird nesting habitat
river works - loss diversity habitats, siltation of bed, wetland loss, increase access to bed, damage bird nesting areas
irrigation - loss of water quantity at critical times

CONTACTS:

DoC Christchurch.

North Canterbury Fish and Game Council
Maori Interests - see Appendix 4

SIGNIFICANT ECOLOGICAL TIMES:

Trout move up from coastal waters to spawning grounds - **Jan through March**; spawning and incubating juveniles (upper reaches) - **May through August**.

Riverbed birds nesting and rearing young - **September through February.**

Whitebait spawning (tidal/freshwater boundary) and carried to sea - **February through May**; move from sea to freshwater - **August through November.**

Wading birds overwinter at rivermouth/ estuary - **June through August.**

APPENDIX 2

HYDROLOGICAL REGIME OF THE ASHLEY RIVER
(analyses by Tony Gray, Environment Canterbury)

Table 1. Mean, minimum, and maximum flows, Ashley at Gorge, 1988-1999.

```
~~~ NIWA Tideda ~~~ Environment Canterbury                              25-JAN-2001
~~~ PEXTREME ~~~
Source is H:\Audits\Gldniwa\ashfinal.mtd Site 66204 Ashley at Gorge
From  871231 240000 to  991231 240000
Interval =          0
Rating applied
Flow l/s
                 Coeff.
 Year     Mean   of Var.  Minimum          Date         Maximum          Date
 ----     ----   -------  -------          ----         -------          ----
*1988   9217.4     1.83   1728.0     881228  13000  2.99753E+05  880913 130000
 1989   9804.2     1.58   1658.0     890123   4500  2.88414E+05  891008 164500
*1990   8163.1     1.31   1612.0     900418  14500  1.53983E+05  900825  14500
*1991   11521.     1.29   2371.0     910116  81500  2.56441E+05  910817  61500
 1992   14632.     1.00   1694.0     920312  21500  1.61428E+05  920720 120000
 1993   11328.     2.75   2286.0     930317  10000  8.75577E+05  931223 134500
*1994   13628.     1.81   2623.0     941229 220000  5.35016E+05  940726 193000
*1995   12561.     1.19   1250.0     950219  13000  1.64170E+05  950818 111500
 1996   11722.     0.92   1956.0     960203  31500  1.13291E+05  960718 111500
 1997   12277.     1.51   2344.0     971215 120000  4.57061E+05  970206  11500
*1998   6009.3     1.25   1157.0     980217 234500   97427.      981019 214500
*1999   10378.     1.05   1136.0     990223  14500  1.25043E+05  990314  91500

Average Annual Minimum    1987.6          Maximum   3.79154E+05 (complete yrs)

'*' denotes years with gaps in the data or incomplete years
Coeff. of Var. = sd/mean

Minimum is          1136.00     at  990223  14500
Maximum is          875577.     at  931223 134500
Mean is             10943.3
Std. Dev. is        17284.8
Coeff. of Var. is      1.58

End of process
```

Table 2. Flow duratoin curve, Ashley at Gorge, 1988-1999.

```
~~~ NIWA Tideda ~~~ Environment Canterbury                        25-JAN-2001
~~~ PDIST ~~~
Source is H:\Audits\Gldniwa\ashfinal.mtd Site 66204 Ashley at Gorge
From  871231 240000 to  991231 240000
Flow l/s

DISTRIBUTION                PERCENTAGE OF TIME "VALUE" IS EQUALLED OR EXCEEDED

 DAYS  HHMMSS  "VALUE"   %  0        20        40        60        80        100
                875577      *MAXIMUM  |         |         |         |          |
    0   2928    856067  .00 *         |         |         |         |          |
    0  10451    831491 .002 *         |         |         |         |          |
    0  13321    806915 .003 *         |         |         |         |          |
    0   4300    782339 .004 *         |         |         |         |          |
    0   4558    757763 .004 *         |         |         |         |          |
    0   4417    733187 .005 *         |         |         |         |          |
    0   4401    708611 .006 *         |         |         |         |          |
    0   2401    684035 .006 *         |         |         |         |          |
    0   3129    659459 .007 *         |         |         |         |          |
    0   4931    634883 .008 *         |         |         |         |          |
    0  14844    610307 .009 *         |         |         |         |          |
    0   2517    585731 .010 *         |         |         |         |          |
    0   4029    561155 .010 *         |         |         |         |          |
    0   2218    536579 .011 *         |         |         |         |          |
    0  21609    512003 .013 *         |         |         |         |          |
    0  33929    487427 .016 *         |         |         |         |          |
    0  11958    462851 .018 *         |         |         |         |          |
    0  43322    438275 .022 *         |         |         |         |          |
    0  43257    413699 .026 *         |         |         |         |          |
    0  30602    389123 .029 *         |         |         |         |          |
    0  31957    364547 .033 *         |         |         |         |          |
    0  21141    339971 .035 *         |         |         |         |          |
    0  25904    315395 .037 *         |         |         |         |          |
    0  33235    290819 .041 *         |         |         |         |          |
    0 121405    266243 .053 *         |         |         |         |          |
    0 125707    241667 .065 *         |         |         |         |          |
    0 140034    217091 .078 *         |         |         |         |          |
    0 235536    192515  .10 *         |         |         |         |          |
    1 111036    167939  .14 *         |         |         |         |          |
    3  10327    143363  .21 *         |         |         |         |          |
    5  81212    118787  .33 *         |         |         |         |          |
    8 180455     94211  .53 *         |         |         |         |          |
   18  83501     69635  1.0 *         |         |         |         |          |
   51 145804     45059  2.1 |*        |         |         |         |          |
  368 235132     20483  11. |    *    |         |         |         |          |
 3882 193352      1136 100. |MINIMUM  |         |         |         |          *
   38  44500=GAPS
 4383      0=TOTAL          MEAN=   10943.3             STD.DEV.=   17284.8

This table uses   36 classes.
Percentages in the printplot table are accurate only to the
precision shown (e.g. 5.0% is 5.0% +/- 0.05%)


Exceedance percentiles

Source is H:\Audits\Gldniwa\ashfinal.mtd Site 66204 Ashley at Gorge
From  871231 240000 to  991231 240000
Flow l/s

        0      1      2      3      4      5      6      7      8      9

  0  875577  68187  46675  38216  33582  30306  27671  25547  23875  22397
 10   21199  20097  19216  18386  17677  17008  16441  15921  15408  14935
 20   14518  14150  13770  13442  13100  12768  12452  12119  11815  11519
 30   11228  10971  10718  10463  10221   9961   9725   9494   9287   9089
 40    8892   8694   8496   8301   8120   7948   7779   7617   7457   7298
 50    7123   6955   6803   6644   6495   6349   6202   6058   5911   5765
 60    5622   5483   5358   5210   5056   4903   4744   4605   4476   4363
 70    4244   4125   4017   3919   3828   3733   3642   3551   3460   3380
 80    3296   3220   3142   3053   2957   2873   2787   2701   2619   2538
 90    2440   2340   2247   2128   2030   1936   1851   1736   1575   1378
100    1136

Values in the exceedance table are not exact.  They are good
approximations based on linear interpolation of 2000 classes.
```

Table 3. Monthly mean flows, Ashley at Gorge, 1988-1999.   25-JAN-2001

```
Source is H:\Audits\Gldniwa\ashfinal.mtd
Monthly means          1988 to 1999          site  66204 Ashley at Gorge

Flow l/s

Year     Jan     Feb     Mar     Apr     May     Jun     Jul     Aug     Sep     Oct     Nov     Dec       Mean

1988    3922    5447    3306    2935    6303   12008   22834   12405   20594   11183    5722       ?      9714?
1989    3138    4337    2576    2397    4833   18326    8352    9409   17019   31728    6844    8337      9804

1990       ?    3065    2904    2109    6331    4285    6346   26079   15351   12477    9006    5133      8520?
1991    3732       ?    3290    9180    8354    9587   16566   27925   12741    8686   17985   12698     11880?
1992    7731    2823    4312    2606    9594    8456   19062   21763   33609   33028   20128   11915     14632
1993    5394    6026    2931    6458   14667   10802    4445    3584   22306   11869   11861   35279     11328
1994   11393    4967       ?    4263    9881       ?   32010   15934   15959   14626   26602    4954     14133?

1995    3703    3013    3403    6400       ?       ?   16338   17254   23660       ?   12160    4890     10125?
1996    3198    5181    6136   11627   10580   12851   27625   18105   17298   14828    8221    4694     11722
1997   11137   24307   13502   14478    8834   13266   14345   19470   11129   10470    3849    3491     12277
1998       ?    1341    2361    2277    3305    5224   17431   10497    7007   10566    5837       ?      6656?
1999    1713    3210    9802    6188       ?       ?   16861   15858    7236    9141   20619    9929     10110?

Min.    1713    1341    2361    2109    3305    4285    4445    3584    7007    8686    3849    3491      9804
Mean    5506    5793    4957    5910    8268   10534   16851   16524   16992   15327   12403   10132     11953
Max.   11393   24307   13502   14478   14667   18326   32010   27925   33609   33028   26602   35279     14632
       The Min Mean and Max of Annual means are for complete years only.

End of process
```

Table 4. Monthly 7-day low flows, Ashley at Gorge, 1988-1999.

Site 66204 Ashley at Gorge

Monthly 7-day low flows

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	2.8	2.9	2.8	2.4	2.3	3.7	6.6	8.1	8.0	7.3	3.6	2.0
1989	1.7	2.4	1.9	1.8	2.4	8.8	6.0	6.1	10.6	10.6	4.4	3.5
1990	2.5	2.0	2.0	1.8	2.9	4.0	3.5	8.1	8.8	8.0	6.4	3.7
1991	3.1	3.5	2.6	3.0	4.1	5.7	7.2	10.2	6.4	7.0	7.3	6.8
1992	3.8	2.1	1.9	2.2	2.1	5.3	6.5	15.4	24.2	26.9	12.3	8.2
1993	3.7	4.2	2.5	3.6	4.7	7.1	3.4	2.8	7.8	6.0	4.8	8.7
1994	7.2	3.8	3.5	3.3	3.0	9.0	10.6	9.1	9.3	12.1	11.3	3.0
1995	2.5	1.5	2.3	4.3	3.4	17.6	7.4	8.2	13.4	13.1	7.3	3.5
1996	2.8	2.5	3.8	8.0	5.7	8.2	8.4	13.3	13.5	9.2	6.3	3.6
1997	4.9	6.6	6.5	5.5	4.5	8.5	7.0	14.8	7.9	5.7	3.0	2.7
1998	1.5	1.2	1.4	1.6	1.8	3.3	7.8	6.6	5.2	4.2	3.8	2.1
1999	1.6	1.2	2.6	4.1	3.4	8.8	9.1	10.1	5.2	7.8	15.2	5.6
Mean	**3.2**	**2.8**	**2.8**	**3.5**	**3.4**	**7.5**	**7.0**	**9.4**	**10.0**	**9.8**	**7.1**	**4.5**
Min	1.5	1.2	1.4	1.6	1.8	3.3	3.4	2.8	5.2	4.2	3.0	2.0
Max	7.2	6.6	6.5	8.0	5.7	17.6	10.6	15.4	24.2	26.9	15.2	8.7

Table 5. Statistics for occurrence of low flows, Ashley at Gorge, 1988-1999.

Site 66204 Ashley at Gorge												
No of days	**Q<2m3/s**	**Q<1.5m3/s**	**Q<1.5m3/s**	**Q<2m3/s**	**Q<4m3/s**	**Q<4m3/s**	**Q<4m3/s**	**Q<4m3/s**	**Q<4m3/s**	**Q<4m3/s**	**Q<4m3/s**	**Q<3m3/s**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0	0	0	0	10.8	5.6	0	0	0	0	7.7	17.5
1989	17.7	0	0	12.1	18.5	0	0	0	0	0	0.5	0.02
1990	0	0	0	13.1	11.1	13.6	13.2	0	0	0	0	0
1991	0	0	0	0	3.1	3.5	0	0	0	0	0	0
1992	0	0	0	0.01	7.6	0	0	0	0	0	0	0
1993	0	0	0	0	0.06	0	13.2	25.6	3.4	0	0.3	0
1994	0	0	0	0	11.1	0	0	0	0	0	0	4.4
1995	0	3.3	0	0	7.3	0	0	0	0	0	0	0.2
1996	0	0	0	0	0	0	0	0	0	0	0	0.9
1997	0	0	0	0	0	0	0	0	0	0	18.4	14.9
1998	22.7	25.8	12.4	19.8	24.8	15.5	0	0	0	2.2	9.8	15.7
1999	28.2	17.2	0	0	9.4	1.9	0	0	0	0	0	0

Table 6. Mean, minimum, and maximum flows, Okuku at Fox Creek, 1989-1999.

```
~~~ NIWA Tideda ~~~ Environment Canterbury                              30-JAN-2001
~~~ PEXTREME ~~~
Source is H:\Audits\Gldniwa\66213.mtd Site 66213 Okuku at Fox Ck
From  890202 130000 to 1000830 124500
Interval =          0
Flow m3/s
                 Coeff.
 Year     Mean   of Var.  Minimum          Date          Maximum          Date
 ----     ----   -------  -------          ----          -------          ----
*1989   5.1345     1.98  0.41300     890320  54500      178.51       891008 150000
 1990   3.0385     2.19  0.46200     900207 111500      113.31       900824 230000
 1991   4.8344     1.69  0.49700     910116 151500      152.81       910719 103000
 1992   5.9338     1.26  0.54500     920312  21500      114.35       920720  84500
 1993   4.4909     2.99  0.62600     930317 224500      332.99       931223 123000
 1994   4.8829     2.39  0.58800     941229 230000      241.71       940726 193000
 1995   5.2841     1.44  0.41200     950220  41500      97.223       950818  91500
*1996   4.7384     1.55  0.42300     960203  70000      96.927       960716  90000
 1997   4.7347     1.43  0.41500     971228  83000      126.67       970206   3000
*1998   2.2390     1.49  0.20000     980215  51500      47.246       980702 200000
*1999   4.6304     1.24  0.29200     990226  44500      49.386       991120 164500
*2000   5.0343     2.82  0.51200    1000312 194500      258.69      1000819  60000

Average Annual Minimum   0.50643           Maximum      168.44      (complete yrs)

'*' denotes years with gaps in the data or incomplete years
Coeff. of Var. = sd/mean

Minimum is          0.200000     at  980215  51500
Maximum is           332.988     at  931223 123000
Mean is              4.56555
Std. Dev. is         8.93336
Coeff. of Var. is       1.96

End of process
```

Table 7. Flow duration curve, Okuku at Fox Creek, 1989-1999.

```
~~~ NIWA Tideda ~~~ Environment Canterbury                        30-JAN-2001
~~~ PDIST ~~~
Source is H:\Audits\Gldniwa\66213.mtd Site 66213 Okuku at Fox Ck
From  890202 130000 to 1000830 124500
Flow l/s
Full period
DISTRIBUTION                PERCENTAGE OF TIME "VALUE" IS EQUALLED OR EXCEEDED

 DAYS  HHMMSS  "VALUE"   %  0        20        40        60        80        100
                332988      *MAXIMUM  |         |         |         |         |
    0   2602    328028  .00 *         |         |         |         |         |
    0  11712    319836 .002 *         |         |         |         |         |
    0   4622    311644 .002 *         |         |         |         |         |
    0   3631    303452 .003 *         |         |         |         |         |
    0   5503    295260 .004 *         |         |         |         |         |
    0   4943    287068 .005 *         |         |         |         |         |
    0  10720    278876 .006 *         |         |         |         |         |
    0   1452    270684 .006 *         |         |         |         |         |
    0   5008    262492 .007 *         |         |         |         |         |
    0   5258    254300 .008 *         |         |         |         |         |
    0  15920    246108 .010 *         |         |         |         |         |
    0  22754    237916 .012 *         |         |         |         |         |
    0  45003    229724 .017 *         |         |         |         |         |
    0  44536    221532 .022 *         |         |         |         |         |
    0  30320    213340 .025 *         |         |         |         |         |
    0  34349    205148 .028 *         |         |         |         |         |
    0  34320    196956 .032 *         |         |         |         |         |
    0  45849    188764 .037 *         |         |         |         |         |
    0  32039    180572 .040 *         |         |         |         |         |
    0  43432    172380 .045 *         |         |         |         |         |
    0  44128    164188 .049 *         |         |         |         |         |
    0  33423    155996 .053 *         |         |         |         |         |
    0  50531    147804 .058 *         |         |         |         |         |
    0  40019    139612 .062 *         |         |         |         |         |
    0  54325    131420 .068 *         |         |         |         |         |
    0  54341    123228 .073 *         |         |         |         |         |
    0  74745    115036 .081 *         |         |         |         |         |
    0 135121    106844 .095 *         |         |         |         |         |
    1  22155     98652  .12 *         |         |         |         |         |
    1 175252     90460  .16 *         |         |         |         |         |
    2  10904     82268  .21 *         |         |         |         |         |
    2 154801     74076  .27 *         |         |         |         |         |
    2 234415     65884  .34 *         |         |         |         |         |
    4 234600     57692  .46 *         |         |         |         |         |
    5  55723     49500  .59 *         |         |         |         |         |
    8 224349     41308  .80 *         |         |         |         |         |
   15 152128     33116  1.2 |*        |         |         |         |         |
   27  71121     24924  1.8 |*        |         |         |         |         |
   75 125659     16732  3.6 | *       |         |         |         |         |
  338 194710      8540  12. |     *   |         |         |         |         |
 3658  84122       348  98. |         |         |         |         |        *|
   67  74655       200 100. |MINIMUM  |         |         |         |          *
   10  64500=GAPS
 4226 234500=TOTAL          MEAN=   4565.55             STD.DEV.=   8933.36

This table uses   42 classes.
Percentages in the printplot table are accurate only to the
precision shown (e.g. 5.0% is 5.0% +/- 0.05%)

Exceedance percentiles

Source is H:\Audits\Gldniwa\66213.mtd Site 66213 Okuku at Fox Ck
From  890202 130000 to 1000830 124500
Flow l/s

        0      1      2      3      4      5      6      7      8      9

  0   332988  36234  23453  18432  15834  14159  12818  11789  10868  10108
 10     9411   8846   8383   7974   7626   7289   6987   6696   6408   6180
 20     5951   5723   5535   5341   5159   4987   4834   4687   4540   4403
 30     4270   4134   4009   3904   3797   3685   3586   3491   3392   3284
 40     3187   3098   3008   2918   2836   2757   2679   2602   2531   2464
 50     2397   2327   2257   2195   2137   2079   2023   1969   1917   1864
 60     1811   1756   1707   1659   1608   1556   1509   1458   1407   1357
 70     1313   1271   1232   1195   1157   1119   1077   1038    996    963
 80      932    902    870    840    809    780    754    727    701    677
 90      653    628    601    573    543    509    470    427    364    307
100      200
```

Table 8. Monthly mean flows, Okuku at Fox Creek, 1989-1999.

```
30-JAN-2001

Source is H:\Audits\Gldniwa\66213.mtd
Monthly means          1989 to 2000          site  66213 Okuku at Fox Ck

Flow l/s

Year    Jan    Feb    Mar    Apr    May    Jun    Jul    Aug    Sep    Oct    Nov    Dec      Mean

1989      ?      ?    641    619   1895   9963   3838   7064  10903  14989   1870   2825      5456?

1990    922   1419    886    649   2047   1531   2286  14008   4960   3259   2827   1442      3039
1991    936   2797    870   4766   3620   5786   8825   9633   6273   2784   6799   4863      4834
1992   3146    919   1302    749   4522   4322   9738   7402  18355  11833   4627   4106      5934
1993   1484   2059    829   2402   6001   3775   1455   1204  11693   3460   5429  14038      4491
1994   3228   1435   2535   1108   3248   4168  14797   6720   5368   4916   9635   1128      4883

1995    974   1087   1082   3084   2918  15258   6336   9203   9604   8877   3877   1048      5284
1996      ?   2131   1829   4296   4435   6791  15901   8292   5542   3506   2132   1058      5105?
1997   4151   8791   5889   5387   3288   6142   5771   8508   4329   3455    755    670      4735
1998    360    281    533      ?   1301   2258   7462   4377   2759      ?   2169   1243      2293?
1999    438      ?   3545   2497   3258   7032   9232   8108   2336   3761   9858   3548      4867?

2000   3844   1288   3401   4411      ?   5590   3331      ?      ?      ?      ?      ?      3655?

Min.    360    281    533    619   1301   1531   1455   1204   2336   2784    755    670      3039
Mean   1949   2221   1945   2724   3321   6051   7414   7683   7466   6084   4544   3270      4743
Max.   4151   8791   5889   5387   6001  15258  15901  14008  18355  14989   9858  14038      5934
        The Min Mean and Max of Annual means are for complete years only.

End of process
```

Table 9. Monthly 7-day low flows, Okuku at Fox Creek, 1989-1999.

Site 66213 Okuku at Fox Creek												
Monthly 7-day low flows			(l/s)									
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1989			472	449	680	3552	2048	2393	5658	3277	1131	968
1990	603	497	520	526	835	1038	1216	2361	2181	1770	1552	887
1991	651	1017	631	987	1213	2464	3117	3128	1658	1648	1793	2082
1992	1133	626	581	669	638	2466	2512	5588	12920	7439	2600	2344
1993	798	927	710	1114	1550	2107	948	830	2814	1583	1355	2789
1994	1955	1063	907	868	781	3018	3684	3234	2585	2600	2977	673
1995	639	473	738	1655	1214	5098	2450	4483	4137	3837	1952	722
1996	623	635	1016	2693	1951	3012	3821	5342	3024	2189	1576	675
1997	1132	1980	2075	1546	1099	3543	2354	5915	2926	1217	567	531
1998	295	239	255	337	470	1130	2596	2398	1650	1433	1116	576
1999	408	420	775	1165	1070	1935	3477	4276	1513	1945	6398	1739
2000	1527	827	626	2663	1643	3722	1526	2405				
Mean	**888**	**791**	**776**	**1223**	**1095**	**2757**	**2479**	**3529**	**3733**	**2631**	**2092**	**1271**
Min	295	239	255	337	470	1038	948	830	1513	1217	567	531
Max	1955	1980	2075	2693	1951	5098	3821	5915	12920	7439	6398	2789

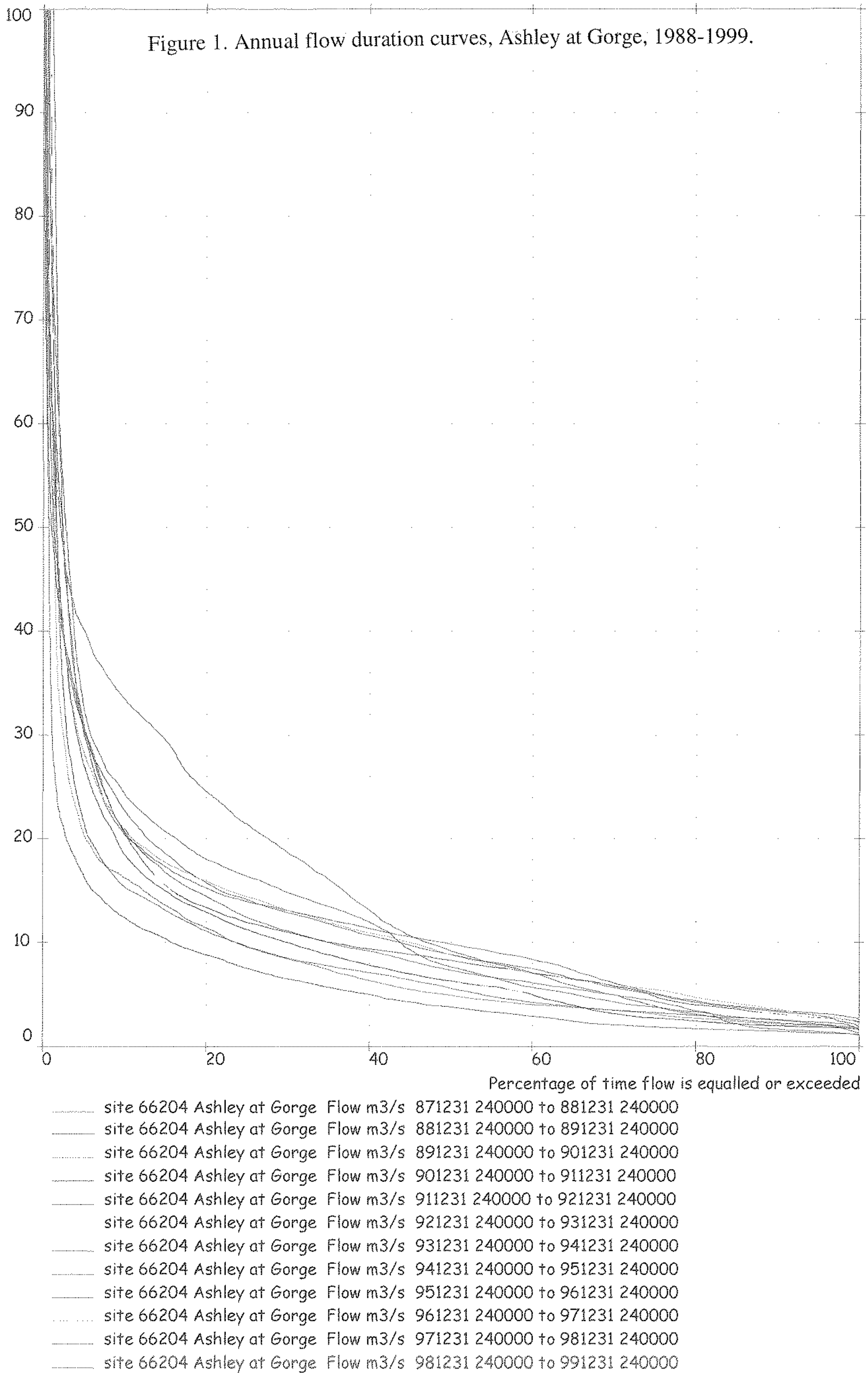
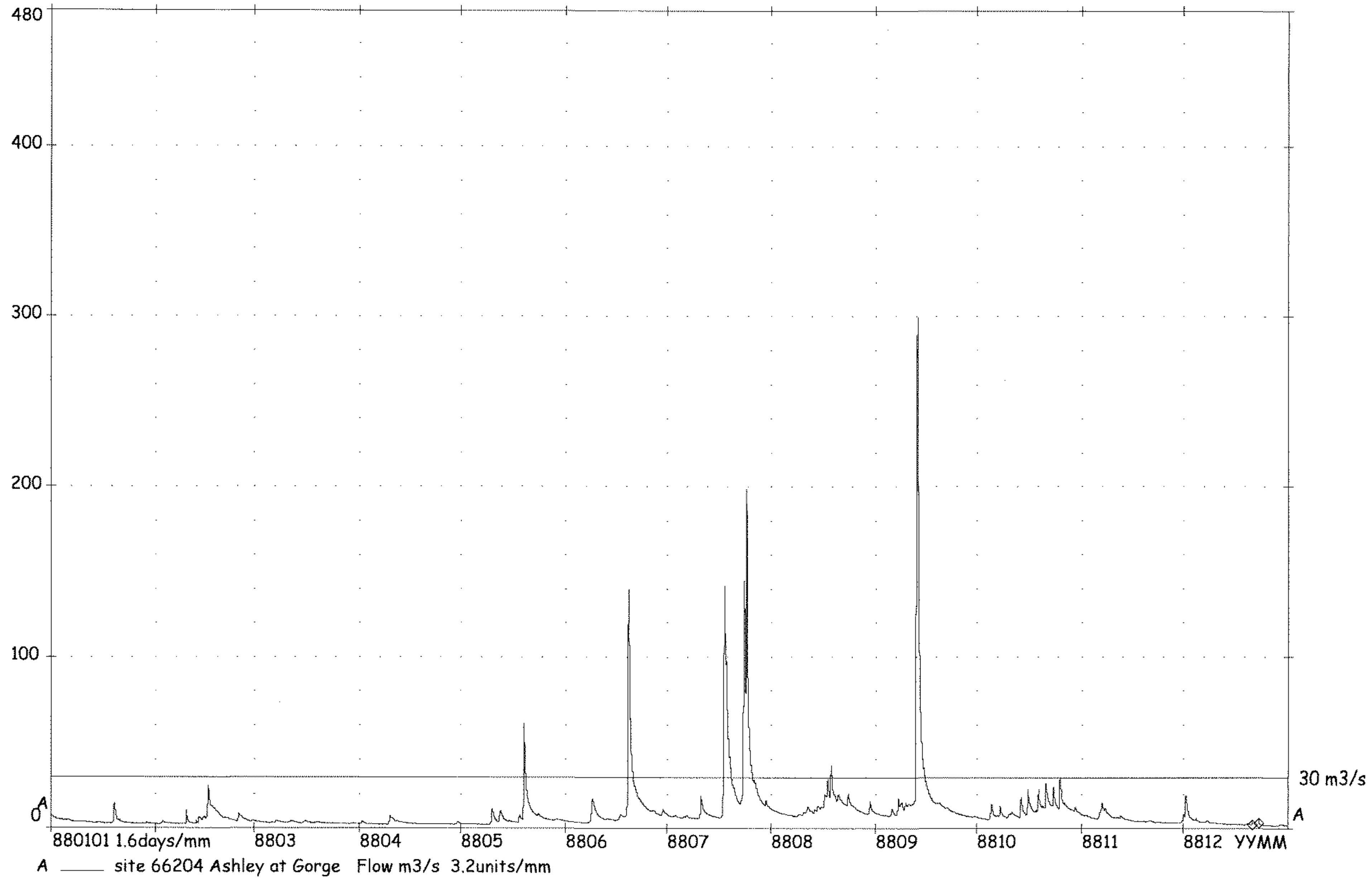


Figure 1. Annual flow duration curves, Ashley at Gorge, 1988-1999.

Plotted 26-JAN-2001

Figure 2. Annual hydrographs, Ashley at Gorge, 1988-1999.



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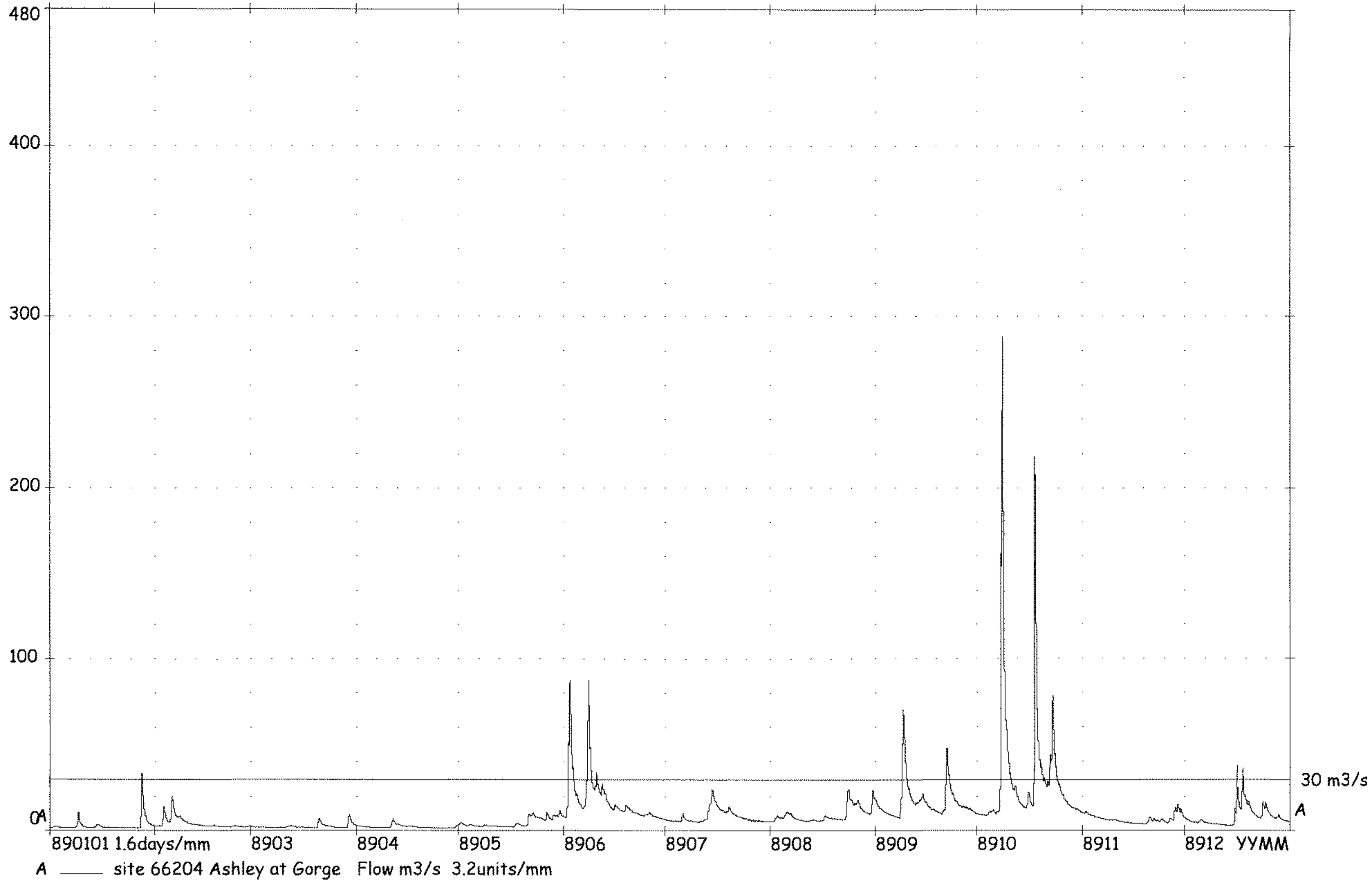

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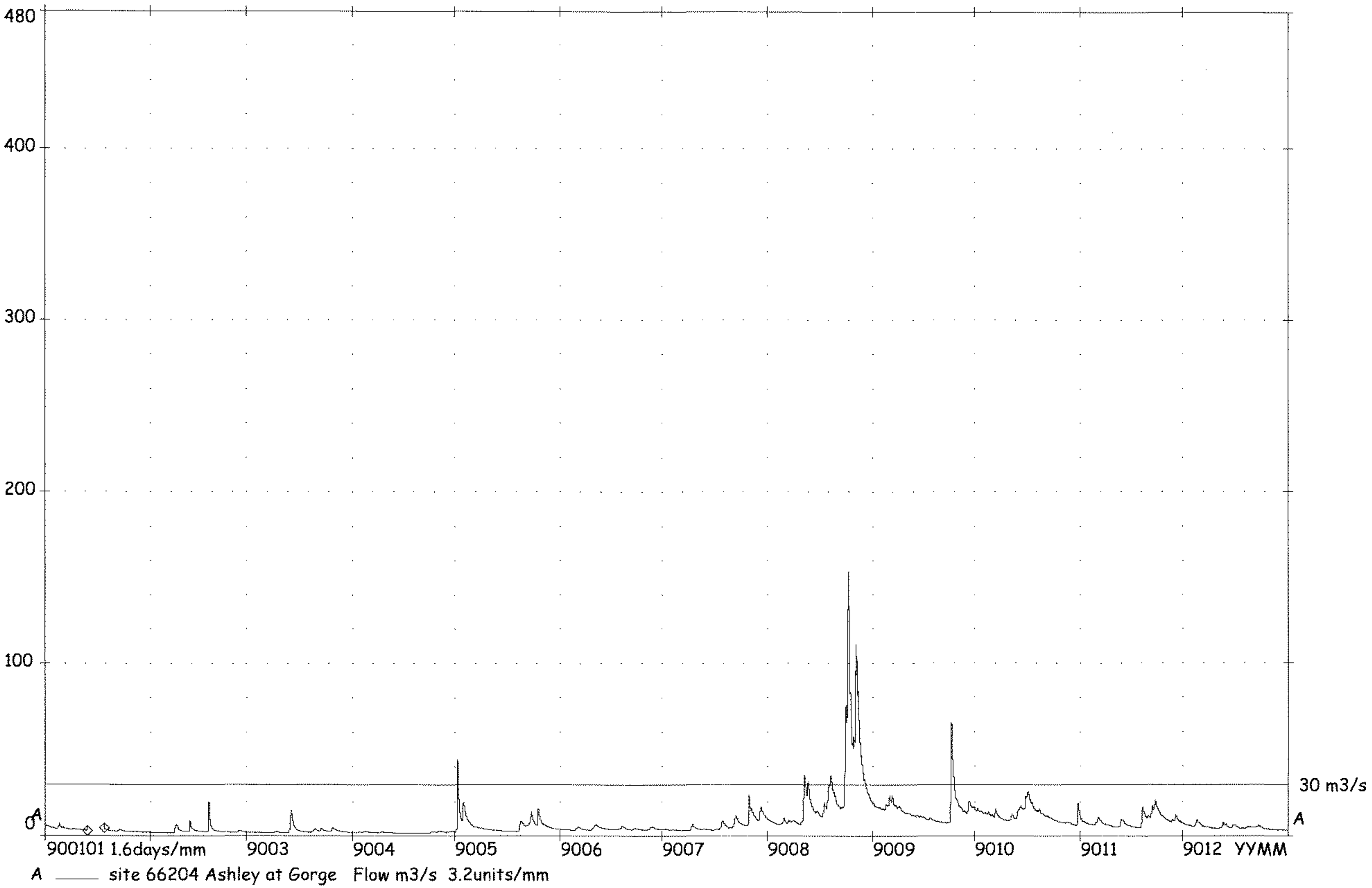

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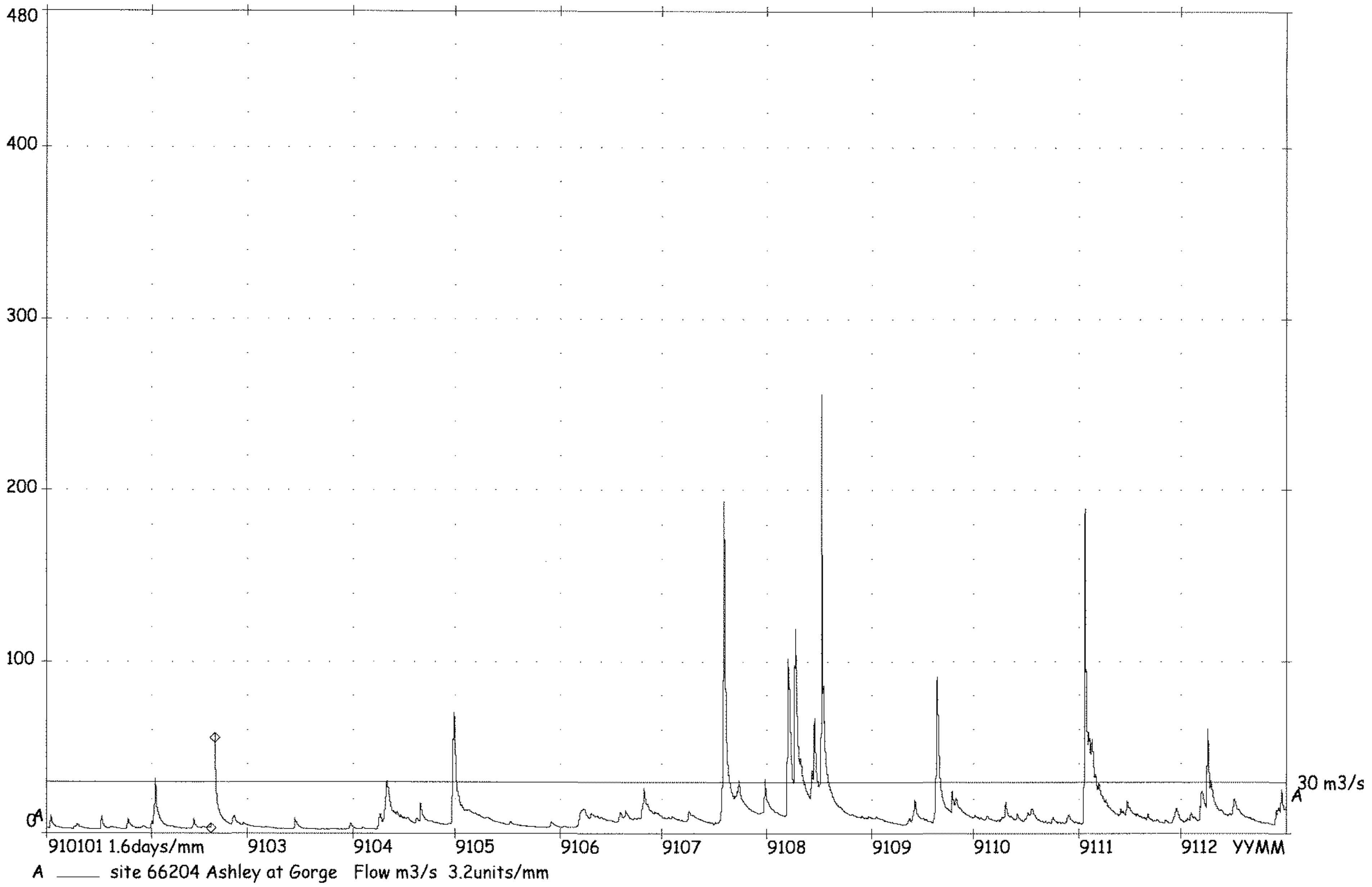

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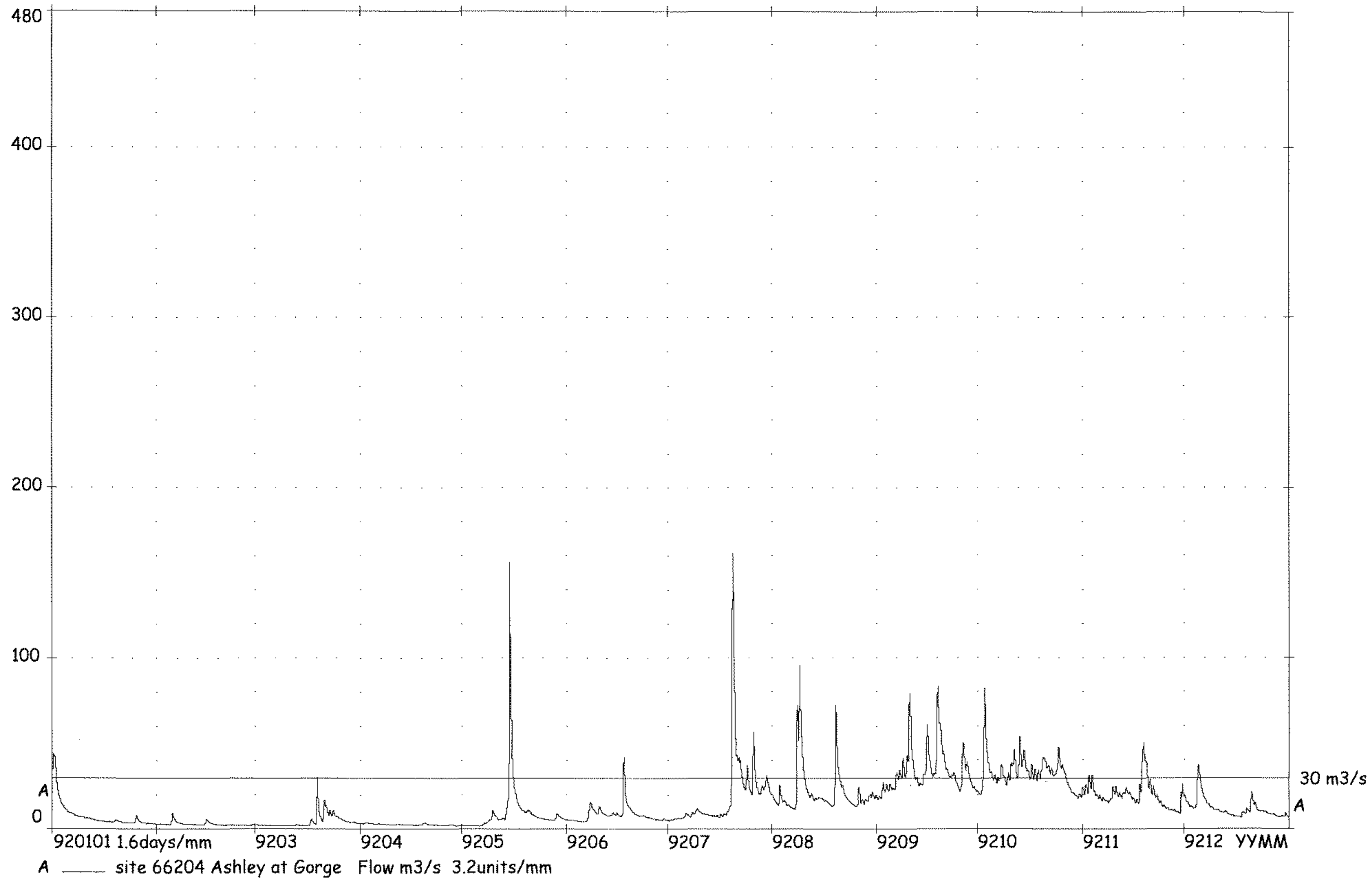

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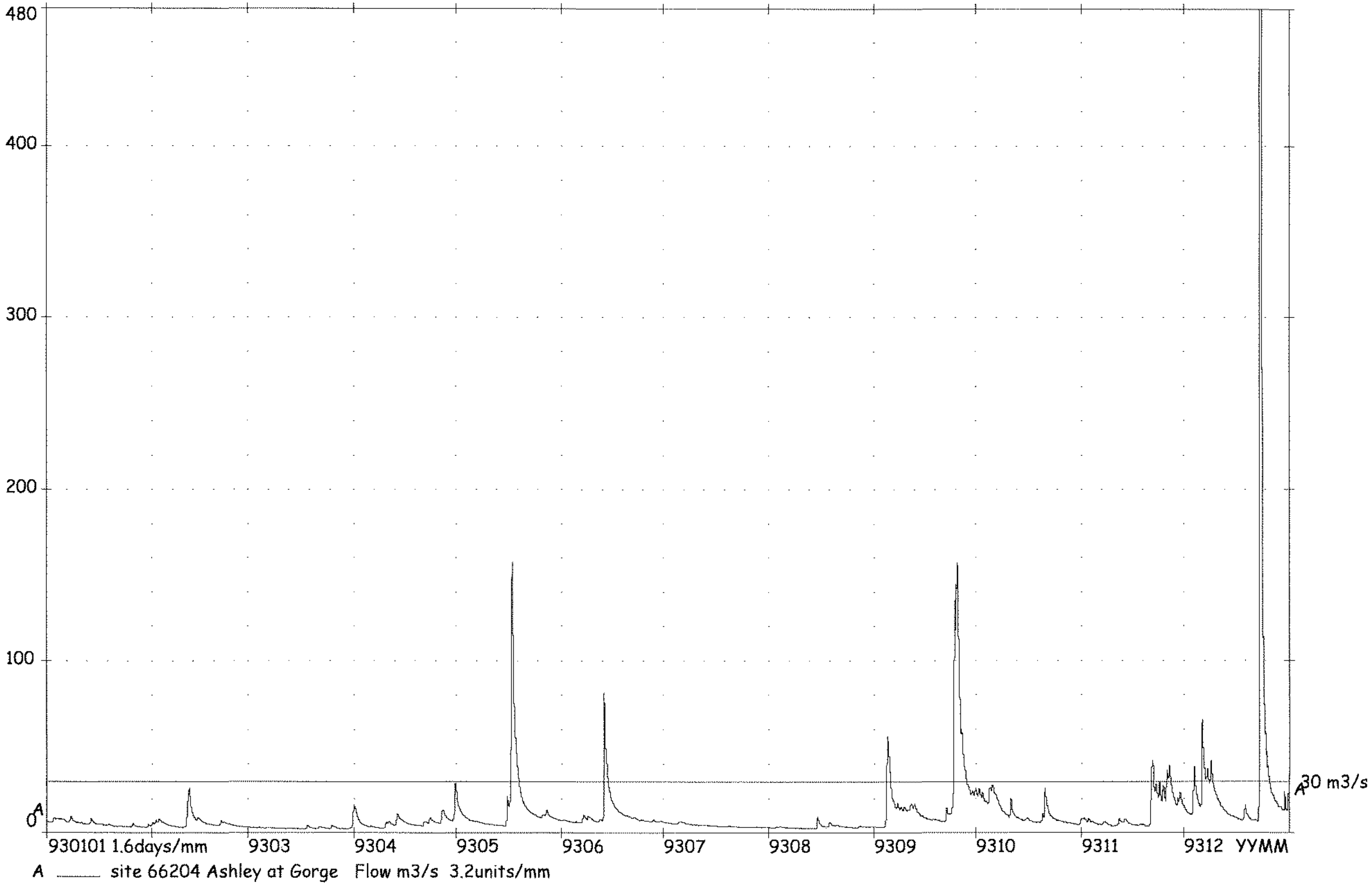

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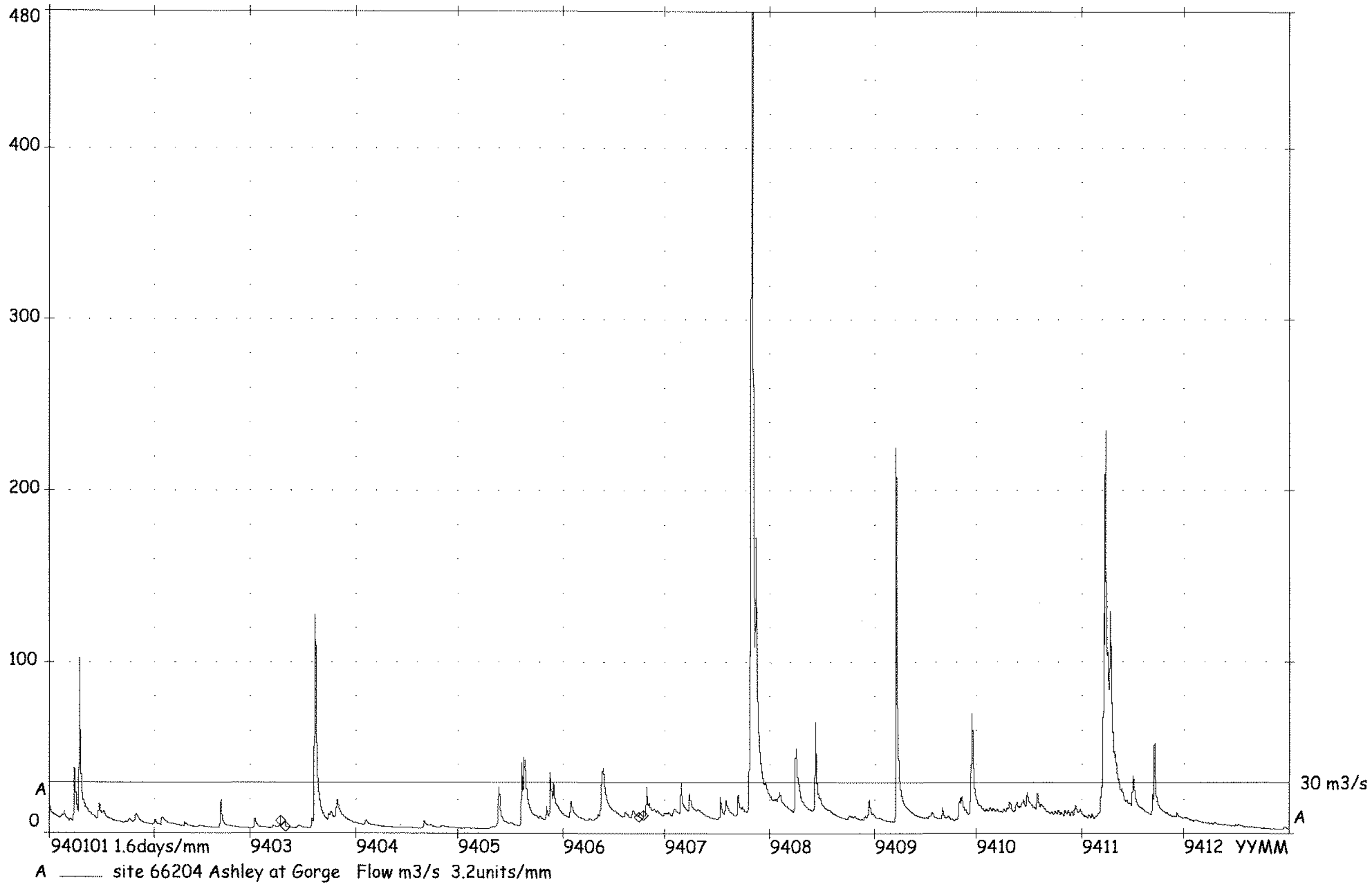

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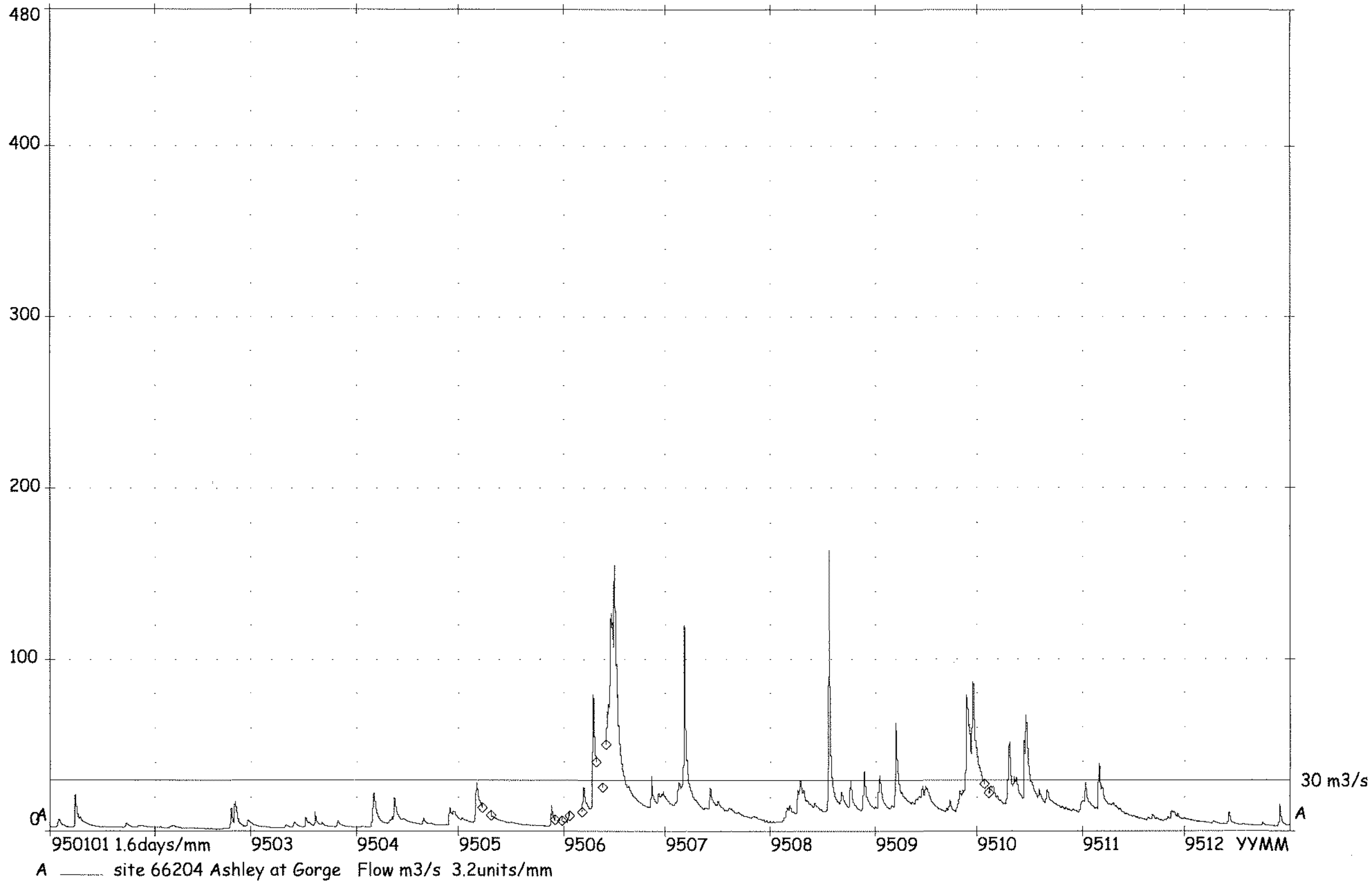

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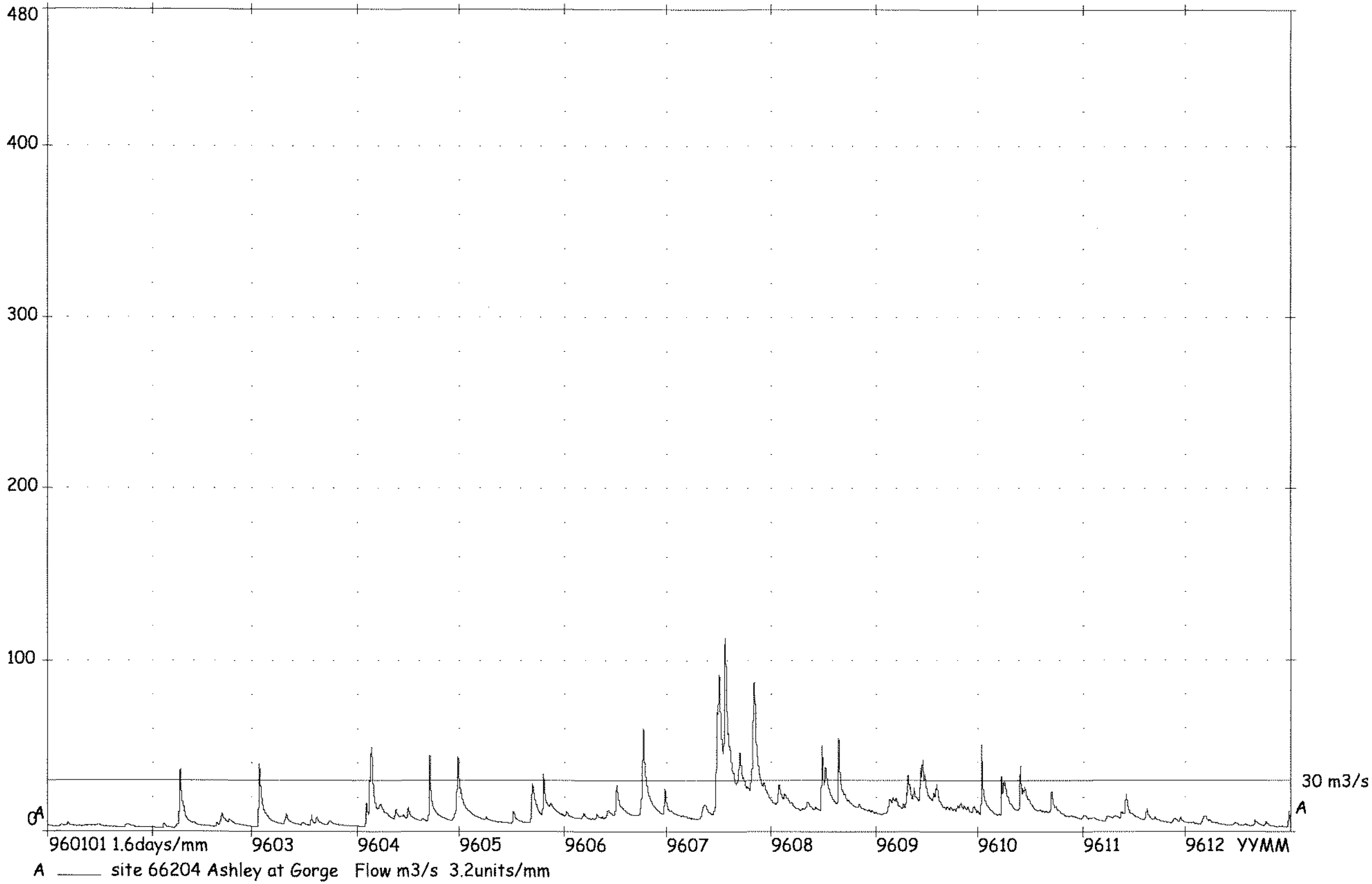

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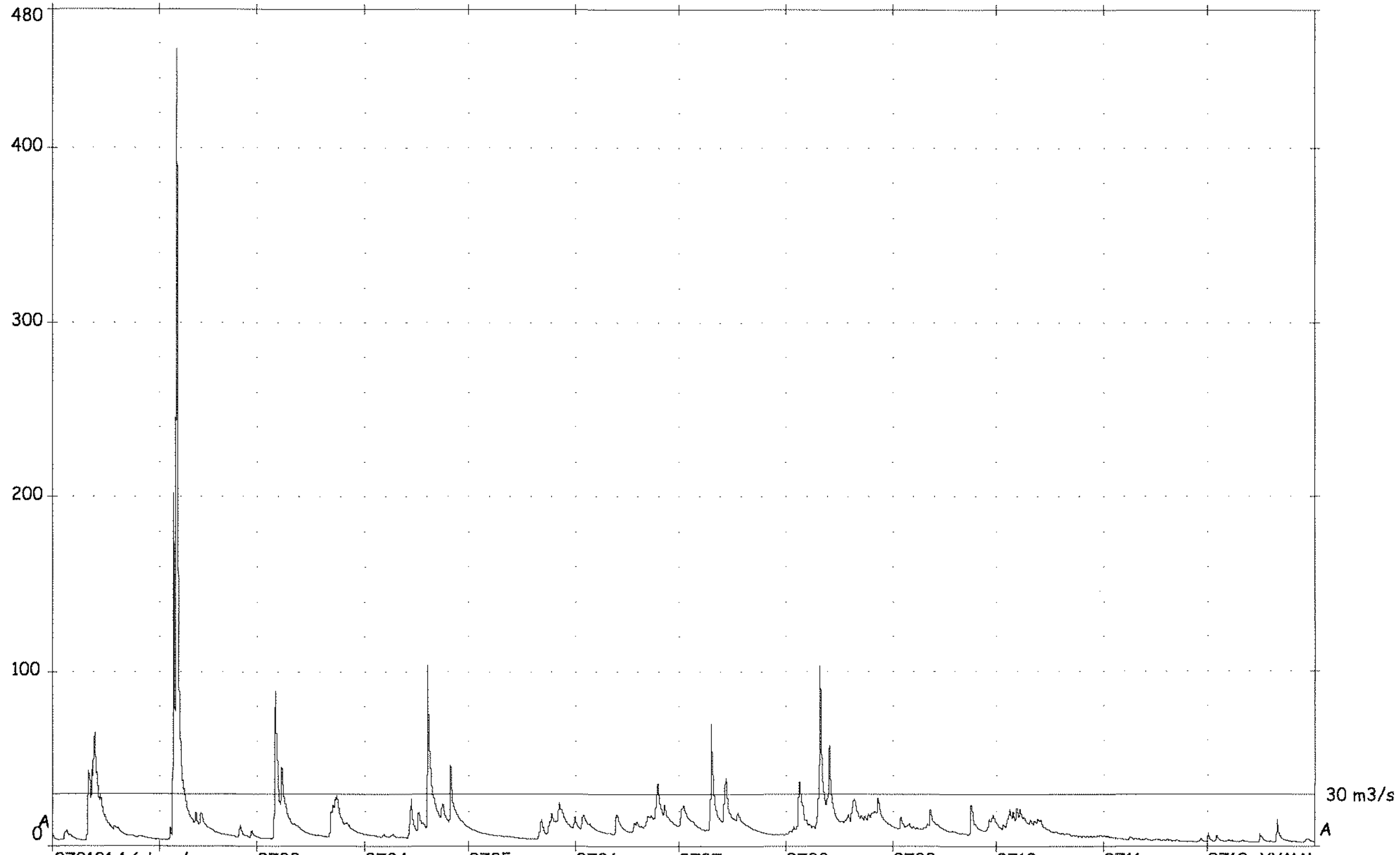
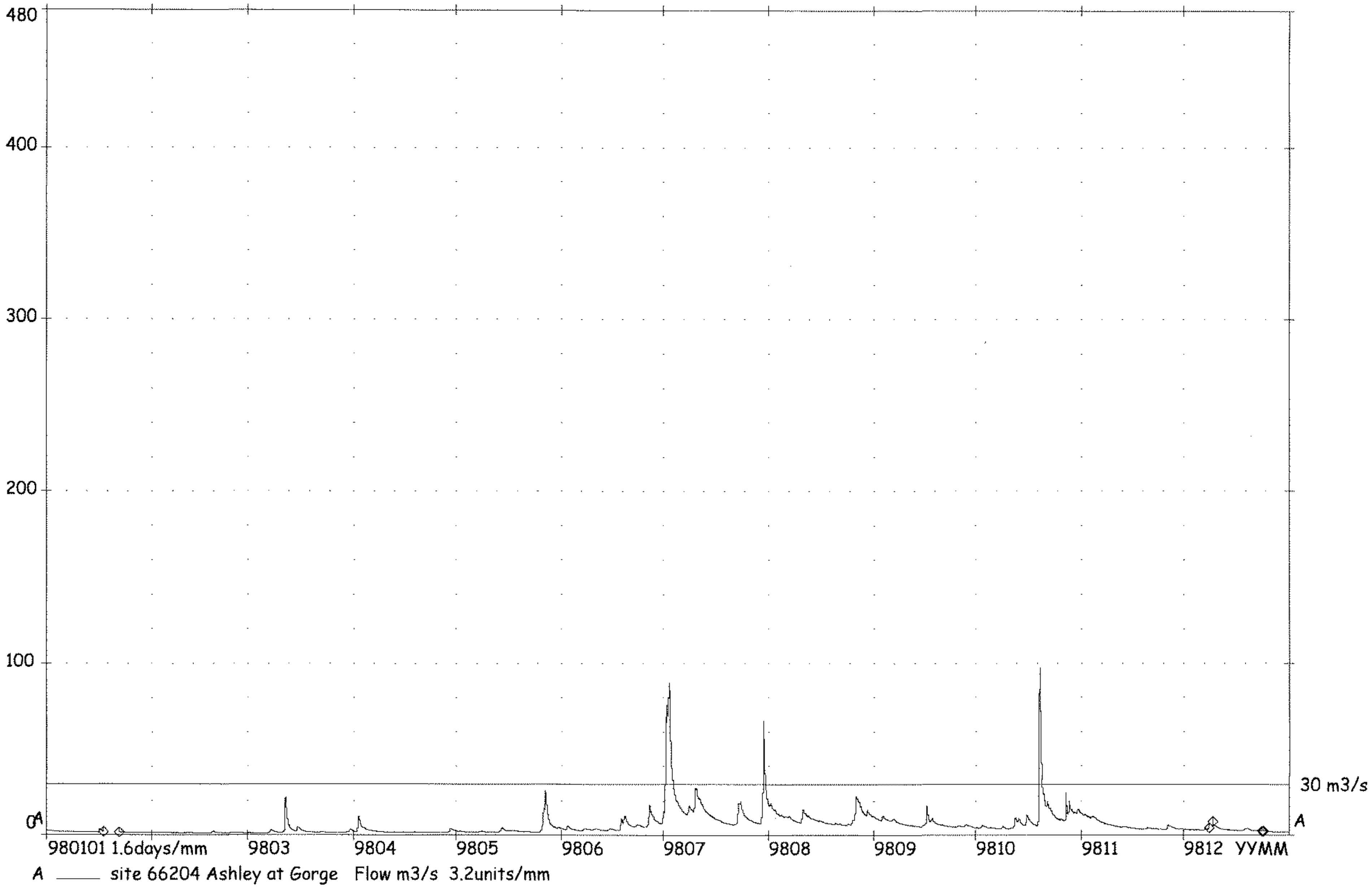


A ——— site 66204 Ashley at Gorge Flow m3/s 3.2units/mm

Plotted 26-JAN-2001



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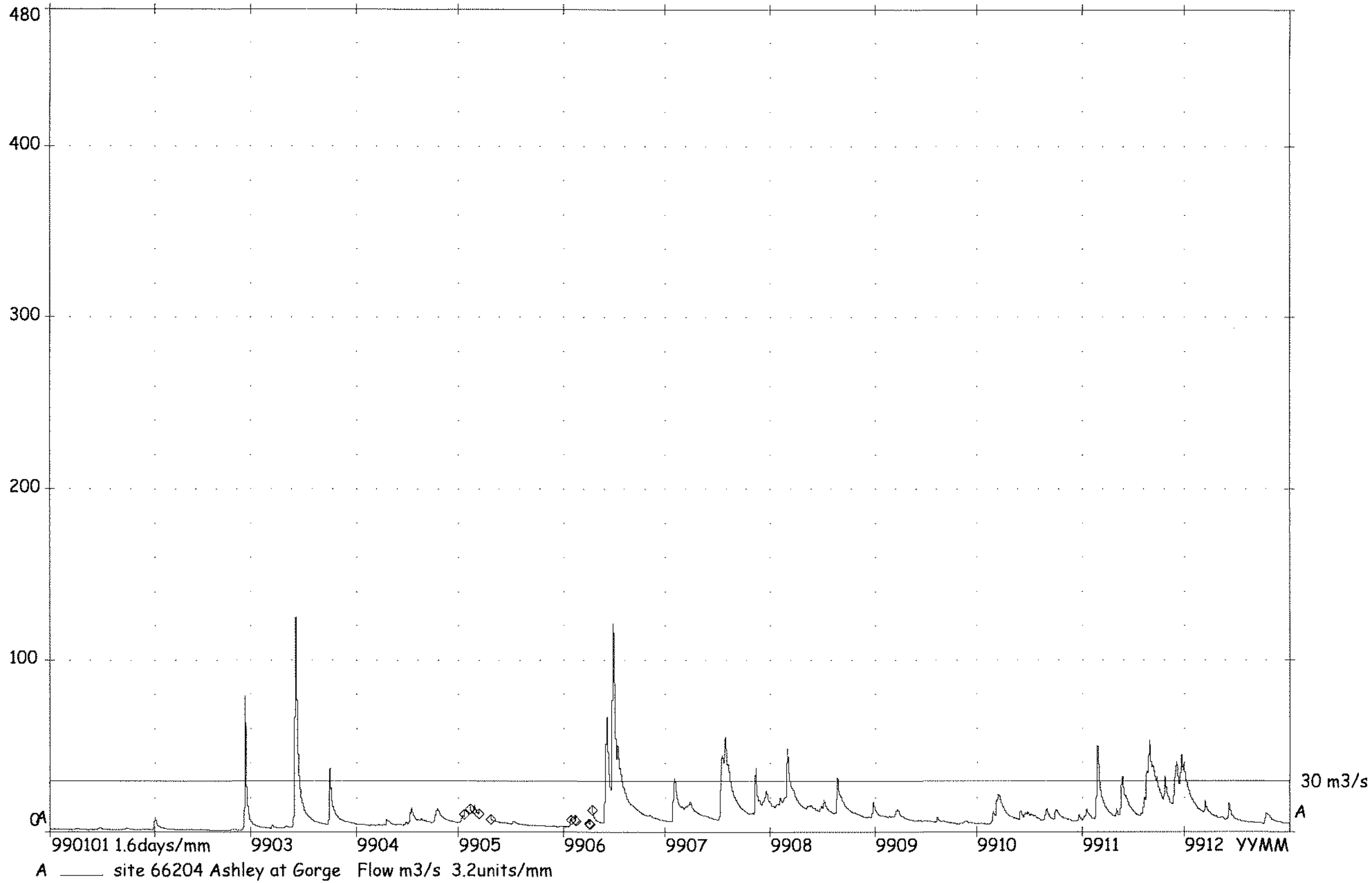
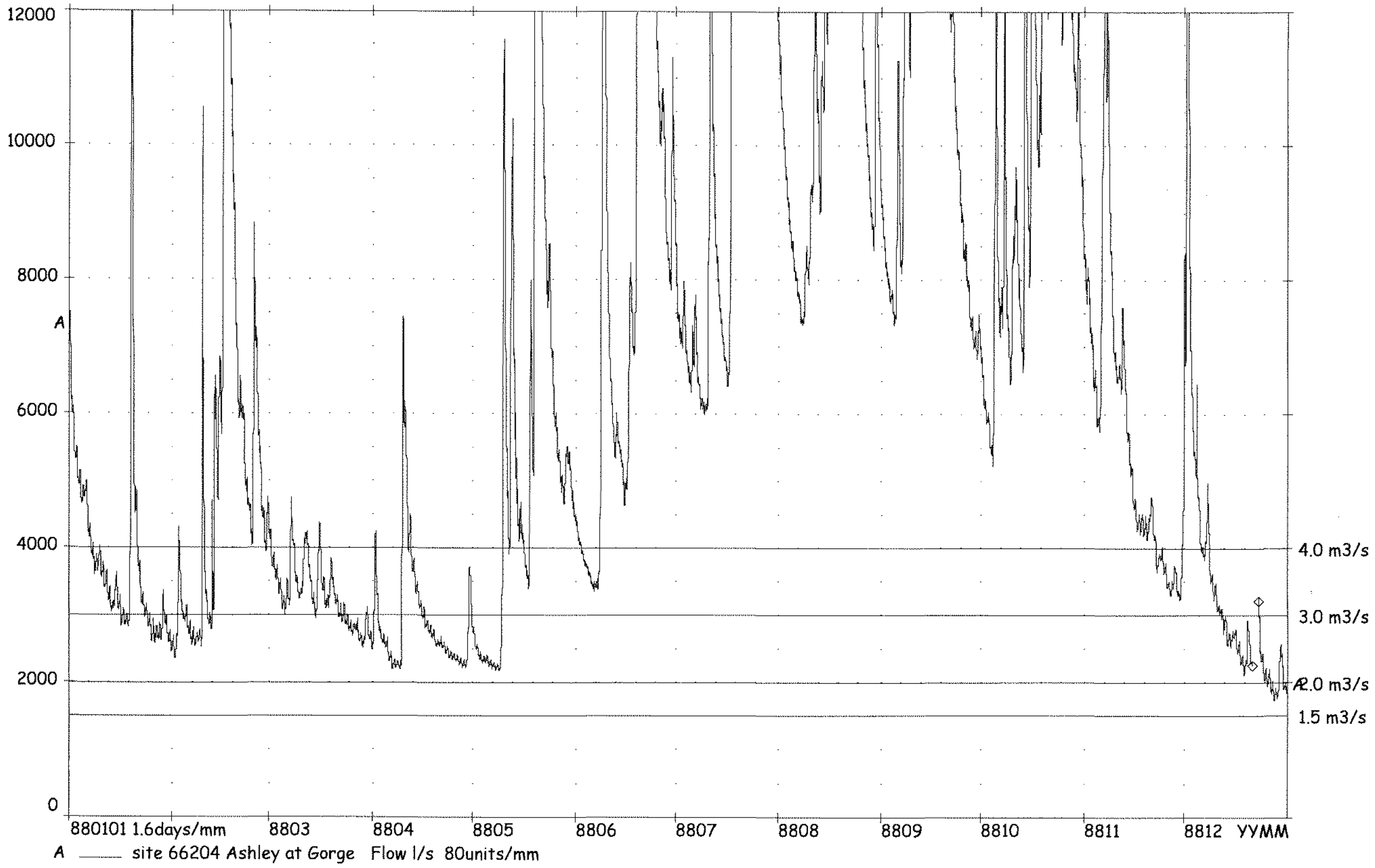


Plotted 26-JAN-2001

Figure 3. Annual hydrographs, Ashley at Gorge, 1988-1999, flow range up to 12 m^3/s.



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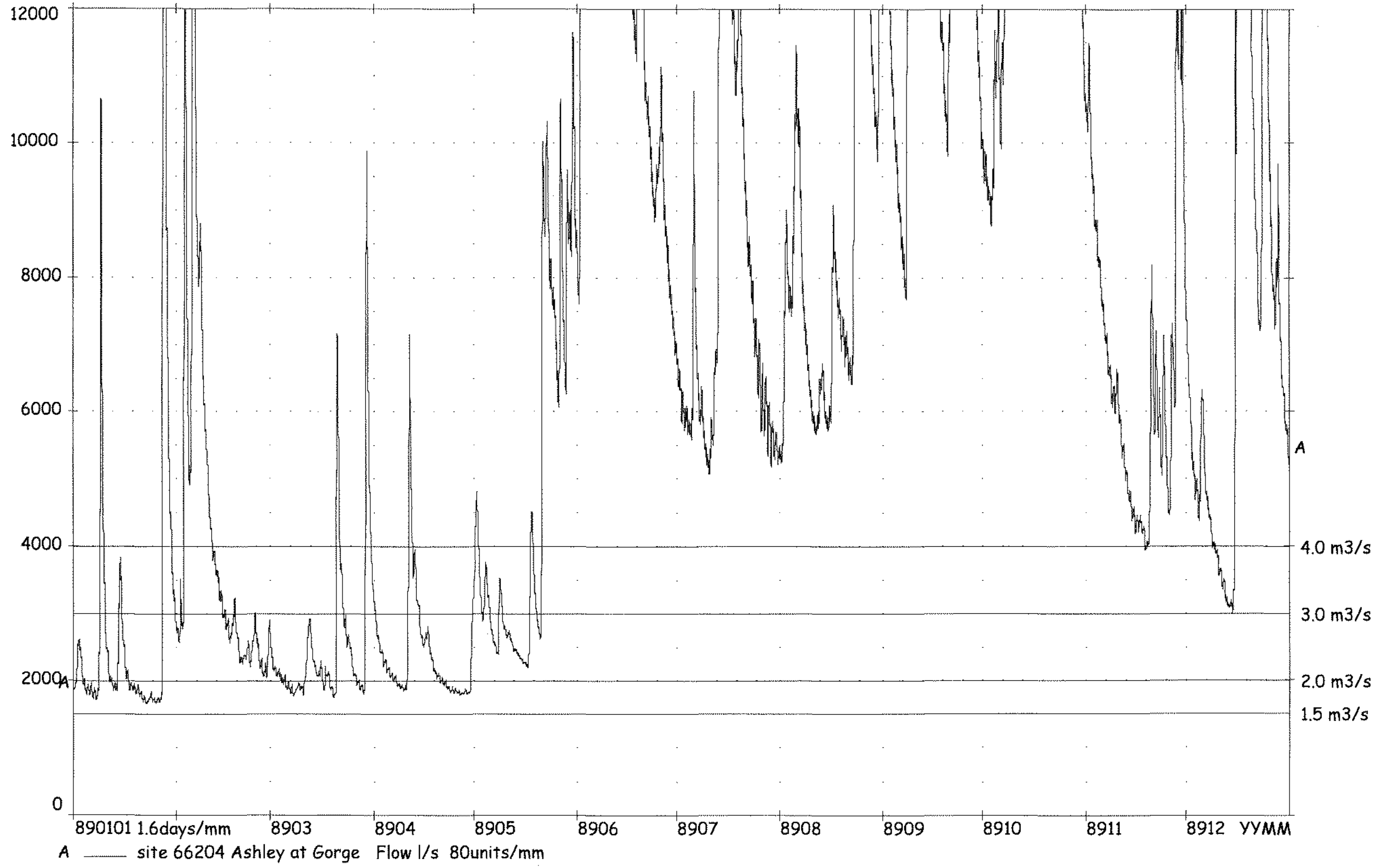

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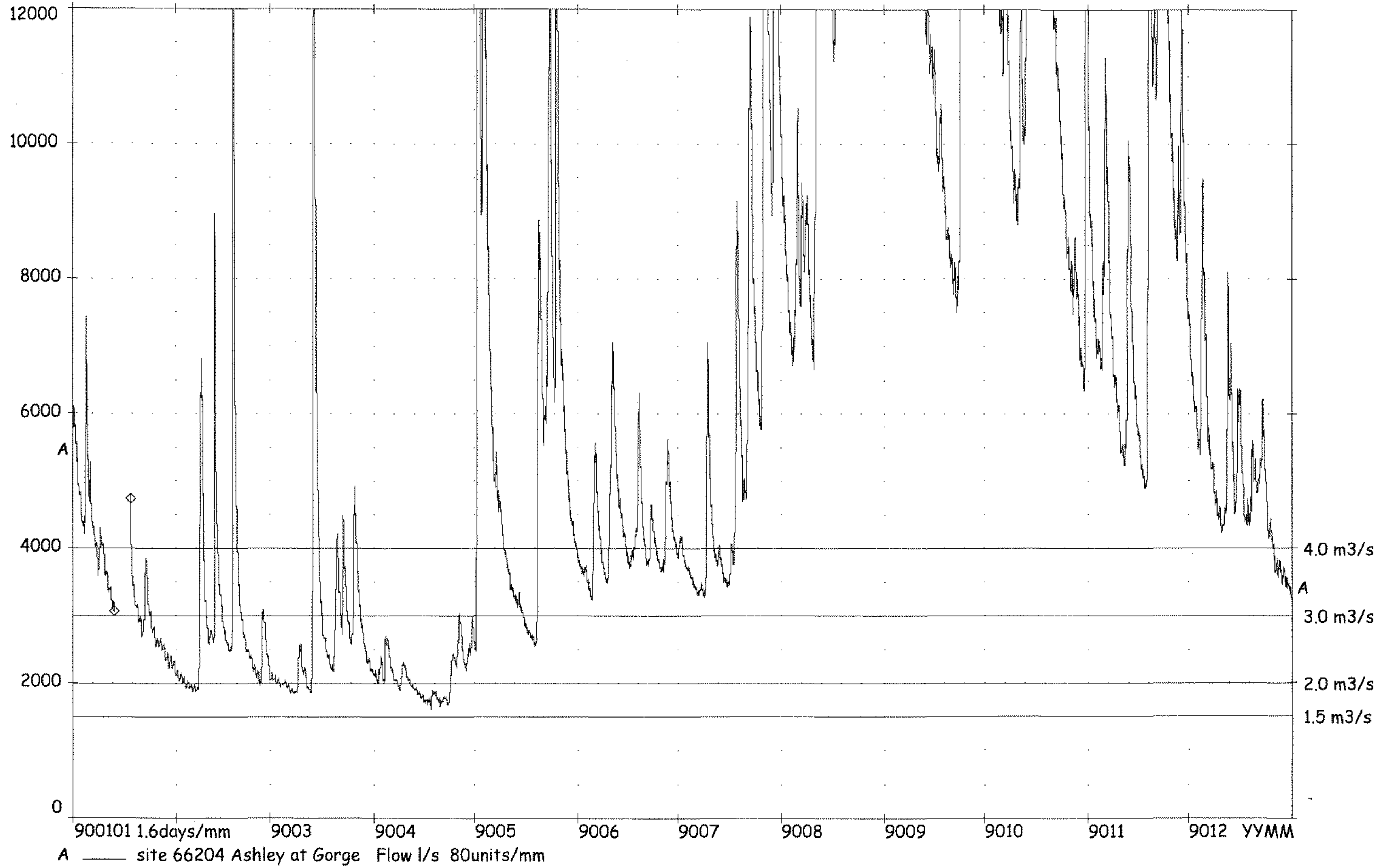

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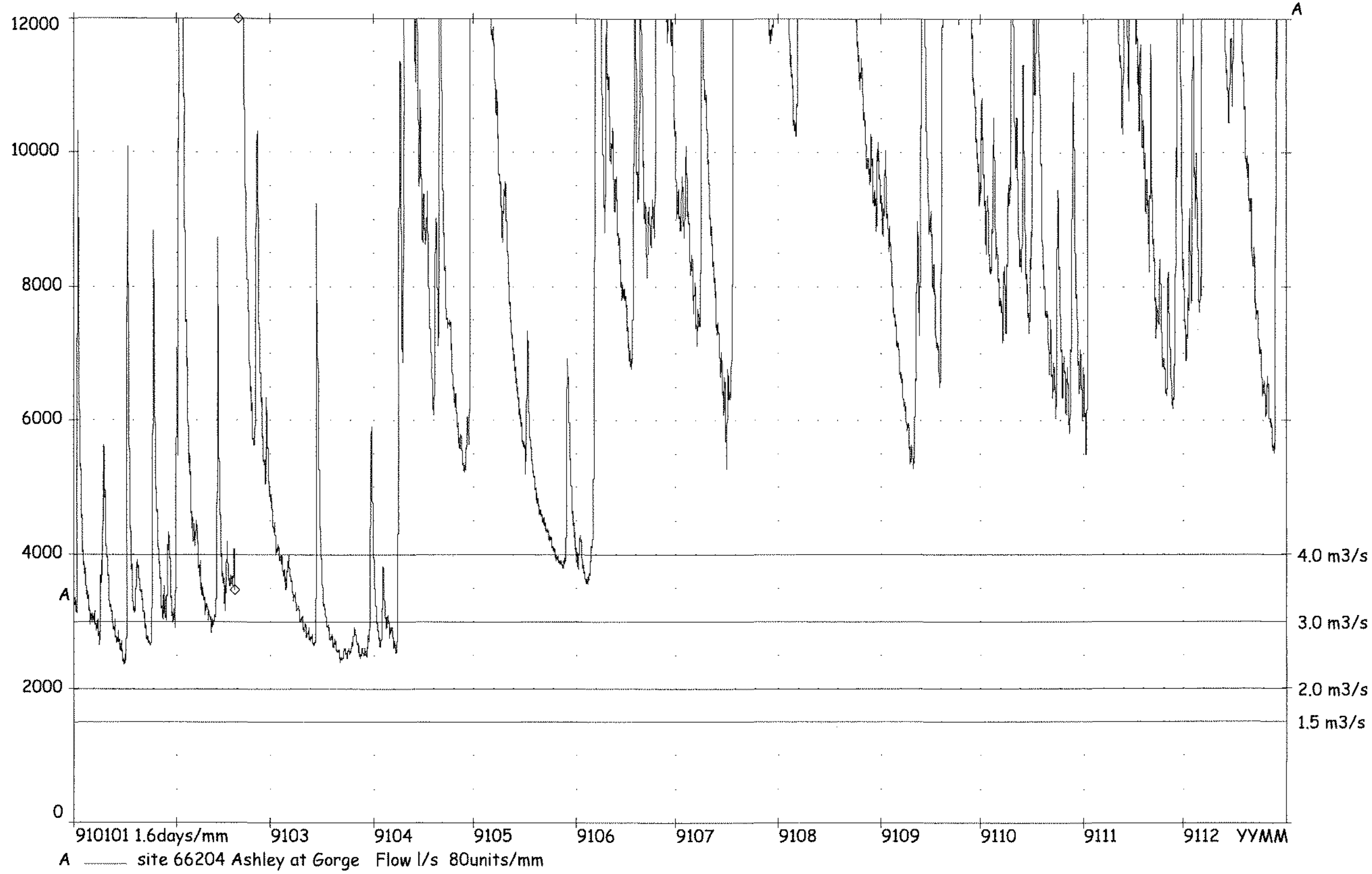

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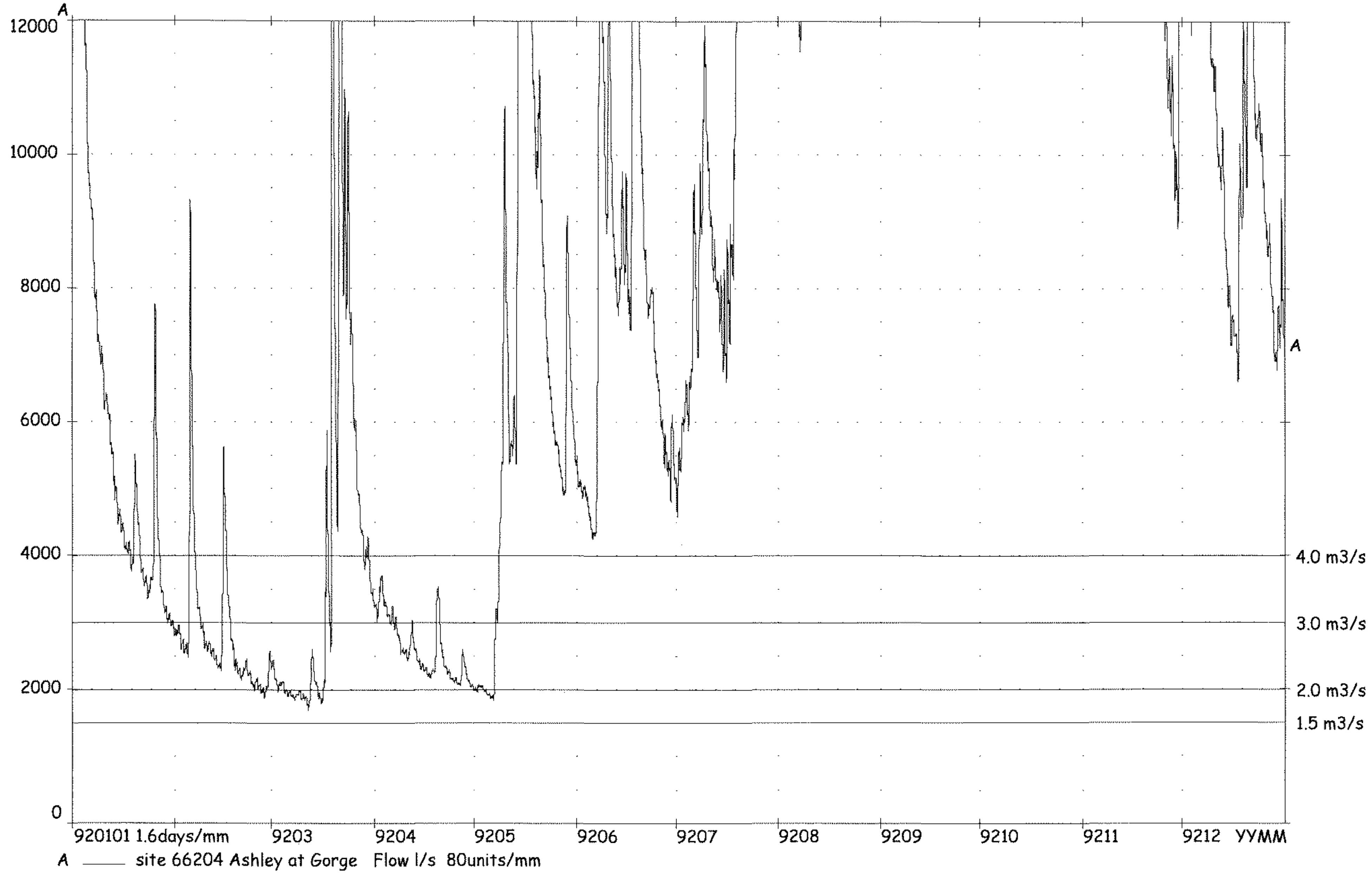

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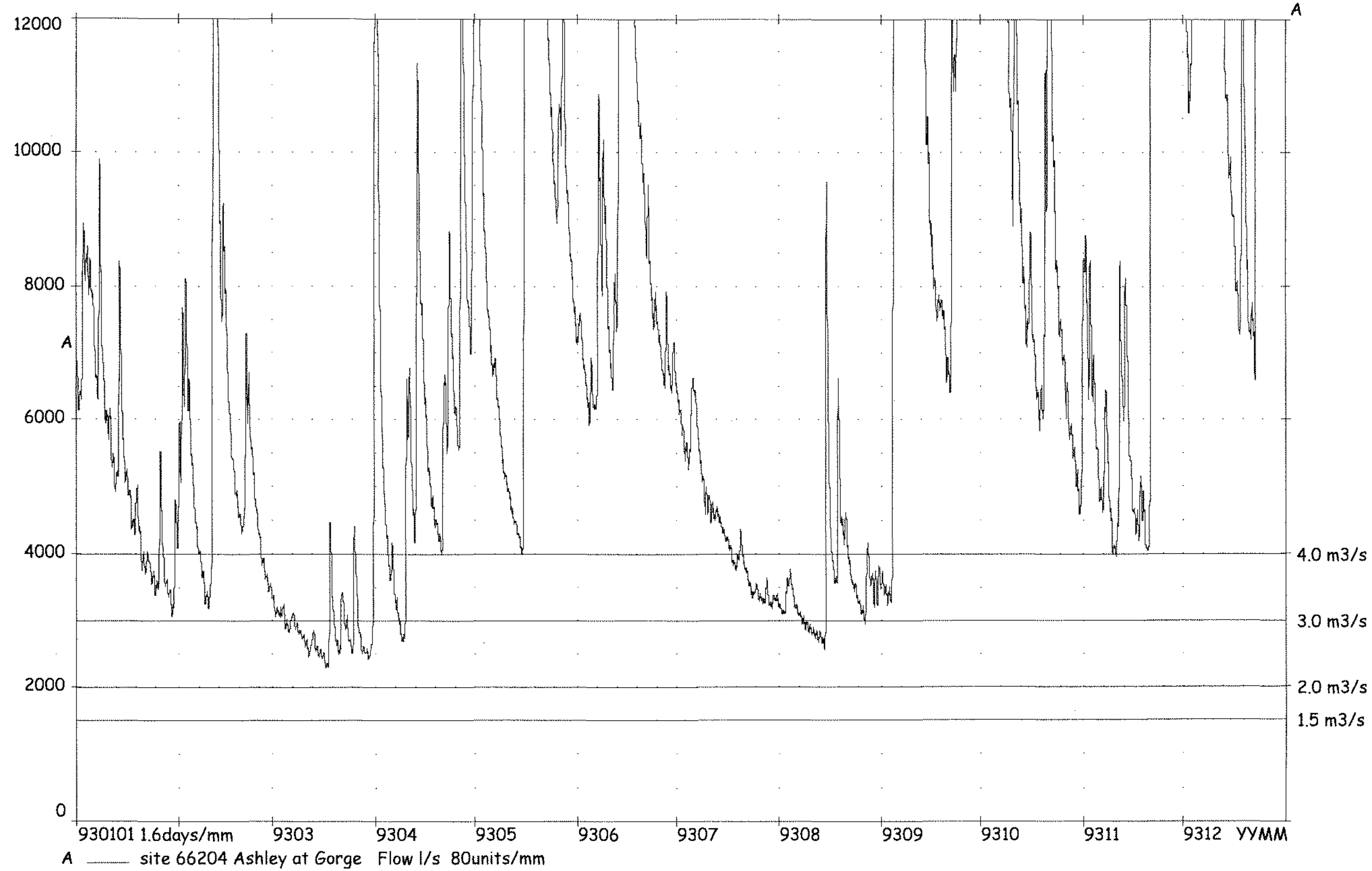

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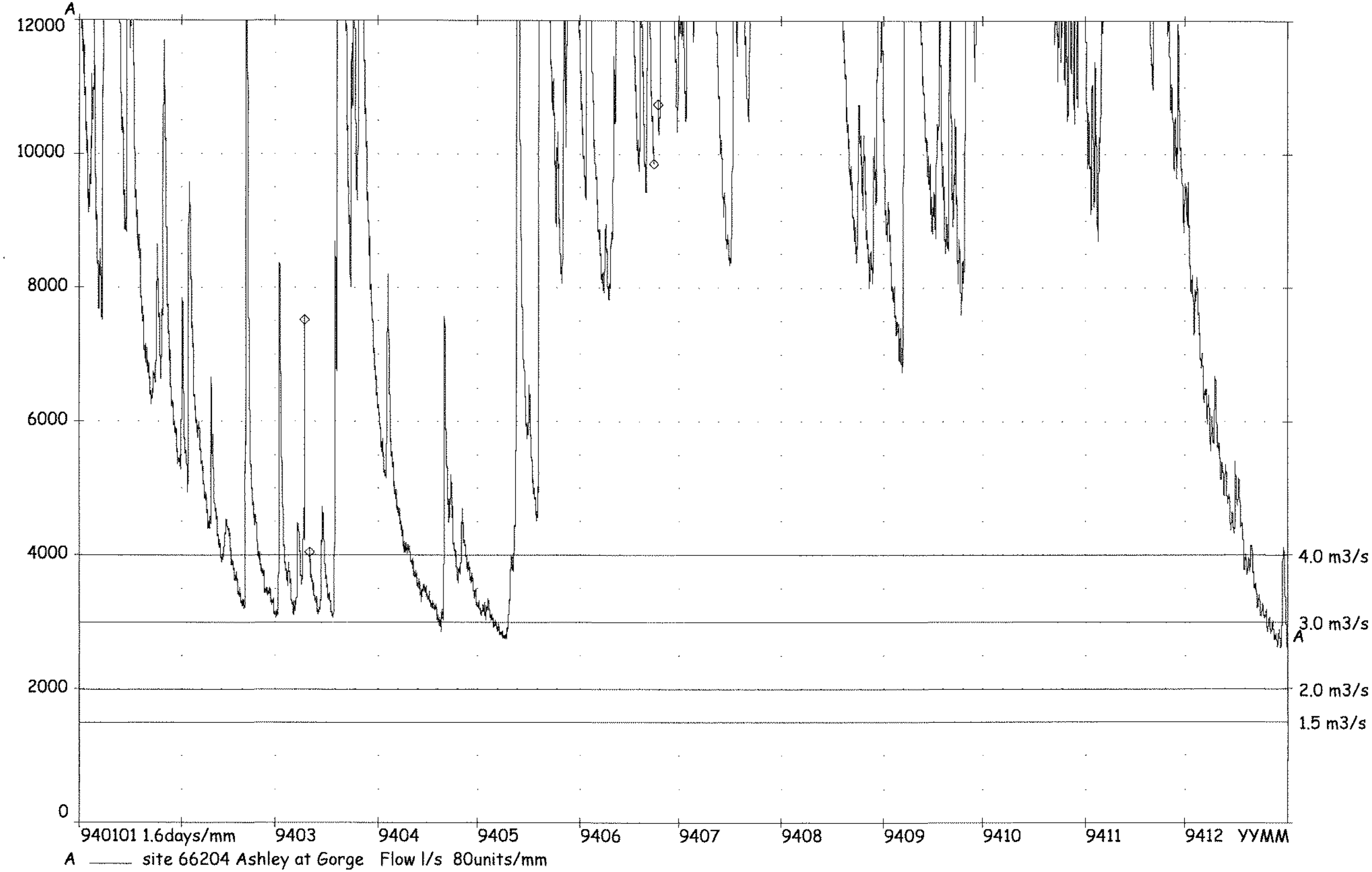

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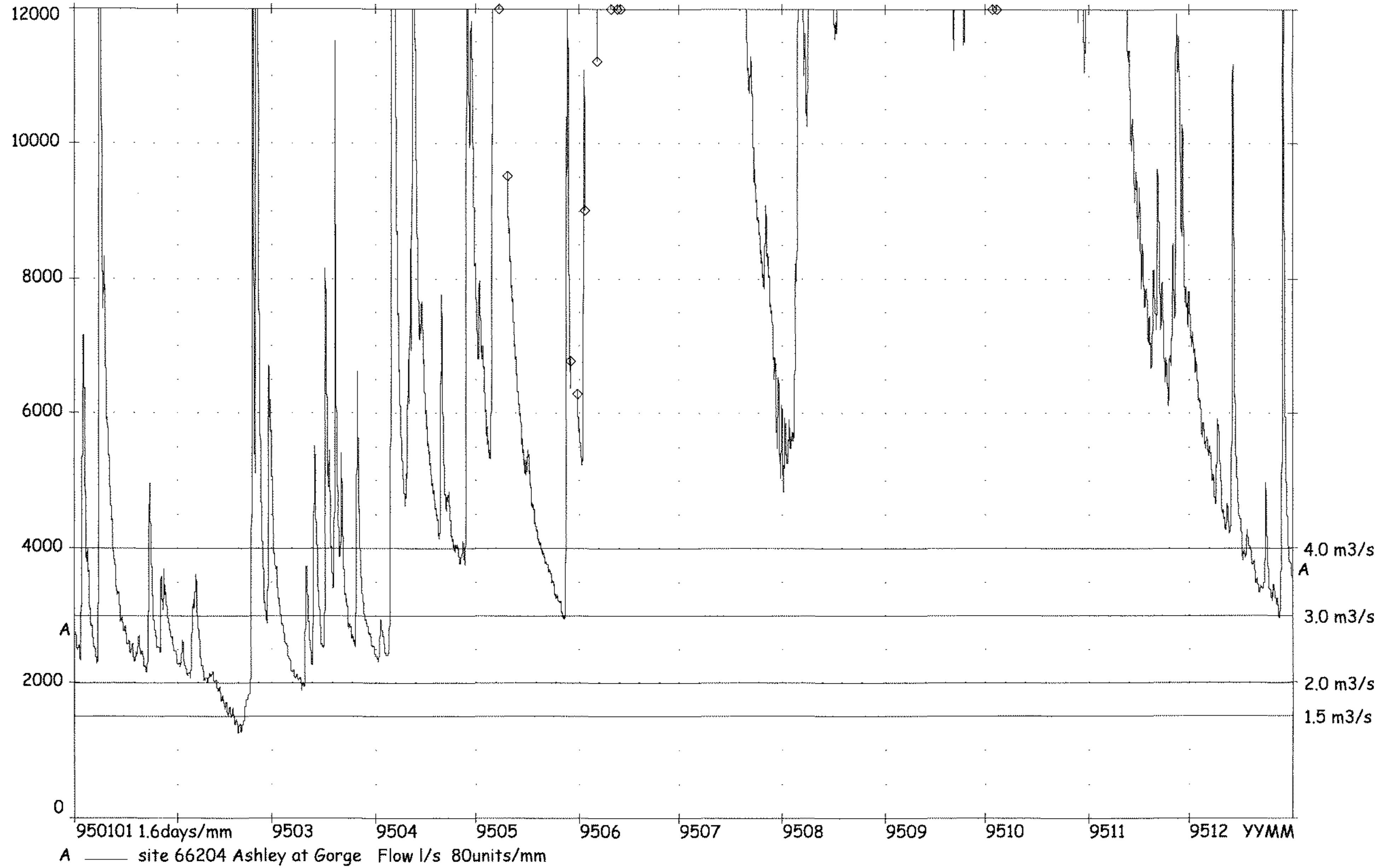

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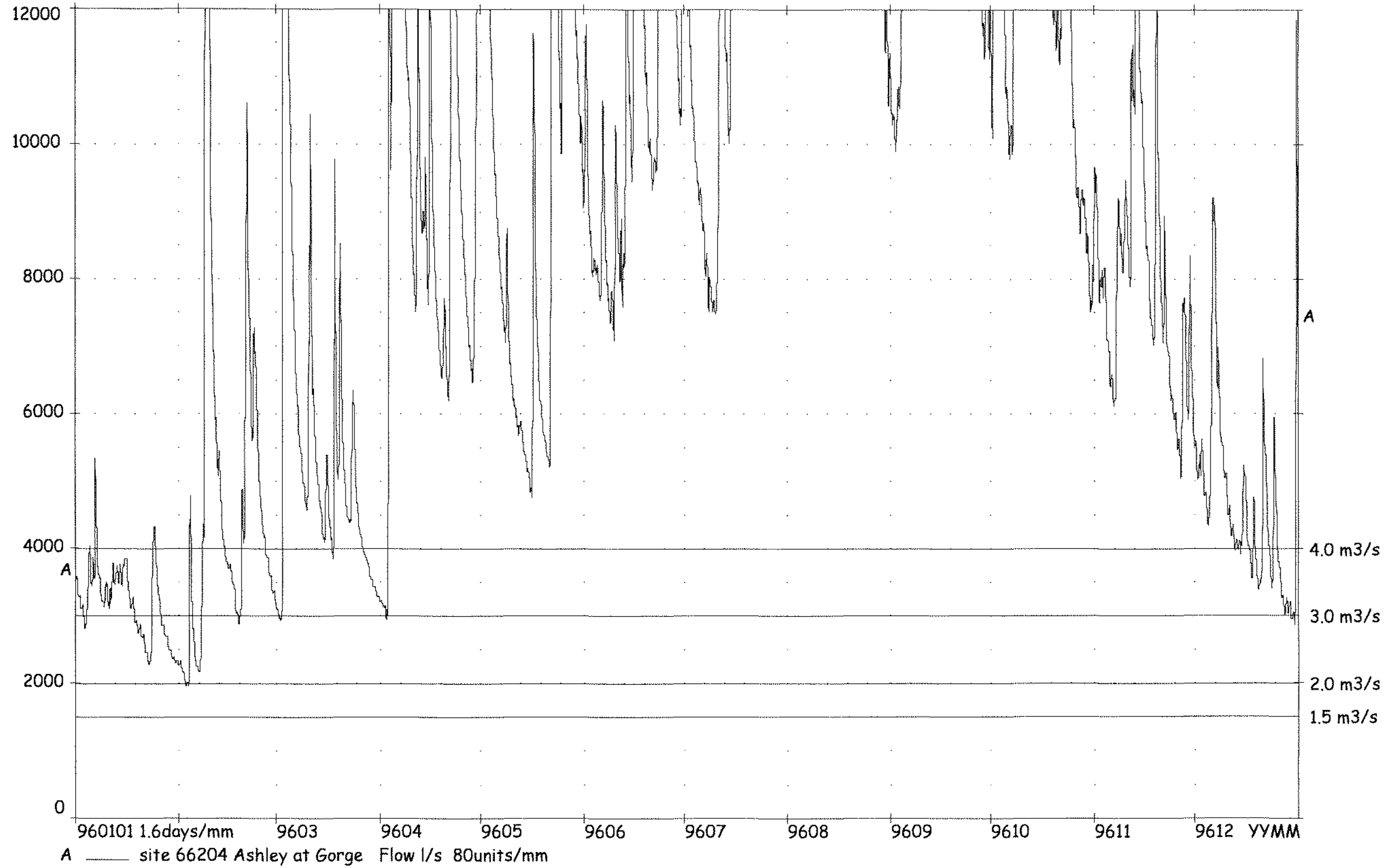

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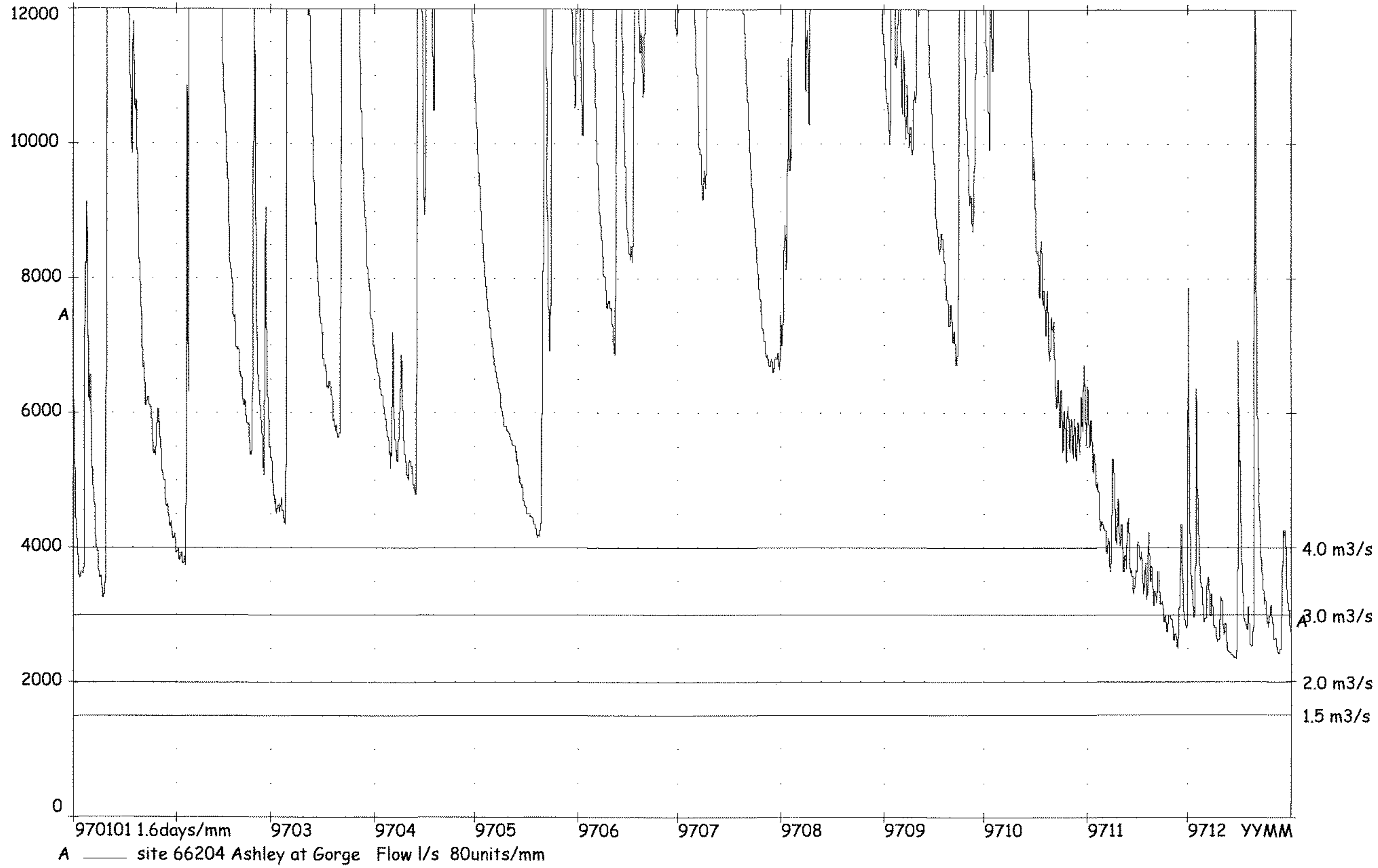

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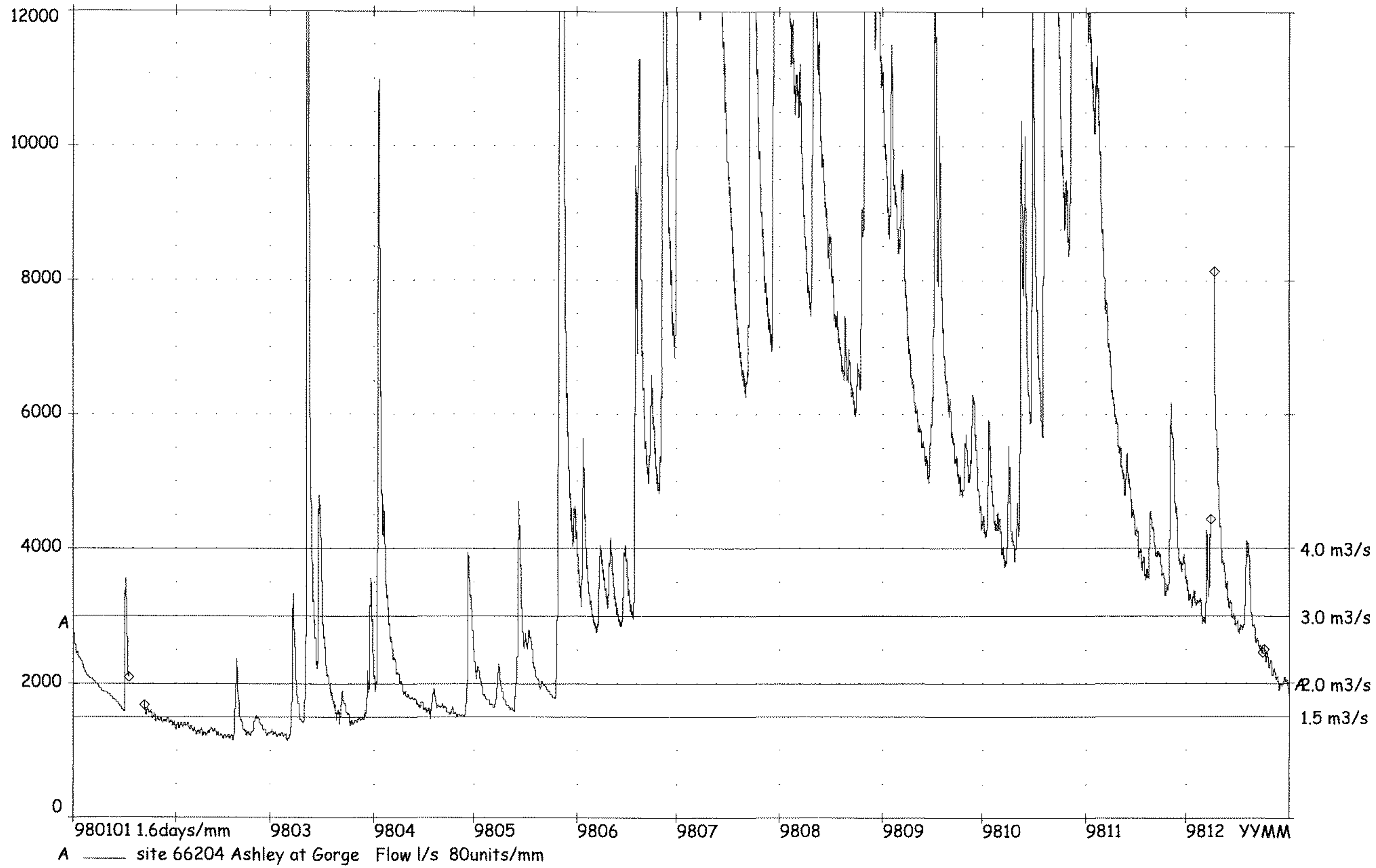

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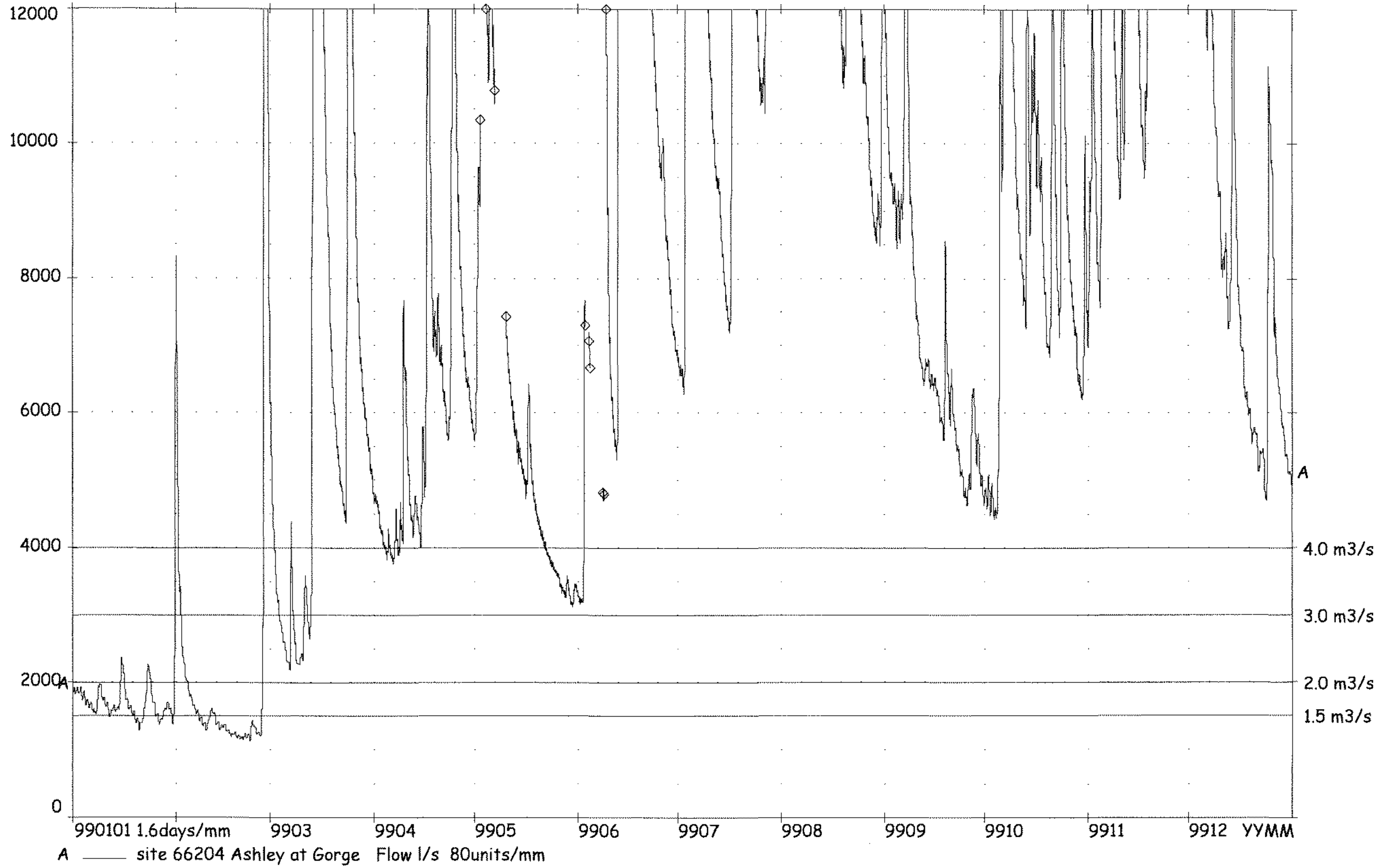


APPENDIX 3

SUMMARY OF RELATIONSHIPS BETWEEN CHANNEL CHARACTER, INSTREAM VALUES, AND HYDROLOGICAL CONTROLS

(from Mosley, 1999b)

Table 1. Summary of relationships between channel character, instream values, and hydrological controls

Aspect of channel character and ecology	Process and controlling variables	Hydrological control	Effect of abstraction
Overall channel dimensions and channel type	An alluvial channel is adjusted to carry the water and sediment load imposed on it from upstream. Its overall (bankfull) dimensions and shape reflect the dominant channel-forming floods that are able to mobilise bed material over large areas of the bed, and erode the bankline. This is dependent on the balance (which varies widely from place to place in a channel) between sediment mobility and water depth, velocity and shear stress. The nature of the sediment strongly controls channel type. The presence of bedrock or fluvio-glacial gravels in channel bed and banks is a dominant influence on channel morphology, and vegetation on the banks can also have a major effect.	Channel-forming floods are generally considered to recur about every one to ten years on average, depending on channel type. Stable, single-thread channels appear to be adjusted to the more frequent floods, and unstable, braided rivers to the less frequent floods.	Flow abstraction will have limited impact on channel-forming floods – and therefore on the form and natural/amenity values of channels – because normal levels of flow abstraction are substantially smaller. Channel-forming floods tend to occur in winter and spring, when abstractions are generally small. Flow regulation has an impact only in rivers affected by impoundments with substantial live storage, namely Tekapo, Pukaki, Ohau.
Shape of the channel bed	Within the overall limits of the bankfull channel that is created by the large channel-forming floods, lower flows mobilise sediment over smaller areas of the bed, reforming the gravel bars, low water channels and other features. Again, this process is dependent on the (highly spatially variable) balance between sediment mobility and water depth, velocity, and shear stress. The minimum flow is that at which the water velocity at some point on the bed exceeds that required to mobilise the sediment at that point; as flow increases, the area over which sediment is mobilised also increases.	Flows that reshape the channel bed are associated with freshes that occur a few times a year, on average. An index is the most effective flow, that which transports the greatest portion of the total sediment load. It tends to have an average recurrence interval of rather less than a year, but needs to be established for a particular river.	Flow abstraction (and also regulation), where it is large relative to the freshes normally experienced during summer and autumn, may reduce the frequency and size of channel-shaping freshes, and increase the duration of periods in which no bed reshaping occurs. This effect will be greatest in semi-braided and braided channels. The effect of abstraction will be noticed to the extent that the discharge during the freshes is reduced to and below the critical discharge required for entrainment of bed material, so it is not possible to specify an acceptable level of abstraction without reference to the specific flows experienced in a given year. The effects on natural/amenity values principally will be ecological, rather than geomorphological (see below).

Table 1 (continued). Summary of relationships between channel character, instream values, and hydrological controls

Hydraulic geometry	Many elements of the hydraulic geometry of a channel (the way that the water accommodates itself to the river bed), such as water depth, surface width and velocity, change progressively as flow changes. Some elements, such as the number of braids, are relatively independent of flow. The rate at which each element changes with flow is related to channel type, so that there are no regionally applicable relationships.	Hydraulic geometry is associated with the full range of flows, and its variation with varying flow is an aspect of a channel's natural character. .	Flow abstraction will result in a proportionate reduction in most elements of hydraulic geometry – water surface width, mean depths, etc. Some elements such as the number of braids or deep pools may be relatively unchanged. Because of considerable variability of hydraulic geometry along a channel, it is unlikely that many laypersons would be able to discern the differences caused by flow abstraction that is less than about 50% of the natural flow, although river users with very specific requirements – anglers, jetboaters – would be able to do so.
Floodplain and riparian zone	The morphology, sediments and soils of floodplains and riparian zones are a function of the flows that are large enough to spill out of the bankfull channel (note that break out may be only a few locations along the channel banks). Floodplain vegetation, insofar as it is affected by inundation, disturbance by flowing water, introduction of fresh sediments, nutrients, seeds etc, impeding of biological processes such as germination, also is affected by these overbank flows. Their effect increases as the size of the flow increases, although effects are highly variable from place to place on a floodplain. Natural processes are dominated by riparian management (e.g. bank protection planting) and floodplain land use in the middle and lower reaches of many Canterbury rivers.	Overbank flows are less frequent than the bankfull, dominant discharge taken to be responsible for overall channel dimensions. They therefore recur less frequently than once a year to once every ten years on average, depending on channel type.	As for "overall channel dimensions and type". It should be noted that riparian zone and floodplain management are in any case dominant over natural processes in the middle and lower reaches of most Canterbury rivers.
Flushing flows	Flushing flows are essentially those same flows that reform the bed (see "shape of the channel bed" above). An additional element is the spacing in time of flushing flows, with respect to continuing build-up of fine sediment and/or nuisance biological growths. The time required for nuisance growths to fully establish varies widely, because their rates of growth are controlled by degree of enrichment and other factors.	As for "shape of the channel bed". In addition, an important index is the duration (modal and maximum) of low flows between successive flushing flows.	As for "shape of the channel bed". Where flow abstraction increases the duration of low flows between successive freshes, the flushing effect can be seriously impeded, resulting in more extensive and dense nuisance biological growths, if nutrients are available. On the other hand, increased duration of low flows also increases the duration of conditions suitable for re-colonisation, which may enable a shift in the assemblage of species towards those with a greater requirement for substrate stability.

Table 1 (continued). Summary of relationships between channel character, instream values, and hydrological controls

Ecosystem disturbance: effect of freshes and floods	Ecosystem disturbance is accomplished by the same freshes and floods that would be regarded as flushing flows or those that reshape the channel bed. They have their effect essentially by entraining bed sediments that provide habitat for invertebrates and small fish, and by physically displacing fauna in a downstream direction. The effect of freshes varies widely among different types of rivers, according to the balance between streambed stability (a function of sediment size and arrangement, channel shape, and features such as accumulations of large woody debris). A critical element also is the presence of refugia provided by areas of still water, zones of undisturbed bed material, etc. The large, unstable braided rivers experience the greatest degree of disturbance. In the long term, flow disturbances do not appear to have a negative impact on biological diversity, because of recolonisation, but in the short term the abundance of fauna may be severely reduced by flow disturbances, particularly if they are closely spaced, or coincide with critical life stages such as fry emergence.	As for "shape of the channel bed". In addition, an important index is the duration (modal and maximum) of low flows between successive flow disturbances, that provide opportunity for recolonisation. Flow disturbances have the greatest significance in specific seasons or months of year, associated with the life cycle of the fauna that are present in the river, such as nesting of wrybill plover, or emergence and rearing of trout fry. The relevant season varies from river to river, depending on the species present.	As for "shape of the channel bed" and "flushing flows". It is noted that, while frequent reshaping of a channel bed, and frequent flushing of fine sediment and nuisance biological growths, may be regarded as desirable, ecosystem disturbance by exactly the same flows may be regarded as undesirable, at least for some species.

Table 1 (continued). Summary of relationships between channel character, instream values, and hydrological controls

Areas of instream habitat and barriers	Areas of instream habitat preferred by particular species, and the presence of barriers to movement, vary with flow in the same way that hydraulic geometry varies. Since different species (including people) have different preferences, the rates of change and the flow at which optimum habitat occurs may also differ. Indeed, a particular change in flow may advantage one species and disadvantage another. Optimum habitats are generally found during times of low flow or baseflow, in the range between annual low flow and mean flow. At such times, the substrate is stable, and velocities and turbidity are not excessive. Flow is not the only determinant, since factors such as water temperature, cover provided by overhanging trees, and particular features such as deep pools may have a controlling influence on habitat suitability within which flow variations have an effect.	As for hydraulic geometry, areas of instream habitat and the presence and significance of barriers vary continuously across the full range of flows. Optima may be calculated for each species, life stage, or human use. The point (shoulder) at which area starts to decline rapidly as flow declines may be identified in some cases. For many species and life stages, optima or the shoulder tend to occur at a flow about 1-5 times the annual low flow, although this is not necessarily general. Such optima are characteristic of particular river types. Human recreational uses of rivers tend to be at weekends and during holidays, so that the effect of varying flow on use-related elements has a significant temporal aspect	Flow abstraction will result in a proportionate reduction in most elements of instream habitat, depending on the particular combination of depths, velocities, substrates etc that are required for a given species/life stage. Some species/life stages have optimum conditions at "lowish" flows, somewhere between annual low flow and mean flow, so the effect of abstraction will depend on where the natural flow is relative to that optimum. Many elements start to decline rapidly at a flow that is somewhat larger than the annual low flow. Some elements such as the availability of deep pools may be relatively unchanged by a change in flow. In a braided river, the area suitable for a particular species/life stage may remain relatively unchanged, with flow, but its location will shift; however, the need for colonisation to occur must be considered.

Table 1 (continued). Summary of relationships between channel character, instream values, and hydrological controls

Water quality	Determinands of physical and chemical water quality may vary with flow, other things being equal. This is particularly the case with the passage of flood events. During floods, concetnrations of different solutes may increase or decrease, reflecting the fact that solutes are being introduced from the land surface at the same time as low-concentration rainwater is reaching the channel. During periods of low flow, water temperature tends to increase as flow declines, in accordance with the heat balance equation. Concentrations of solutes, particularly nutrients, vary with flow, depending on solute sources and the source and quantity of runoff that has low solute concentrations and therefore is able to dilute solutes. At low flow, concentrations of nutrients and other contaminants may or may not decrease, depending on their source and whether there is a source of low-concentration water to provide dilution.	Water temperature, during times of low flow, increases as flow declines, other things being equal. The effect is greatest in wide, shallow, unshaded rivers. The rate of decline is dependent on the particular characteristics of the river, including such factors as elevation, topographic shading and orientation. Solute concentrations at low flow may increase as flow declines, if there is a significant dilution effect. Where the principal streamflow source is enriched, then the dilution effect may be unimportant and there may be little relationship to flow.	Flow abstraction will, at low tend to increase water temperatures, particularly in semi-braided and braided rivers that have little streamside vegetation. Abstraction at low flow may well not affect solute and nutrient concentrations, if it simply abstracts water having average concentrations. If the abstraction point is above the point or zone of inflow of enriched water, and takes water having low concentrations, then downstream concentrations will increase in proportion. Water quality effects are dependent on the particular characteristics of the river.

APPENDIX 4

INSTREAM FLOW CONDITIONS FOR RECREATION, AND EFFECTS OF FLOW REGIM CHANGE

(from Ministry for the Environment, 1998, chapters A15 and B9)

Activity	**Water surface width m, depth m, velocity ms^{1} requirements**			**Preferred Sediment Requirements**	**Preferred Other Requirements**
	Minimum	**Maximum**	**Preferred**		
Paddling/ wading	W - D - V -	W - D 1.2 V 1.8	W - D 0.4-0.6 V <0.5	Sand and gravel preferred. Algal or silt coating undesirable No debris, broken glass etc.	Bacteriological and toxicant water quality standards to be met. Water temperature 15-25°C preferred. DxV product less than 1.0. Bottom visible. Easy access and sloping beach desirable
Angling/ wading	As above	As above	As Above	As above	As above, and/or fish habitat requirements Water temperature below 19°C is desirable, as trout stop feeding at higher temperatures.
Swimming	W 5.0 D 0.8 V -	W - D - V 1.0	W >10.0 D 1.5 V <0.3	As for paddling/wading.	As for padding/wading. Length of channel useable >50 m. For diving from bank, D ≥2.0 m
Tubing/ drift diving	W 5.0 D 0.3 V -	W - D - V -	W - D 0.8-1.5 V 1.0-2.0	As for paddling/wading. For "white-water" form of sport, as for rafting/canoeing.	No hazards-overhanging/submerged trees, etc. Bacteriological and toxicant water quality standards met. Bottom visible. Water temperature 10-25°C Access at top and bottom of reach to be travelled. Class 11 or 111 on international scale. (1 or 11 for drift diving). Obstacles can be portaged. Slots between rocks >1.0 m
White water rafting/ canoeing	W 7.5 D 0.2 V -	W - D - V 4.5	W >20.0 D 0.8-1.5 V 1.0-3.0	Presence of large boulders and bedrock outcrops to provide interest. Sediment on riffles of gravel size and not angular to minimise wear and tear.	As for tubing/drift diving except, Class II to IV on international scale. Slots between rocks >2 m.
Tramping* (riverbed routes)	W - D - V -	W - D 1.2 V 1.8	W - D - V -	Gravel bed desirable for easy travel. Algal or silt coating undesirable. Stable boulders, rock outcrops and small waterfalls desirable for interesting travel.	DxV product less than 1.0 on skewed gravel shoals for easy crossing, or footbridges available. River does not impinge on bluffs, to minimise need for river crossings, Floodplain or terrace surfaces present for easy travel. Water temperature >10°C. Bottom visible.
Angling (bank).	W - D - V -	W - D overbank V -	W as for fish D habitat V preferences	As for fish habitat preferences. No snags on stream bed.	As for fish habitat preferences, and: Easy access to and along bank. Stable (non-caving) bank.
Angling (boat).	W 7.5 D 0.3 V -	W - D - V 3.0	as for fish habitat preferences, and W >7.5 D 0.6-1.5 V <1.5	As for angling (bank)	As for fish habitat preferences. and/or As for boating (non-powered)
Boating (non-powered)/ rowing/ flat water canoeing.	W 7.5 (20.0 rowing) D 0.5 V -	W - D - V 1.5	W >20.0 D 0.6-1.5 V <0.5	Sand bed preferable. No snags on stream bed.	No snags in stream. Easy access to river No hazards - weirs, etc.
Sailing.	W 30.0 D 0.8 V -	W - D - V 0.5	W >60.0 D ~1.5 V ~0.0	As for boating (non-powered)	As for boating (non-powered).
Flatwater power-boating (low power).	W 7.5 D 0.6 V -	W - D - V 3.0	W >30.0 D ~1.5 V <1.5	As for boating (non-powered)	As for boating (non-powered).
Flatwater power-boating (high power)/ water skiing.	W 30.0 D 1.5 V -	W - D - V 4.5	W >90 D ~3.0 V <1.5	As for boating (non-powered)	As for boating (non-powered).
Jetboating.	W 5.0 D 0.1 V -	W - D - V 4.5	W >5.0 D >0.6 V <4.5	As for white water rafting.	Easy access to river. Minimum depth over riffles >0.2 m. No hazards - weirs, submerged piles, overhanging trees, etc. Bottom visible.
Camping (for water supply and washing bathing).	W 0.5 D 0.1 V -	W - D - V -	W - D - V -	As for paddling/wading.	As for paddling/wading.

* *Width, depth and velocity criteria for tramping in river gorges must be relaxed, when swimming across pools is expedient. The extreme form of this activity is pack floating, for which sport hydraulic criteria can hardly be set.*

Table 8 Effects of change in flow regime on fishing activities

Change in physical conditions	Effect
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	Fouls lures, clogs nets for whitebaiters
Fixed debris, such as logs, branches, etc	Snares lines
Turbidity	Various effects depending on fishing method adopted (for example, fly fishing is best in clear water, particularly when stalking fish, spinning may be better in slightly turbid water-likewise salmon fishing ("light colour" preferred). Turbidity reduces the ability of whitebaiters to see the bait, which is important.
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns-this requires site-specific assessment. Perceptions may play a large role-anglers may correlate a particular flow level with good fishing, when there may be no causal relationship. This will play a large role with the concept of a controlled or "unnatural" flow pattern generally. A change in flow may also encourage other users (kayakers for example) which may conflict with anglers. Flood flows during whitebaiting are likely to be detrimental (regardless of ecological requirements).
Low flows	May strand launching ramps for boats and change traditional fishing spots. May cause fish to pond, thereby increasing the chance of poaching activities (foul hooking or "scratching"). Fishable area (a key indicator of value) may be reduced (for example, reduced width brings margins of river closer). River character may change (loss of pools, increase in riffles, etc). Exposure of slippery rocks, mud, etc. Impacts on alternative locations may result through dispersal of use to other sites. High or low temperatures affect trout behaviour. Above or below these temperatures trout are relatively inactive and have little interest in feeding. Fish may be more difficult to approach (and therefore catch) even though their ecological requirements are catered for.
Altered form, channel type	Loss of cover for stalking. Changes in access (may be significant for established whitebaiting sites).

Table 9 Effect of change of flow regime on paddling and floating activities

Change in physical conditions	Effect
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	Few concerns beyond aesthetic if debris is small.
Fixed debris, such as logs, branches, etc	Can pose very serious risks for paddlers (pinning). If stationary large debris are termed strainers. If mobile, termed mobile strainers. Strainers may take many forms, including willow roots and branches (live) and dead trees.
Turbidity	Is unlikely to alter the physical ability of the river to support the activity but may reduce the quality of the experience, particularly where the natural character of the river is significant (consider the Whanganui).
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns. This requires site-specific assessment, as river hydraulics will change with flow regime, and many river features (holes, waves, rapids, etc) are dependent on specific flow levels. Perceptions of control may play a large role, as for anglers. Concentration of good flow patterns at particular times may cause or increase crowding. Reliability of flow can be an improvement, although variability may be sought by many users. Different flows may expose or hide many hazards (undercut rocks, strainers, for example).
Low flows	May strand launching sites, expose mud and slimey rocks and will change river hydraulics (as above). In some cases the river may be more user friendly at low flows, but such a state is likely to satisfy only a portion of the user population. Dangerous strainers are often exposed, and low flows will not necessarily reduce the risks of being pinned.
Altered form, channel type	Changes in access. Changes in hydraulics, possible loss of many features of river (as above).

Table 10 Effect of change of flow regime on swimming activities

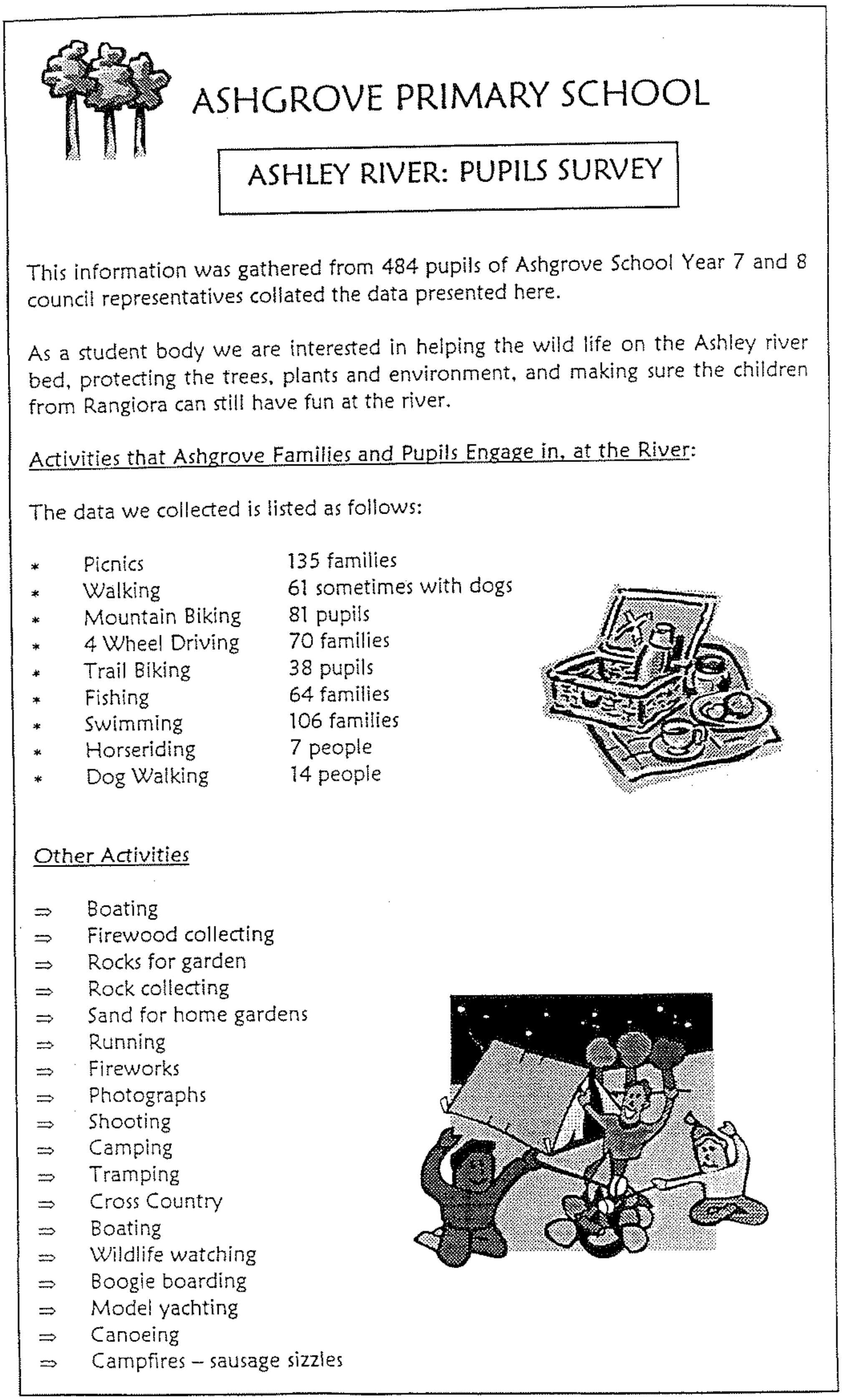
Change in physical conditions	**Effect**
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	May reduce the use of a site significantly. Mobile phytoplankton (algae) would be of concern. Perceptions of water quality are important (it is difficult to subjectively judge water quality, and what is visible will guide that judgement).
Fixed debris, such as logs, branches, etc	Can pose very serious risks for swimmers (entrapment).
Turbidity	Perceptions of water quality are significant, and turbidity will have a significant effect, as for particulate matter. Dangers (strainers, rocks) may be obscured. The natural character of the river is likely to be important (odours, reflections, clarity, etc).
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns this requires site-specific assessment, as river hydraulics will change with flow regime, and many river features (holes, waves, rapids, strainers, etc.) are dependent on specific flow levels. The natural character of the river is likely to be an important element of the experience (sound of riffles, etc.)
Low flows	Exposed mud, slimey rocks and siltation are major issues. Shallow pools and reduction in depth may reduce swimming opportunities, and may remove jumping sites (need depth). In some cases the river may be more user friendly at low flows, and temperature in pools may increase.
Altered form, channel type	Changes in access. Changes in hydraulics, possible loss of many features of river, such as swimming holes.

Table 11 Effect of change of flow regime on mechanical activities

Change in physical conditions	**Effect**
Particulate matter mobile in river, including weed mats, small pieces of floating debris, etc	Floating matter of any sort may damage intake ports, water pumps and the general drive mechanism of jet boats. Large debris (branches) may puncture a boats hull at high speed.
Fixed debris, such as logs, branches, etc	Can pose serious risks to vessels.
Turbidity	Fine matter may seriously damage water pumps and the propulsion mechanism of jet boats and jet skis.
Controlled flows	A variety of impacts may result through the change in low flows, high flows, the creation of stable flows or the change in seasonal patterns. This requires site-specific assessment, as river hydraulics will change with flow regime, and many river features (holes, waves, rapids, etc) are dependent on specific flow levels.
Low flows	May strand launching facilities. In braided rivers, can reduce quality of experience by reducing area of resource. Jet boats plane over very little water, but require deep pools for take-off and for stopping. Exposed mud, slimey rocks and siltation are issues, although some reports suggest weed on rocks may protect hulls. Mud may trap launching vehicles. In some cases the river may be more 'user friendly' at low flows. Safety may be compromised during low flows. Jet boats generally keep right as a rule, but in narrow gorges where visibility is restricted, collisions may be a potential - and more-so when river width is reduced. Reduction in width will increase conflicts with shore users (anglers, whitebaiters) and other river users (kayakers, etc).
Altered form, channel type	Changes in access. Changes in hydraulics, possible loss of many features of river, such as take-off and stopping areas, as above.

APPENDIX 5

ASHLEY RIVER: PUPILS' SURVEY, ASHGROVE PRIMARY SCHOOL



ASHGROVE PRIMARY SCHOOL

ASHLEY RIVER: PUPILS SURVEY

This information was gathered from 484 pupils of Ashgrove School Year 7 and 8 council representatives collated the data presented here.

As a student body we are interested in helping the wild life on the Ashley river bed, protecting the trees, plants and environment, and making sure the children from Rangiora can still have fun at the river.

Activities that Ashgrove Families and Pupils Engage in, at the River:

The data we collected is listed as follows:

*	Picnics	135 families
*	Walking	61 sometimes with dogs
*	Mountain Biking	81 pupils
*	4 Wheel Driving	70 families
*	Trail Biking	38 pupils
*	Fishing	64 families
*	Swimming	106 families
*	Horseriding	7 people
*	Dog Walking	14 people

Other Activities

⇒ Boating
⇒ Firewood collecting
⇒ Rocks for garden
⇒ Rock collecting
⇒ Sand for home gardens
⇒ Running
⇒ Fireworks
⇒ Photographs
⇒ Shooting
⇒ Camping
⇒ Tramping
⇒ Cross Country
⇒ Boating
⇒ Wildlife watching
⇒ Boogie boarding
⇒ Model yachting
⇒ Canoeing
⇒ Campfires – sausage sizzles

APPENDIX 6

ASHLEY RIVER RESPONSE TO CHANGING DISCHARGE

Introduction

The Ashley River naturally dries up in the vicinity of Rangiora, during summer low flows, as a result of losses to groundwater. Concurrent gaugings carried out at several locations along the Ashley River over a range of flows indicate that dewatering is likely to occur at discharges (at Ashley Gorge) less than approximately 2.5 m^3/s (Figure 1).

The spacing of concurrent gaugings is insufficient to define exactly where dewatering occurs. Vertical aerial photographs of the Ashley River are available for 1.23, 3.19, 4.45, and 20.5 m^3/s. They have been used to map the location at which continuous flow ceases and restarts.

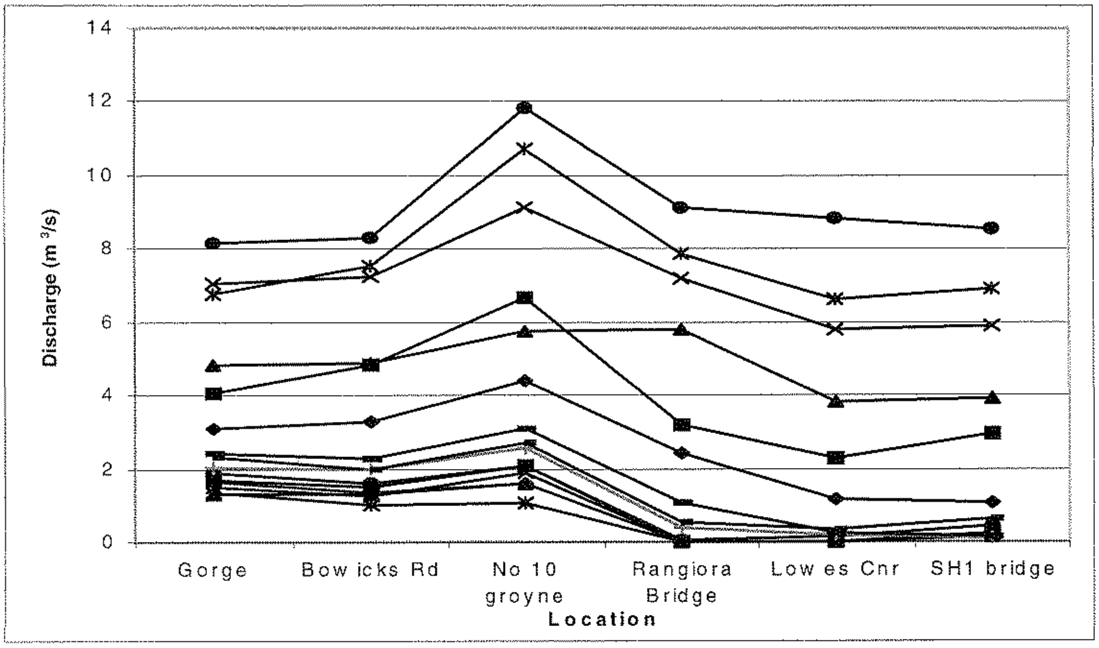


Figure 1. Discharge at points along the main Ashley River at a range of discharges.

Procedure

Each set of aerial photographs was laid out as a mosaic, and cross-sections at 1 km spacing identified, with reference to the 1:50,000 topographic map. The scale of the aerial photographs was measured at 5 km spacing, again with reference to identifiable points on the 1:50,000 topographic map. At each 1 km cross-section, water surface width and the width of fresh gravel were measured, perpendicular to the bankfull channel, using an engineer's scale viewed under a magnifying glass. All measurements were made in mm on the photos; data were entered into a series of Excel spreadsheets, which automatically calculated gravel and water surface width in metres on the ground, and the percentage of the gravel bed covered by water. The number of channels (including disconnected pools with water but no continuous flow) at each 1 km cross-section also was entered into the spreadsheets.

The estimates of gravel and water surface width are imprecise, because of the difficulty of measuring small lengths on the aerial photographs. Accuracy cannot readily be quantified, because no simultaneous ground measurements were made, against which to compare the measurements on the photographs. The estimates presented herein therefore should be taken only as indicative of differences between flows and along the channel.

Results

Following pages present plots, for each flow and at each 1 km cross-section, of the width of gravel, the width of water, the percentage of water, and the number of channels. Three summary plots are also presented, which compare width of water, percentage of water, and number of channels at each flow.

At 1.23 m^3/s, there is no continuous flow between 16.8 and 2.3 km from the sea, but the sections 16.8-15.8 km and 4.7-2.3 km from the sea have a series of pools of water that are not connected, and presumably are maintained by groundwater. The wholly dewatered section is therefore between 15.8 and 4.7 km from the sea. At 3.19 m^3/s, there is continuous flow throughout, which is consistent with the results of the concurrent gaugings. At 4.45 m^3/s, continuous flow ceases between 8.7 and 6.7 km from the sea, and the intervening section features a series of pools.

Discharge (m^3/s at Ashley Gorge)	**1.23**	**3.19**	**4.45**
Distance from mouth (km) at which continuous flow ceases	16.8		8.7
Distance from mouth (km) at which bed becomes completely dry	15.8		
Distance from mouth (km) at which pools reappear	4.7		
Distance from mouth (km) at which continuous flow re-establishes	2.3		6.7

The sensitivity of water surface width to declining discharge is indicated in Figure 1, where average width declines from about 30 m at 3.19 m^3/s to zero at 1.23 m^3/s, in the de-watered reach. (Figure 1).

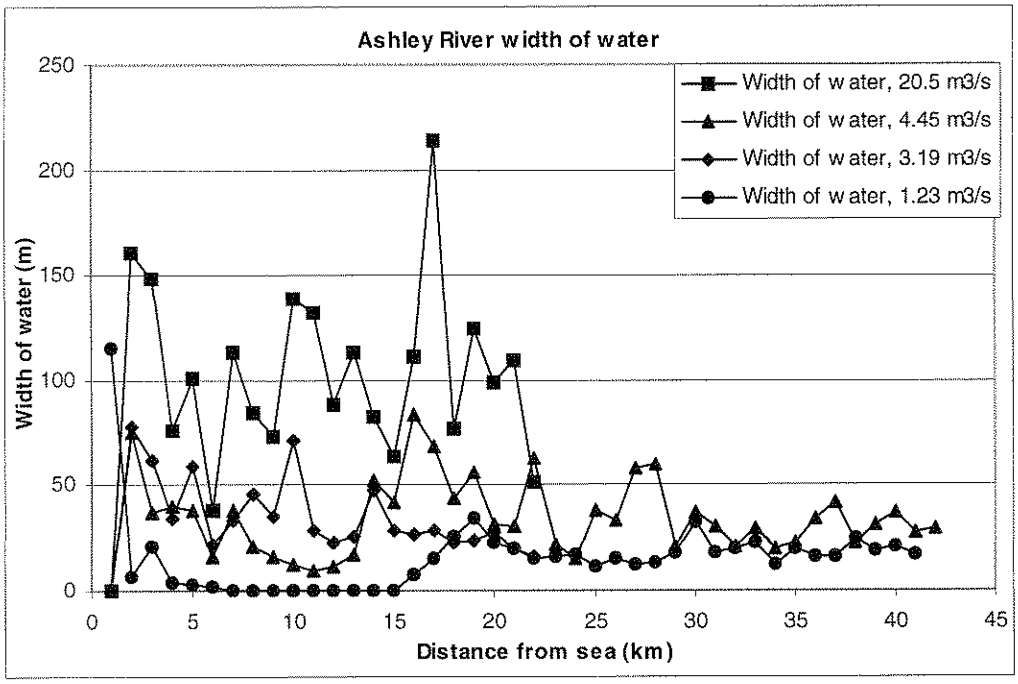


Figure 1. Water surface widths, Ashley River at a range of flows.

This decline in water surface width can be expressed as a decline in the percentage of the whole river bed that is covered by water, from around 10-15% at 4.45 m^3/s to zero at 1.23 m^3/s (Fig 2).

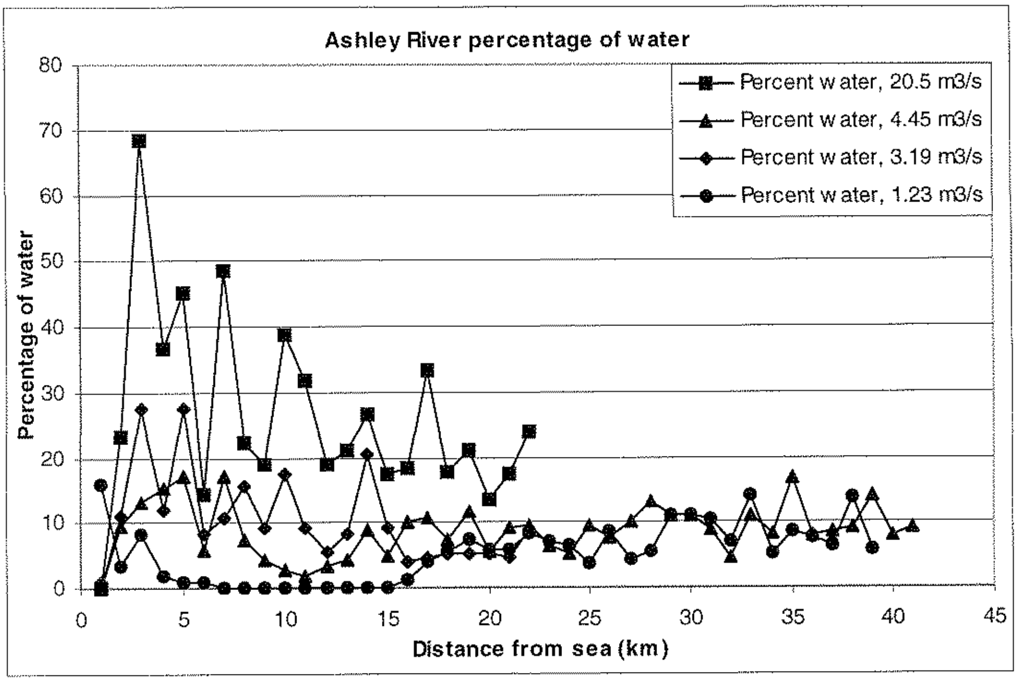


Figure 2. Percentage water surface width, Ashley River at a range of flows.

Similarly, the effect of declining flow can be seen in the reduction in the number of braids at a given cross-section (Figure 3). It should be noted, however, that at these low flow there are more than three channels at only a few cross-sections.

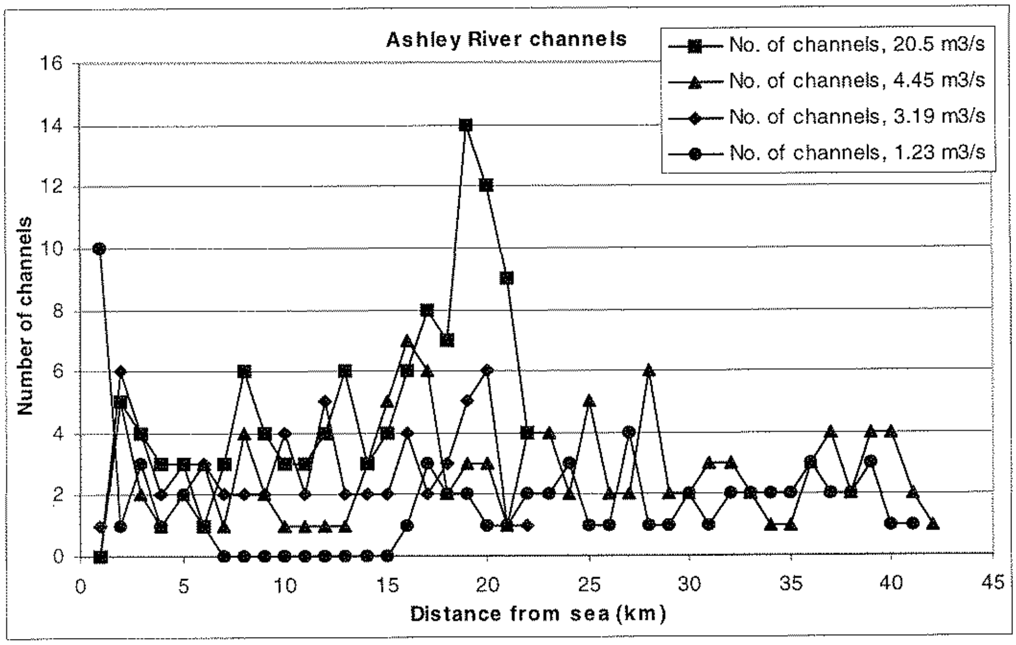
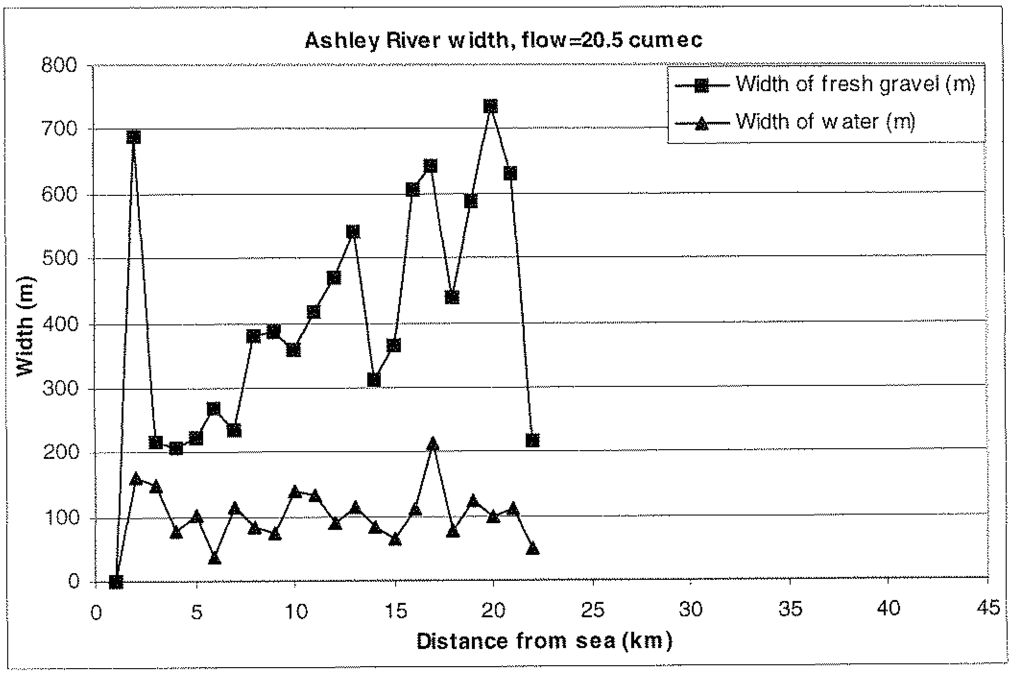
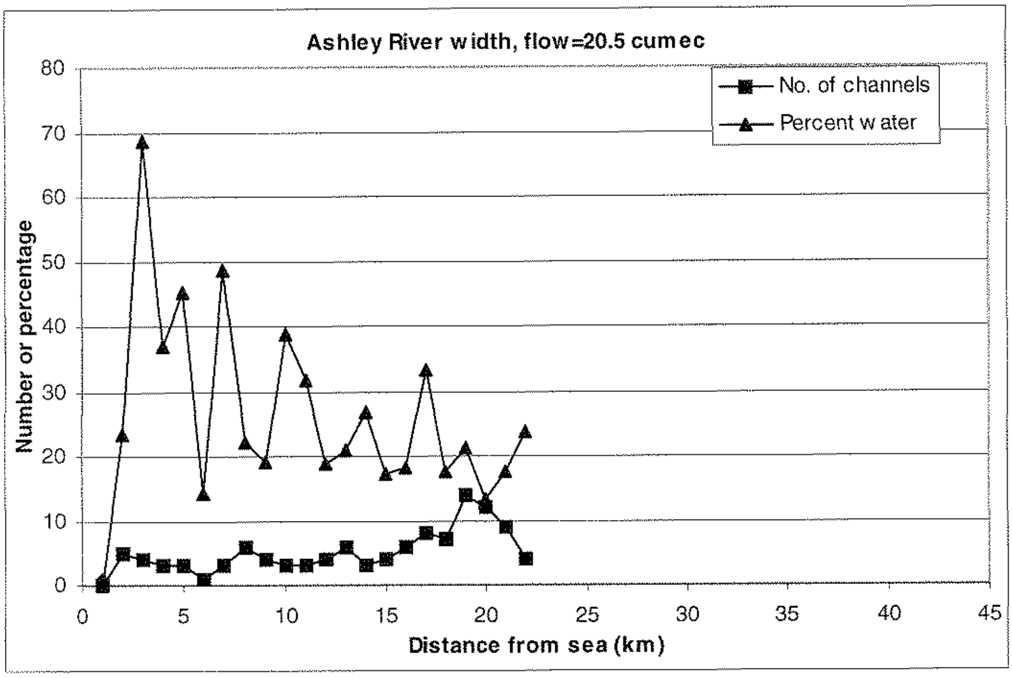
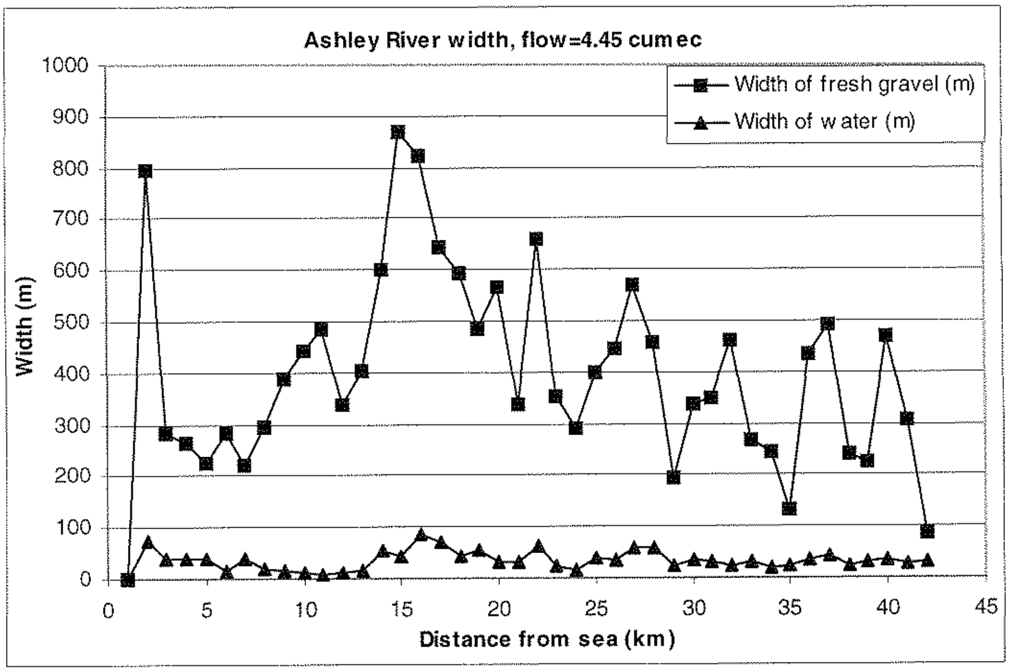
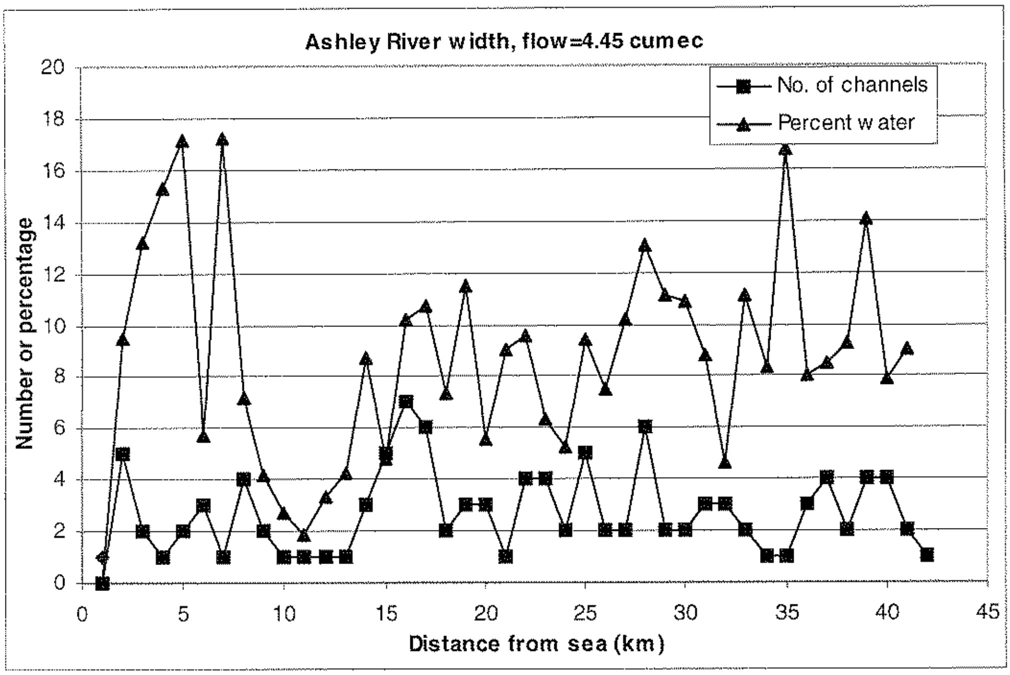


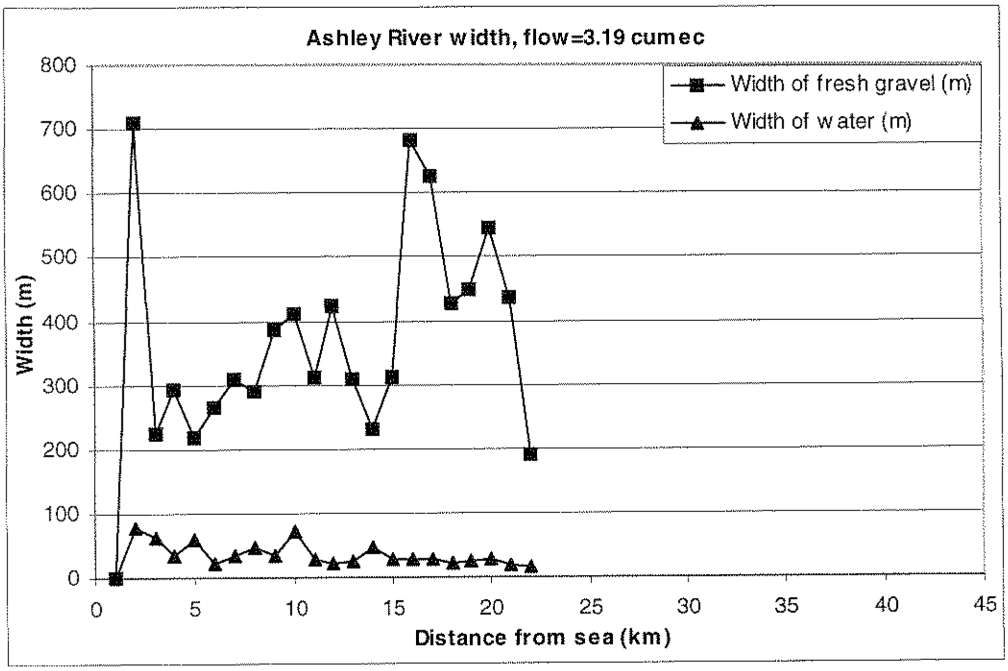
Figure 3. Number of channels, Ashley River at a range of flows.

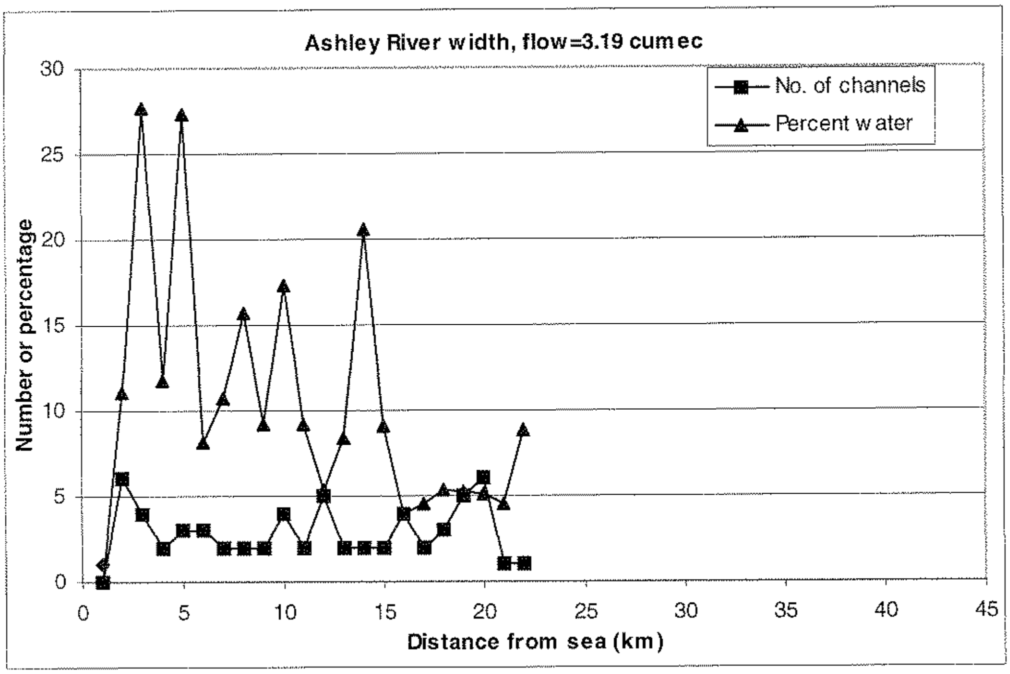

Ashley River width, flow=20.5 cumec
Width of fresh gravel (m)
Width of water (m)
Width (m)
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)

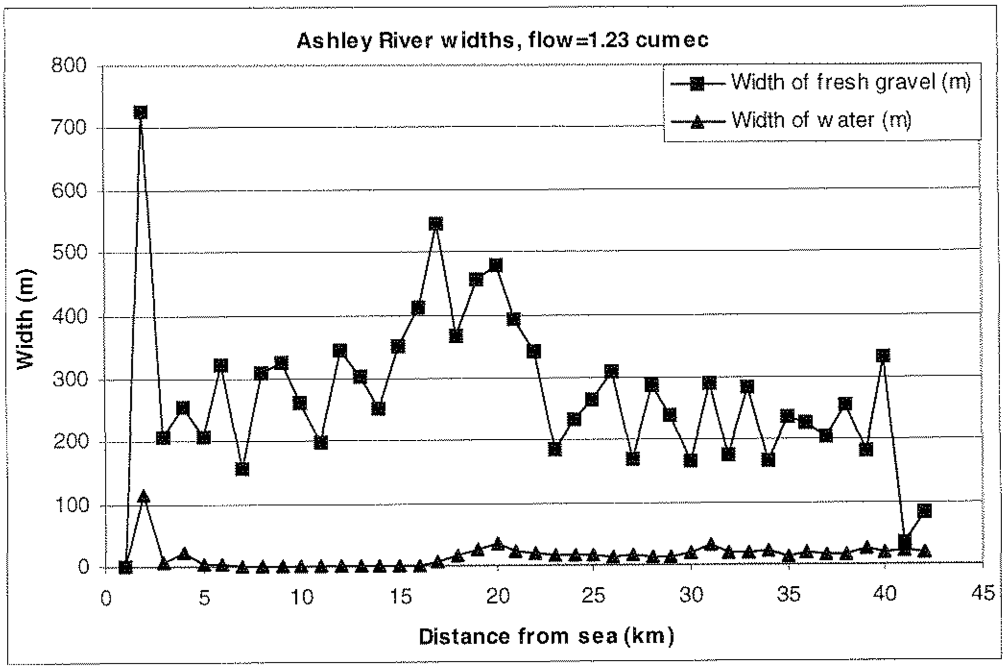

Ashley River width, flow=20.5 cumec
No. of channels
Percent water
Number or percentage
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)

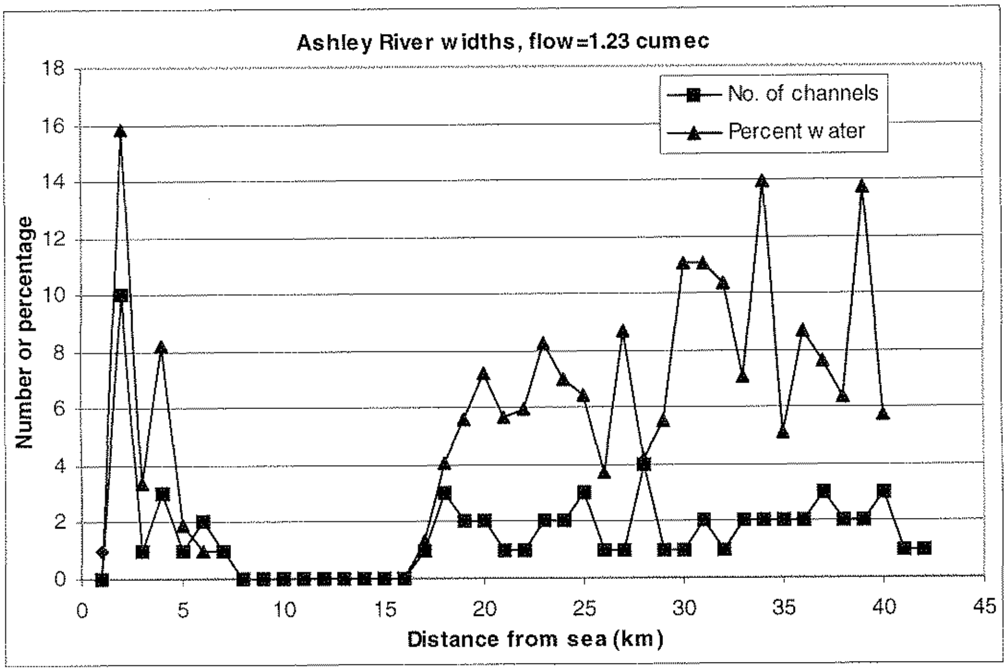

Ashley River width, flow=4.45 cumec
Width (m)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)
Width of fresh gravel (m)
Width of water (m)


Ashley River width, flow=4.45 cumec
Number or percentage
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)
No. of channels
Percent water


Ashley River width, flow=3.19 cumec
Width of fresh gravel (m)
Width of water (m)
Width (m)
0
100
200
300
400
500
600
700
800
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)


Ashley River width, flow=3.19 cumec
No. of channels
Percent water
Number or percentage
0
5
10
15
20
25
30
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)


Ashley River widths, flow=1.23 cumec
Width (m)
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)
Width of fresh gravel (m)
Width of water (m)


Ashley River widths, flow=1.23 cumec
Number or percentage
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
40
45
Distance from sea (km)
No. of channels
Percent water

APPENDIX 7

SUMMARY: RELATIONSHIPS BETWEEN NATURAL CHARACTER, AMENITY VALUES AND FLOWS IN THE ASHLEY RIVER

Table 1. Relationship to flow regime of instream values in the Ashley River, and their flow management requirements

Instream Value	Relationship to flow regime	Flow management requirements
Life-supporting capacity: terrestrial plants on riverbed and berms	Terrestrial vegetation is controlled principally by human agency (exotic species introduction, river control work, etc) and by large floods (occurring a few times a decade, at any time of year) able to rework gravel surfaces on which vegetation has become established.	To prevent permanent establishment of vegetation on the riverbed, maintain frequency of large floods. (No conceivable modification of the Ashley's flow regime is likely in practice to have any effect on vegetation colonisation.)
Life-supporting capacity: terrestrial animals on riverbed and berms	Presence of terrestrial animals is largely unrelated to flow regime. Cover is provided by terrestrial vegetation, so animals may be favoured by an increase in vegetation (see above). Access to the riverbed is increased at low flows, as side braids become dewatered. The effect is greatest during natural low flows in mid- to late-summer, but this loss of braids at low flow (estimated average loss of 0.2 braids per 1 m^3/s reduction in flow) may be less significant than is often suggested.	To prevent enhanced cover for terrestrial animals, maintain frequency of large floods (see above). To limit access of animals to riverbed, maintain low flows as high as possible. (The effect of flow variation on animal access is probably minor during the critical period for vulnerable nesting birds: see below).
Life-supporting capacity: birds	Birdlife in the Ashley estuary is affected to a limited extent by the flow regime. There is an undetermined potential for birds in the lower spring-fed tributaries to be affected by flow reduction, through habitat reduction. Other factors (drainage, land use change, agricultural operations) are probably more significant, however. Birds in the main river are affected by the large floods (at any time of year) that provide clear gravel surfaces for nesting and remove vegetation and cover for predators (see above). They are affected directly by the sequence of flows that occur during the nesting and breeding season (August to January/February): freshes may destroy nests; low flows may provide enhanced access to nests by predators (see above) and reduced food-producing areas along side-braids and in main channel riffles (see below: macroinvertebrates). Water quality in the Ashley is not a limiting factor on birdlife. Many other aspects of the environment (disturbance by people, gravel extraction, predation) have greater significance than flow regime.	To maintain clear gravel surfaces for nesting and minimise cover for predators, maintain frequency of large floods (see above). To limit access of predators to riverbed, maintain low flows as high as possible. (The effect of flow variation on predator access during the critical period is probably minor). To maximise food-production, maintain a flow in the range 2.0-2.5 m^3/s during the principal breeding season (through to January/February). For the spring-fed tributaries, no information is available on which to base recommendations for management of the flow regime.
Life-supporting capacity: aquatic plants	The biomass of aquatic vegetation (principally periphyton) in the Ashley River is related to the frequency of flood events (>30 m^3/s) that remove growths, and the duration of intervening stable flows during which periphyton is re-established. Biomass per unit area increases exponentially with declining flows, and exponentially with the duration of periods of stable flow, up to a maximum at around 70 days. Species in the Ashley are	To minimise nuisance growths of periphyton, maintain the frequency and magnitude of flood events >30 m^3/s, maintain low flows as high as possible, and prevent the addition of phosphates.

	similar to those in other Canterbury rivers, and the assemblage of species is adjusted to the unstable flow regime. Periphyton growth in the Ashley is nutrient-limited (phosphorus).	
Life-supporting capacity: aquatic invertebrates	The response to flow regime of aquatic invertebrates in the Ashley is similar to that of periphyton (above). Species are similar to those in other Canterbury braided rivers with unstable flow regimes. After disturbance by a flood, species diversity and biomass increase with the duration of stable flows. Disturbances by floods have a temporary effect, since recolonisation from upstream sources is rapid.	To maximise invertebrate biomass and species diversity, reduce the frequency of flood events > 30 m^3/s, and maximise the duration of stable flows. (Note that this would encourage periphyton growth, which might be unfavourable to some invertebrate species).
Life-supporting capacity: fish	Fish in the Ashley respond to flow regime in a variety of ways, and fish communities are resilient to the naturally unstable regime. Usable habitat declines with flow at different rates for different species; the optimum flow is in the range 1.5-4 m^3/s for several of the species present. The actual number or biomass of fish present is not directly related to flow or available habitat, however. Floods may displace fish and reduce the number below what could be supported, while low and declining flows may concentrate fish into dwindling habitat at much higher densities than they would prefer. Flows below 2.5 m3/s at the Gorge may result in de-watering of the bed below the Okuku, causing stranding and death of fish. For salmonids migrating upstream during November-March, a flow of >3-4 m^3/s is desirable, and prolonged low flows without freshes may impede upstram movement (particularly in the Okuku to SH1 reach). Water temperatures reach levels (23-24°C) that are sub-lethal for salmonids during summer low-flows, usually for an hour or so in the main channel. 30-40% of the water surface area may be less than this, because of cool underflow, while some disconnected pools may reach up to 35°C. Reducing flow theoretically will increase water temperature, but this effect in practice is likely to be moderated by cool underflow, and there is no hard evidence that fish kills have resulted from elevated temperatures. Fish in the Ashley estuary are not materially affected by hydrologic regime. Fish in the lower spring-fed tributaries and wetlands are likely to be affected by hydrologic regime, especially flow reduction, but there is minimal information on this effect. Other factors, particularly habitat loss, drainage, agricultural operations, etc, are likely to be of more significance.	To maximise fish biomass, reduce the frequency of floods large enough to displace fish (especially juveniles), and maintain low flows in the preferred range (1.5-4 m^3/s, depending on species). To enable unhindered upstream salmonid migration, maintain flows >3-4 m^3/s (or maintain the frequency /size/duration of freshes if stable flows are lower than that), during November-March. To minimise fish kill due to elevated water temperatures, maintain low flows at natural levels. (The impact of reducing flow on temperature is likely to be moderated by cool underflow).
Mahinga kai	As for life-supporting capacity: fish	As for life-supporting capacity: fish

Natural character	Overall, the natural character of the Ashley (in terms of its appearance) is created principally by geomorphic processes during large floods, and several non-hydrological processes and phenomena (e.g. river control work, invasion of exotic vegetation, etc). (Several aspects of natural character are dealt with under "life-supporting capacity" and other values.) The low flow regime affects natural character, principally through changes in the number and sizes of braids, riffles and pools, the wetted area, the nature of the water surface, and aquatic habitat. These could all be regarded as changing adversely as flow declines, but the considerable spatial variability hinder even an expert onlooker from being able to observe changes, except when complete de-watering occurs. The flow regime (annual pattern of flows, frequency/duration/magnitude of flood events and low flow periods, is crucial to defining the character of the river.	To maintain overall appearance of the river (braided, broad gravel-bed), maintain the frequency and magnitude of floods. To maintain the low flow appearance of the river, particularly with respect to the number of braids and extent of wetted area, maintain the natural flow regime. To maintain the hydrologic regime of the river, maintain the annual pattern of flows and the frequency/duration/magnitude statistics of flood events and low flow periods. (No conceivable modification of the flow regime will impact on the large floods. In practice, it is difficult to discern the effect of discharge variations at low flows upon the appearance of the river). For other aspects of natural character, see other values.
Trout and salmon habitat.	As for "life-supporting capacity: fish"	As for "life-supporting capacity: fish"
Amenity values: scenic quality	Scenic quality is related to flow regime to only a minor extent, principally in terms of water colour and turbidity and the relative extent of bare gravel and water. These factors will change little at the flows that are observed by most visitors to the Ashley.	To maintain scenic quality, maintain the natural flow regime and avoid any activities that discolour the water. (Scenic quality is unlikely to change noticeably with foreseeable changes to low/medium flows.
Amenity values: recreational fisheries	For most aspects, as for "life-supporting capacity: fish". The minimum flow for maintenance of habitat for adult brown trout is 2.5 m^3/s. Some practical aspects of angling (access, fishability, etc) are affected by flow regime, and in general the quality of angling will decline progressively as flow declines to and below 2.5 m^3/s. Angling in the estuary area is largely unrelated to river discharge, except that large floods with turbid water curtail the activity.	As for "life-supporting capacity: fish". To maintain quality of angling, maintain flow above 2.5 m^3/s.
Amenity values: other recreation	Most recreational uses of the Ashley are flow-enhanced rather than flow dependent, and high levels of use are due to its proximity to population centres rather than its quality. The river is of low to insignificant value for most flow-dependent activities (boating, kayaking). Swimming (in association with picnicking and camping) is the major flow-dependent use, but usage is insensitive to the particular flow experienced, so long as the water appears to be clean – spring-fed disconnected pools may be acceptable (or preferred) for safe family use.	To maintain opportunity for swimming, the principal flow-dependent use, maintain acceptable water quality (appearance, taste, smell) and maintain continuous flow – or at least a series of pools – in the reach most likely to be de-watered (i.e. a discharge of 2.5 m^3/s at the Gorge).

Table 2. Period (grey shade) when flow regime is **most** significant for the instream values of the Ashley River below the Gorge

Value	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Life-supporting capacity: terrestrial plants on riverbed and berms												
Life-supporting capacity: terrestrial animals on riverbed and berms												
Life-supporting capacity: birds		▨	▨	▨	▨	▨	▨					
Life-supporting capacity: aquatic plants												
Life-supporting capacity: aquatic invertebrates												
Life-supporting capacity: fish							▨	▨	▨			
Mahinga kai												
Natural character												
Trout and salmon habitat							▨	▨	▨			
Amenity values: scenic quality												
Amenity values: recreational fisheries					▨	▨	▨	▨	▨			
Amenity values: other recreation					▨	▨	▨	▨	▨			

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