THE EFFECTS OF RURALIZATION AND URBANIZATION ON THE RECREATIONAL FISHERY IN THE UPPER MURRUMBIDGEE RIVER WITH AN ANALYSIS OF CHANGES IN HYDROLOGICAL CHARACTERISTICS AND THEIR POTENTIAL IMPACT ON FISH POPULATIONS.

by

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A dissertation submitted in partial fulfilment of the requirements for the degree Master of Resource and Environmental Studies in the Australian National University.

October 1983

DECLARATION

Except where otherwise indicated, this dissertation is my own work.

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October 1983

Acknowledgements

The author wishes to thank the N.S.W. Water Resources Commission for providing discharge data for the gauging station at Cotter Crossing/Mt McDonald and to Mr. Lou Spandler of the Hydrographics Section of the Department of Housing and Construction for his assistance in providing data fir the Cotter River System.

Special thanks are also due to Mark Greenway for his assistance with the computer processing of the data used in this report.

ABSTRACT

A survey of anglers fishing the Murrumbidgee River and its feeder streams above Burrinjuck Reservoir has revealed that these anglers have perceived a decline in the value of the recreational fishery in the Upper Catchment with fewer fish of smaller size reported in catches in recent years.

A number of changes which have occured due to urban and rural development within the region are reviewed in this report and the relevance to the fishery discussed. Though each of the alterations outlined has probably contributed to some extent to the decline in the fishery, little work has been carried out to determine the relative impact of each of these factors. The management of a fishery in absence such information makes remedial action difficult to recommend with any authority.

In this study the hydrology of the Upper Murrumbidgee River was investigated in detail using flow data from the gauging stations at Cotter Crossing/Mt McDonald (Station No. 410035/410738). The period between 1960 - 1976 was compared to previous years for which records were available in order to isolate the impact of dam construction on patterns of river discharge and the frequency and severity of flood events. The potential impact of any detected changes in hydrological patterns on the recreational fishery was discussed.

The construction of Tantangera Reservoir (1960) could not be shown to have caused any major alteration in mean or median flows, frequency distribution of daily flows or in the frequency or severity of flooding for the months October - March. These months were shown to be crucial for the spawning migrations of native fish.

The months April to September in the post 1960 period were shown to have reduced mean and median flows, an altered frequency distribution of daily flows with many more discharges occurring in the low flow range, and a flooding regime which showed a reduction in the frequency though not severity of the two year flood. These alterations could not be accounted for by changes in climatic patterns and the major impact was attributed to the construction of Tantangera Reservoir. The relevance of these alterations to the trout fishery and more indirectly to the native fishery were discussed.

The Cotter River dams were shown to reduce annual flows in the Murrumbidgee at Cotter Crossing by an average of 3.6 per cent. However, the seasonal reductions brought about by these dams, and by other impoundments in the Upper Catchment were not investigated and reductions may be unevenly distributed throughout the year as was the case for Tantangera Reservoir.

If the protection of a recreational fishery or of aquatic ecosystems in general are to be seriously considered as part of water resource management programs then the assessment of the seasonal impacts of water use practices in association with the seasonal requirements of aquatic organisms is more relevant than annual trends.

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CHAPTER 1

INTRODUCTION

1.1 The Murrumbidgee Catchment - Area Under Consideration

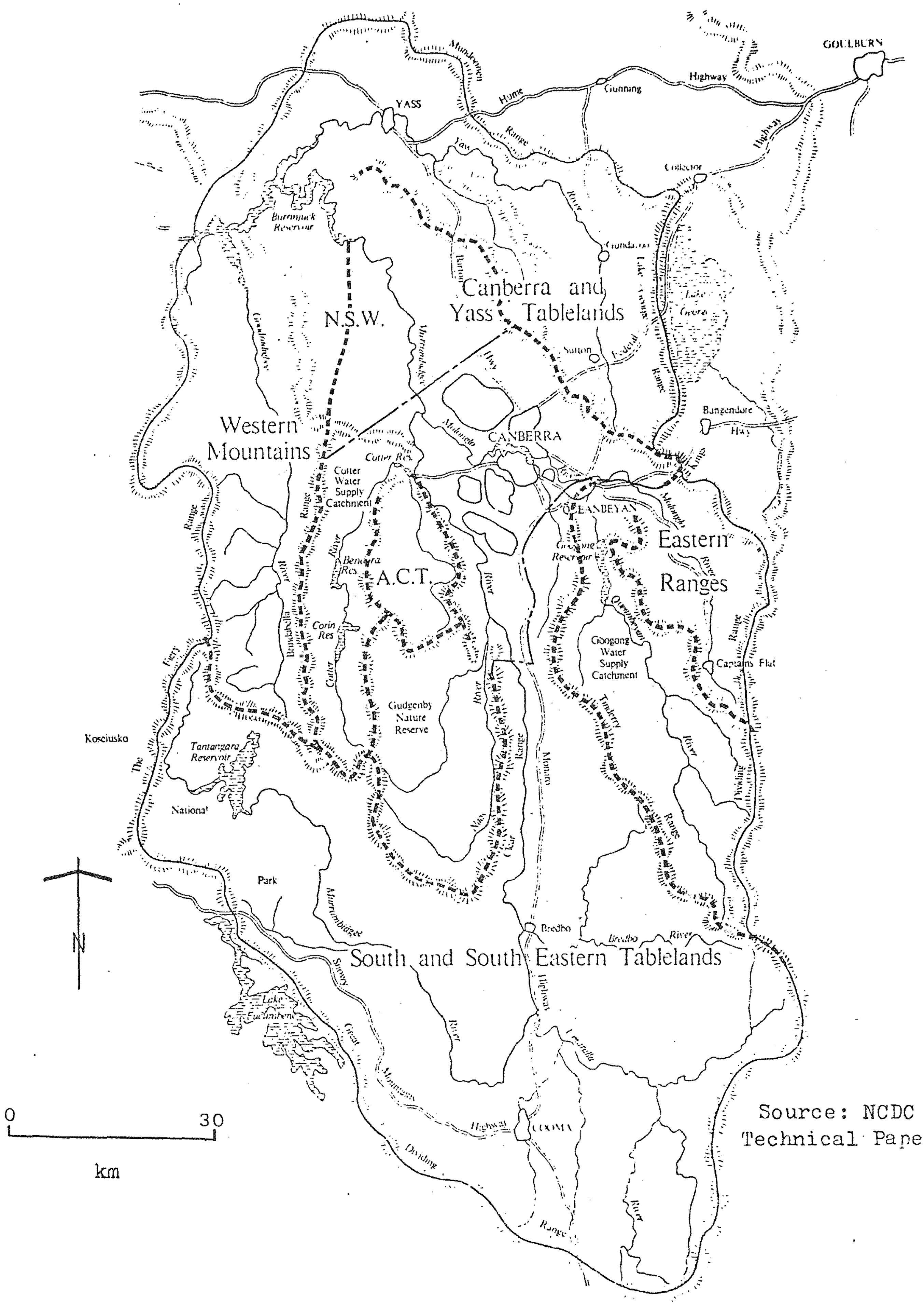
The Murrumbidgee River rises in the Kosciusko National Park in the eastern highlands of N.S.W. at an altitude of 1500m and flows in a south-easterly direction through flat subalpine country. It is dammed near its headwaters to form Tantangera Reservoir. It enters the A.C.T. at Williamsdale and turns north-west to re-enter N.S.W. near Uriarra Crossing. It then turns in a westerly direction to where it is dammed to form Burrinjuck Reservoir.

The river between Tantangera and Burrinjuck Reservoirs is approximately 260km long. Of this approximately 60km lies within the A.C.T. boundary. Its major tributaries between the two reservoirs are the Numarella and Bredbo Rivers, the Naas Gudgenby System and the Cotter and Molonglo Rivers. There are six additional water storages in the catchment between Tantangera and Burrinjuck Reservoir. Figure 1.1 illustrates the relative position of these storages and the tributaries of the upper catchment.

The area under consideration in this study will be referred to as the Upper Murrumbidgee or Burrinjuck Reservoir Catchment and covers an area of 13,000 square kilometres with the A.C.T. (an area of 2,400 square kilometers) located centrally within the basin.

The basin comprises a complex of land uses, drainage patterns, soils and vegetation each of which constitutes an important determinant

Figure 1.1 Major Water Storages and Tributaries of the Upper Murrumbidgee Catchment.



Source: NCDC 1981 Technical Paper 30

of the water quality in the alkes and streams in the region.

Three major land use patterns and vegetation types can be identified. The mountainous regions of the catchments of the Cotter, Paddy's and Goodradigbee Rivers to the west and the Queanbeyan River to the east are predominantly wet to dry sclerophyll forest. The Yass, Molonglo and Southern Murrumbidgee Catchments are predominantly rural in character while Sullivans, Yarralumla, Weston, Ginninderra and Tuggeranong Creeks are highly modified urban catchments (N.C.D.C. 1981). A more detailed outline of land use is given in Appendix 1, and a detailed description of the ecological components of the Murrumbidgee Corridor is presented in a report by Kendall (1980).

1.2 Aim of Study

The presence in the catchment of a range of land uses and a large urban area combined with increasing demands for environmental protection and recreational amenity, produces many conflicts in water quality management as attempts are made to meet the demands of many user groups.

Canberra, as a metropolitan area of relatively low density and planned with the intention of maintaining an aesthetic appeal, may be expected to perform better than most urban areas in maintaining a high level of environmental quality. Nonetheless significant changes have occured in river ecosystems within the catchment. A survey of local anglers has indicated that there has been a marked decline in a once flourishing recreational fishery. This decline has been linked to many of the changes which have occured in the catchment and the associated impacts on the river.

This paper attempts to summarize the effect rural and urban development may have on river ecosystems and their potential impact on the fishery.

The advent of European development in the Upper Murrumbidgee Basin has resulted in many concurrent changes and consequently the relative impacts of each on the fishery are difficult to disaggregate. In the past no attempt has been made to investigate them in isolation. Lack of knowledge of the fishery prior to developmental impacts makes comparison difficult. However many anglers perceived a decline in the fishery to have occured after the completion of Tantangera Reservoir in 1960, and attribute this decline to the diversion of water from the headwaters of the Murrumbidgee River and subsequent low river flows.

Therefore after the general overview is presented, flows in the Murrumbidgee River over the last fifty years are investigated in detail. River flow data from the gauging station Cotter Crossing/Mt McDonald (Station no. 410035/410738) were examined over the period dating from 1928 to determine whether any alterations to the discharge patterns could be detected which would have the potential to influence the movements spawning and/or survival of fish in the river.

1.3 The Upper Murrumbidgee Fishery - A Historical Perspective

The Murrumbidgee River and its tributaries within the Burrinjuck Catchment contain nine species of indigenous fish and at least five introduced species. These are listed in Table 1.1. The Murray Cod, trout cod and the golden, silver and Macquarie perch along with the introduced brown and rainbow trout have for many years formed the basis of a recreational fishery in the upper river catchment.

Table 1.1 Fish Species Known to Occur in the Upper Murrumbidgee Basin

Common Name	Scientific Name
	INDIGENOUS
Murray cod	*Maccullochella peeli* (Mitchell)
Trout cod	*Maccullochella macquariensis* (cuvier and valenciennes)
Golden perch	*Macquaria ambigua* (Richardson)
Silver perch	*Bidyanus bidyanus* (Mitchell)
Macquarie perch	*Macquaria australiasica* (Cuvier and Valenciennes)
River blackfish	*Gadopsis marmoratus* (Richardson)
Smelt	*Retropinna semoni* (Weber)
Western carp gudgeon	*Hypseleotris klunzingeri* (Ogilby)
Galaxids	*Galaxias* spp.
	INTRODUCED
Rainbow trout	*Salmo gairdnerii* (Richardson)
Brown trout	*Salmo trutta* (Linnaeus)
European carp	*Cyprinus carpio* (Linnaeus)
Goldfish	*Carassius auratus* (Linnaeus)
Mosquito fish	*Gambusia affinus* (Baird and Girard)

A survey was conducted by Greenham (1981) in order to determine the degree to which local anglers have perceived a change in the quality of the fishery over the years. Greenham interviewed twelve local anglers with between eighteen and fourty five years of fishing experience in the region and sought their opinions on the numbers of fish (common, some, rare or absent) of recreational species caught in the Murrumbidgee and its tributaries since 1940. There have been no other studies carried out on the recreational fishery in the area and though the categories of information in the survey conducted by Greenham are subjective they do allow comparisons to be made in the same area over time. The results are outlined in Table 1.2.

The results of the survey indicate that anglers have perceived a general decline over the years in both the numbers and size of most of the species taken.

The river blackfish has disappeared from the Murrumbidgee River though it is still present in the Cotter, Bendora and Corin Reservoirs (D.C.T. unpublished data).

Trout cod are now so rare that they are no longer an important angling species. A relict population still exists in the Murrumbidgee River in the A.C.T.

There are still viable populations of the Macquarie perch in the Murrumbidgee River and Cotter Reservoir though this species is considered under threat on an Australian wide basis as its range and abundance has been markedly reduced. They were once abundent in the Queanbeyan River. However surveys conducted by the D.C.T. have indicated a progressive decline in their numbers since the completion of Googong

Table 1.2 Relative Numbers and Size of Recreational Fish in the Upper Murrumbidgee River and its Tributaries

Key to values in table:

Numbers		Size
common	= ***	Large = L
some	= **	Small = S
rare	= *	
absent	=	
possibly present	= ?	

AREA: Murrumbidgee River - Molonglo to Burrinjuck Dam

FISH	1940's	1950's	1960's	1970's to present
Murray cod	***,L	***,L	***,L	**,S
Trout cod	*,S	*,S		
Golden perch			*,L (from late 1960's)	*,L
Silver perch	***,S-L	***,S-L	**,L	*,L
Macquarie perch	***,S-L	***,S-L	**,S-L	*,L
River blackfish	**,S	**,S	*,S	
Rainbow trout [(a)]	***,L	***,L	**,S	
Brown trout [(a)]	***,L	***,L	**,S	

a = normally more common in spring and autumn from migration from Burrinjuck Dam

AREA: Murrumbidgee River - Molonglo to Tharwa

FISH	1940's	1950's	1960's	1970's to present
Murray cod	***,S-L	***,S-L	**,S-L	*,S
Trout cod	**,S	**,S	**,S	*,S
Golden perch				*,S
Silver perch	***,S-L	***,S-L	**,S-L	*,L
Macquarie perch	***,S-L	***,S-L	**,S-L	*,S-L
River blackfish	**,S	**,S	*,S	
Rainbow trout [(a)]	***,S-L	***,S-L	**,S	*,S
Brown trout [(a)]	***,S-L	***,S-L	**,S	*,S

Table 1.2 con't

AREA: Cotter River

FISH	1940's	1950's	1960's	1970's to present
Murray cod	**,S	**,S	*,S	*,S
Trout cod				
Golden perch				
Silver perch	*,S	*,S	*,S	
Macquarie perch	***,S-L	**,S-L	**,S-L	*,S
River blackfish	*,S	*,S	*,S	
Rainbow trout [a]	***,S-L	***,S-L	**,S-L	*,S
Brown trout [a]	***,S-L	***,S-L	**,S-L	*,S

a = normally more common in spring and autumn from migration from Burrinjuck Dam

AREA: Molonglo River [b]

FISH	1940's	1950's	1960's	1970's to present
Murray cod	**,S	**,S	*,S	*,S [c]
Trout cod				
Golden perch				
Silver perch	**,	**,		
Macquarie perch	**,	*,		
River blackfish				
Rainbow trout	**,S-L	**,S-L	**,S-L	*,S-L [d]
Brown trout	**,S-L	**,S-L	**,S-L	*,S-L [d]

(b) = lowest reaches only. Upper reaches polluted from Captains Flat mine

(c) = absent through most of 1970's due to effects of sewage effluenc from Weston Creek

(d) = in and below Lake Burley Griffin.

Table 1.2 con't

AREA: Queanbeyan River (Excluding Googong Reservoir)

FISH	1940's	1950's	1960's	1970's to present
Murray cod	*,S	*,S		
Trout cod				
Golden perch				
Silver perch				
Macquarie perch	**,S-L	**,S-L	*,S-L	*,S-L
River blackfish				
Rainbow trout	***,S-L	***,S-L	**,S-L	*,S
Brown trout	***,S-L	***,S-L	**,S-L	*,S

AREA: Naas/Gudgenby River

FISH	1940's	1950's	1960's	1970's to present
Murray cod				
Trout cod				
Golden perch				
Silver perch	?	?	?	?
Macquarie perch		?	?	?
River blackfish	?			
Rainbow trout	***,S-L	***,S-L	**,S	*,S
Brown trout	**,S-L	**,S-L	**,S-L	*,S

Table 1.2 con't

AREA: Paddy's River

FISH	1940's	1950's	1960's	1970's to present
Murray cod	?	?	?	?
Trout cod				
Golden perch				
Silver perch	?	?	?	
Macquarie perch	**,S-L	**,S-L	**,S-L	*,S
River blackfish	?	?	?	
Rainbow trout	***,S-L	***,S-L	**,S	*,S
Brown trout	***,S-L	***,S-L	**,S	*,S

Source: Greenham, P. (1981)

Reservoir (1976). This decline has been attributed to breeding failure caused by the flooding of spawning sites. No Macquarie perch have been reported from the reservoir since 1980 (D.C.T. unpublished data).

Discussion with local anglers has indicated that golden perch were once present in the Upper Murrumbidgee River. The construction of the dam wall at Burrinjuck (1912) blocked the upstream movements of this highly migratory species, and numbers in the upper reaches of the river declined.

Since the early 1970's however, golden perch have again appeared in significant numbers in the river above the reservoir. Stocking of Burrinjuck Reservoir by N.S.W. State Fisheries has contributed to the re-emergence of golden perch as a significant angling species in the Upper Murrumbidgee. The Department of Territories and Local Government has stocked golden perch in Lake Burley Griffin and Lake Ginninderra. Lake Burley Griffin fish have probably contributed to the stocks in the Murrumbidgee as fish are known to enter the Molonglo below Scrivener Dam when water is released through off take valves. Golden perch have also been stocked in Googong Reservoir in 1981.

The European carp has become prevalent in the Murrumbidgee River above Burrinjuck since about 1976. This species is not considered favourably by anglers in this country (except among the migrant population) though it is a popular angling species and/or food source in parts of Europe and Asia.

1.4 Value of the Recreational Fishery

Fishing is an important recreational activity and with the continued creation of inland impoundments lentic freshwater fisheries can be expected to play an increasingly important recreational role.

A survey commissioned by N.S.W. State Fisheries and conducted by McNair Anderson Associates in May 1977 showed that thirty per cent of N.S.W. residents aged thirteen and over go fishing at least once a year. The results of an opinion poll in Victoria indicated that about thirty six per cent of that States population go fishing at least once a year (Beinssen 1978). The results of a creel survey at Lake Eucumbene, N.S.W., showed that 579,000 man hours were spent fishing during the 1970-1971 season (Richard Tilzey, unpublished data). A survey of inland angling conducted by Collins (1976) revealed that sixty six per cent of freshwater fishing effort in N.S.W. was directed towards trout, twenty seven per cent towards warm water native fish, such as Murray cod, golden perch and the freshwater catfish (*Tandanus tandanus*) and seven per cent towards the Australian bass (*Macquaria novemaculeata*). This survey also indicated an overall annual expenditure of almost five hundred dollars per angler. Undoubtedly many millions of dollars are devoted to the sport of recreational fishing in the form of tackle purchase and upkeep, boat hire, transport and accommodation costs, fishing club dues etc.

In the 1981/82 financial year N.S.W. State Fisheries issued 73,746 full season licences and 27,768 twenty one day licenses, and received half a million dollars in revenue from license sales (N.S.W. State Fisheries Public Relations Section).

If each of the anglers who purchased a full season license spent five hundred dollars per annum on the sport then in N.S.W. alone the inland recreational fishing industry would be worth in excess of thirty six million dollars.

The conservation of habitat to maintain a recreational fishery can therefore be justified on economic grounds. However more importantly it should be realised that many of the indigenous freshwater fish fauna are unique to the Australian continent and are of considerable scientific and aesthetic merit. These reasons alone should provide sufficient justification for the protection of the fish species and their related ecosystems.

CHAPTER 2

CHANGES IN CATCHMENT CHARACTERISTICS

The decline in the recreational fishery is a trend which has been consistent throughout the Murray-Darling System (Cadwallader 1978) and may be attributed to a large extent to the physical changes brought about with the advent of European settlement.

The Murrumbidgee Catchment has been altered over the years by the clearing of native vegetation for forestry and farming practices, the construction of dams and weirs, urbanization, industrial development and increased abstraction of water for agricultural and industrial use. Associated with urbanization has been the establishment of sewerage plants which discharge effluent into the river, and the increased intensity of recreational usage which can have negative effects on the aquatic environment.

The shift from a catchment which is covered by native vegetation to one which is essentially rural and urban in character, and the alterations to the environment that this entails has the potential to influence the quality and quantity of native fish habitat in a number of ways:

(i) Increased sediment loads and siltation.

(ii) Nutrient enrichment and oxygen depletion to lakes and streams.

(iii) Deterioration in water quality due to increased pollution loads from industrial, rural and urban sources.

(iv) Alterations to thermal regimes.

(v) The construction of dams and weirs.

(vi) Changes in total volume of river flow and flow patterns.

Apart from the alterations outlined below, an increasing population with increased access to local water bodies increases the potential for overfishing, illegal fishing, and for the introduction of exotic species.

The potential impact of the above factors on a fishery is reviewed in this chapter.

2.1 Sediment Loads and Siltation

The extent ot which urbanization has contributed to sediment loads in rivers and streams is reported in numerous studies (Bryan, 1972, Beer et al, 1982, Dawdy, 1967, Wolman, 1964, Wolman, 1967). With a change from rural to urban land use there is an enormous increase in the sediment loads carried by streams during the construction phase of development.

Estimates by Wolman (1964) showed that the sediment yields in small urbanizing developed or industrial areas are ten to one hundred times that experienced in rural areas. He also states that sediment derived by erosion form an acre of ground under construction in developments and for highways may exceed by twenty thousand to forty thousand times the amount eroded from farms and woodlands in an equivalent period.

Since sediment load is proportional to discharge and the number of high flows is increased in urban areas, urbanization compounds the problem of sedimentation.

The clearing of native vegetation for pastures and stock grazing can result in a significant increase in sediment loads on a river. In some cases exports from rural catchments can far exceed those in urban areas (Figure 2.1). Figure 2.2 illustrates the potential sediment exports for different forms of land use.

Since the 1830's the Canberra Region has had a history of land use dominated by sheep and cattle grazing on natural and improved pasture. Tree cover has been reduced, new pasture grasses introduced and fertilizers used for pasture improvements. Intermittent droughts, overgrazing and rabbit plagues have led to accelerated erosion and sedimentation of rivers. The grazing of cattle and sheep are the land uses which occupy over fifty per cent of the basin (N.C.D.C. 1981) and is commonly practiced in the tablelands and major river valleys where topography and climate are most favourable.

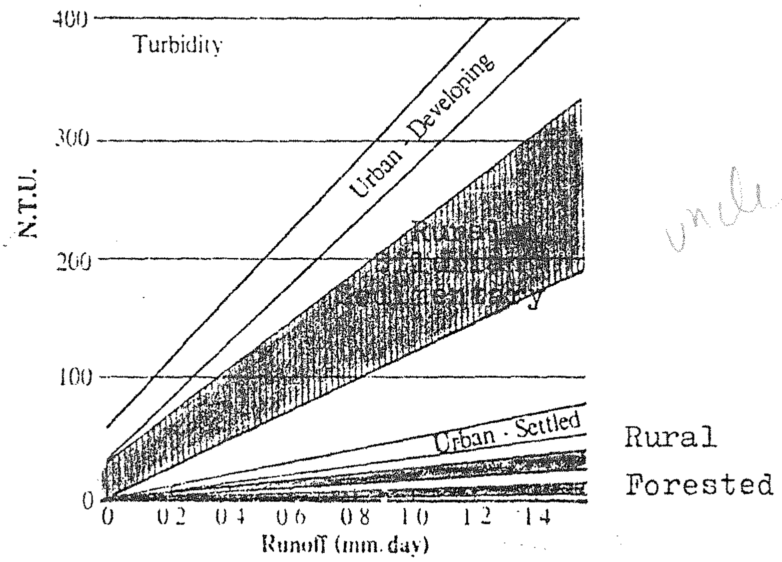
Heavy rainfalls which follow drought periods, during which vegetative cover is reduced, result in deposition of large amounts of sediment in a river.

Though urbanized areas represent only a relatively small part of the catchment in terms of area (Appendix 1), the proportionate effects are larger than for other forms of land use, especially in the development stage.

The Murrumbidgee in its upper basin experiences runoff from the urban catchments of Tuggeranong and Ginninderra Creeks. Beer et al (1980) estimated that a three year flood in Tuggeranong Creek, which occured in January 1980, deposited between 1300-2500 tonnes of sediment in Kambah Pool, a popular fishing hole and recreational area on the Murrumbidgee River.

Though empirical evidence is lacking siltation of rivers and streams is one of the more obvious changes that has occured in the

Figure 2.1 Turbidity Generated in Catchments Under Different Forms of Land Use.

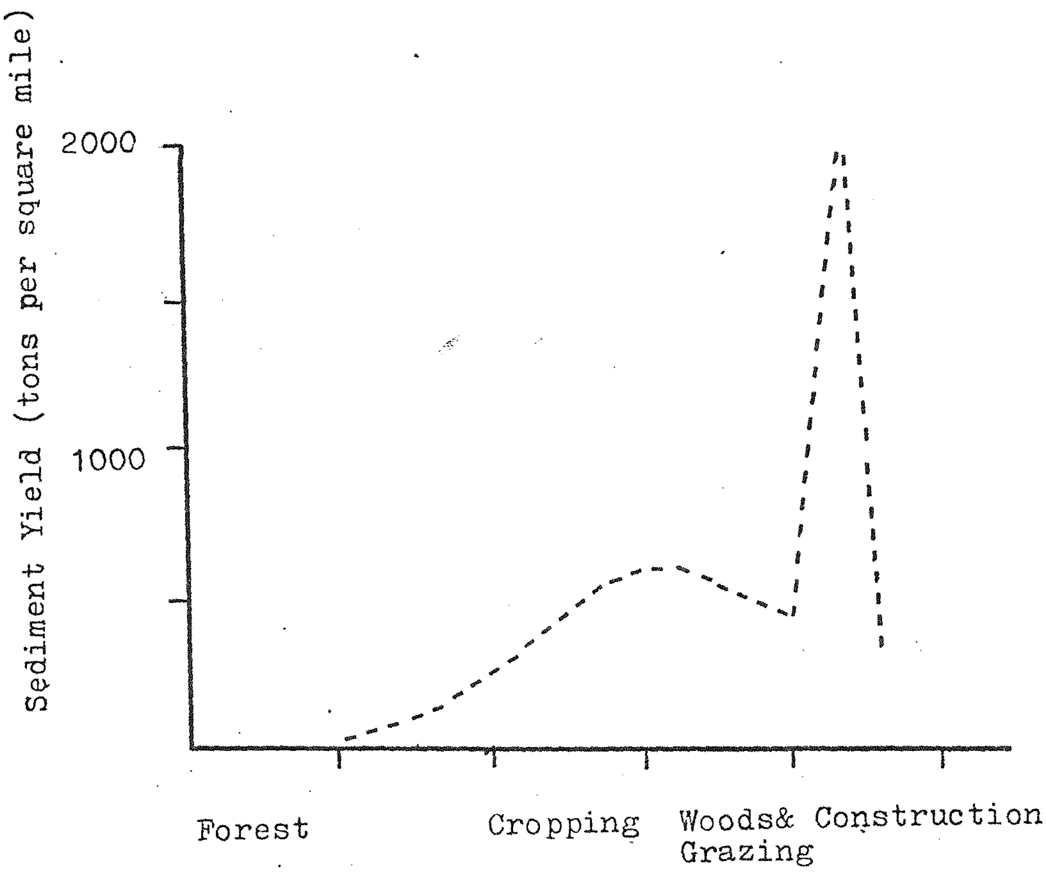


N.T.U. = National Turbidity Units

Source: N.C.D.C. 1981 Technical Paper 30.

Figure 2.2 Sediment Yields Under Different Forms of Land Use.

—But for humid temperate landscapes? or tropical?



Source: Adapted from Wolman (1967).

catchment over the years. Observation of the Murrumbidgee River before and after storm events provides visual evidence of differences which occur depending on what part of the river is being observed. Waters below Tuggeranong Creek exhibit higher turbidities over longer periods.

There is little doubt that rural and urban development in the Upper Murrumbidgee Catchment has resulted in substantial siltation in the waters of the region.

Sedimentation and the resultant turbidity associated with the process can have negative effects on a fishery. Siltation reduces the habitat available to fish species such as the Murray cod and Macquarie perch by filling in deep holes in the river. Solids settling out of suspension will cover gravel beds which serve as spawning sites for species such as the Macquarie perch and trout.

Large amounts of suspended solids will kill sensitive species of fish and reduce the growth rate and resistance to disease of others. Silt may also stick to pelagic eggs and kill them by preventing the efficient exchange of respiratory gases. Suspended sediments may interfere with the filter feeding apparatus of planktonic organisms and smother bottom dwelling organisms both of which act as food sources for stream and river dwelling fish. Alabaster and Lloyd (1980) review the effects of finely divided solids on fish and suggest limits for various species.

The efficiency of catching fish by various angling techniques is reduced in turbid conditions with obvious implications for the recreational fishery.

2.2 Nutrient Enrichment

The amount of nitrogen and phosphorous exported in runoff to lakes and streams varies considerably according to the land use prevalent in the catchment area.

Quantitative estimates of phosphorous and nitrogen exports from land in forested, rural and urban catchments have been made by a number of investigators. Representative studies include those by McColl, (1979). Sharpley and Syers (1979), Olness et al, (1980), and Costin, (1980) for pastures and Menzel et al, (1978), Micholaichuck and Read, (1978), and Holmes, (1978) for cropped land. Forested catchments have been studied by Uttormark, (1974) and Hobby and Likens, (1973). Studies in urban areas include those by Kluesnar and Lee, (1974), Cordery, (1976), Cullen and Rosich, (1979), Rosich and Cullen, (1981), and Gutteridge, Haskins and Davey in conjunction with the Environmental Protection Authority of Victoria (1981).

A comparison of total phosphorous exports for different forms of land use is shown in Figure 2.3 and Table 2.1 indicates values reported for three forms of land use from studies carried out in the local area. From Table 2.1 it can be seen that levels for forested areas are consistently lower than for other forms of land use.

Apart from nutrients carried by runoff, heavy nutrient enrichment may occur due to point sources of pollution. Major point sources of nutrients occur from the Canberra Abattoir and the Queanbeyan Sewerage Treatment Works both of which cause enrichment of the Molonglo River which enters the Murrumbidgee River.

Table 2.1 Phosphorous Exports from Forested, Rural and Urban Catchments.

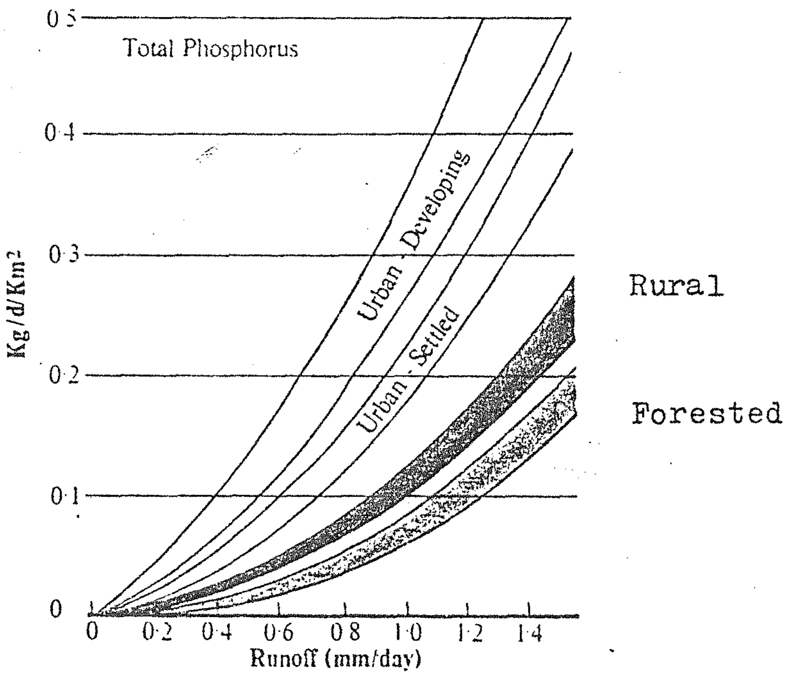
		Forest		Rural		Urban	
		Medium to Low Flow	Flood Flow	Medium to Low Flow	Flood Flow	Medium to Low Flow	Flood Flow
Total Phosphorous (kg/ km^2 day)	1.			.002 - .007	0.37-2.25	0.05-0.10	0.30-0.60
	2.	.001-.022	.073	.001 - .077	0.99-5.20	0.01-0.06	0.20-0.74
	3.					0.03-0.10	0.35-0.47

1. Cullen Rosich and Bek (1978)

2. ACT Region Water Quality Study (1978)

3. Lake Ginninderra Water Quality Study (1978)

Figure 2.3 Total Phosphorous Contained in Runoff From Forested, Rural and Urban Catchments.



Source: N.C.D.C. 1981 Technical Paper 30.

The enrichment of rivers and lakes with surplus nutrients results in excessive weed growth and nuisance algal blooms. These were in evidence when the Weston Creek Sewerage Treatment Works (W.C.S.T.W.) was in operation. In the Murrumbidgee River, pools downstream from this operation were covered by thick algal mats (N.C.D.C. 1981). With buildup of excessive organic matter disagreeable tastes and odours develop and oxygen depletion may occur. Since all living organisms require oxygen in order to survive species sensitive to depleted oxygen levels tend to die out, species diversity is reduced and desirable fish species are replaced by less desirable but more tolerant species (European carp eg.). The hydrological and recreational amenity is therefore reduced.

The commissioning of the Lower Molonglo Water Quality Centre (L.M.W.Q.C.C.) in 1978 has alleviated many of the problems created by nutrient enrichment associated with the W.C.S.T.W.

However even sewerage which is treated to remove nitrogen and phosphorous has residual concentrations of these minerals and some enrochment of waters downstream of the Molonglo confluence still occurs, though the major algal mats of the past are no longer in evidence and aquatic macrophytes are once again dominant. Algal blooms are still a feature of Lake Burley Griffin and Burrinjuck Reservoir. (Molonglo-Murrumbidgee-Burrinjuck Seasonal Water Quality Summary Spring 1981 - Summer 1982).

Nutrient enrichment provides a favourable environment for the proliferation of microorganisms which are pathogenic to fish. Under conditions of nutrient enrichment the susceptibility of fish to disease may be increased (Alabaster and Lloyd 1980).

2.3 Chemical Pollution

Synthetic organic chemicals include organic pesticides, detergents and certain industrial chemicals. These are all potentially toxic to aquatic flora and fauna and can exert both lethal and sub-lethal effects. Long term toxic effects produced by chronic exposure over a number of years cannot be assessed.

Inorganic chemicals and other mineral substances such as metal salts and acids derived from mining, manufacturing and agricultural practices can destroy aquatic life and cause excessive hardness of water supplies.

The extent to which organic and inorganic chemicals pose a problem in the Murrumbidgee River is unknown as no monitoring is undertaken in the area under consideration.

It is of course impossible to monitor a water body for every known toxic substance. However water managers should be fully aware of the nature and sources of pollutants entering the rivers. This can be achieved by requiring those who discharge into the river to obtain a licence thereby allowing a register of likely pollutants to be available. Periodic monitoring for known toxicants can then be carried out to ensure safe levels are not exceeded.

The Water Pollution Ordinance currently being drafted for the ACT will require those who discharge into the waterways to have a licence. Where possible however discharges will be made to the sewer system.

The effects of various chemicals on aquatic fauna is reviewed by Hart (1974), and on the best available evidence, safe standards recommended. However, in many cases these levels are reported as a proportion of the fifty per cent lethal concentrations (LC50's). The LC50's have not yet been determined for the indigenous fish species for most of the chemicals mentioned.

Mine waste pollution from the Captains Flat workings has adversely affected the Molonglo River below Captain's Flat for drinking water, stock watering and irrigation (Joint Government Technical Committee on Mine Waste Pollution of the Molonglo River 1974). Contamination by heavy metal salts and the acidifying of the river water resulted in a significant reduction in diversity and abundance of flora and fauna (Weatherly et al 1967). Minor floods in 1939, 1942 and 1945 resulted in the collapse of mine waste dams and the discharge of polluted materials into the Molonglo River causing extensive damage to downstream pastures.

Remedial works were undertaken in the late 1970's and a follow up survey of macroinvertebrates and monitoring of heavy metal contamination in the river water and sediments is currently being undertaken by the C.C.A.E.

The extent of damage to the fishery in this section of river is unknown.

Chlorine is used to treat effluent from the L.M.W.Q.C.C. The degree to which chlorine residuals have affected the fishery has not been ascertained.

A report presented to the Parent Interdepartmental Committee on Environmental Quality in May 1981 assesses the potential impact of chlorine on freshwater fish.

2.4 Alterations to Thermal Regimes

The construction of dams and weirs, ponding, clear felling of vegetation along stream and river channels, the obstruction of the inflow of snow fed waters and the dishcarge of sewerage effluent all influence the thermal regime of a river.

Impounded waters tend to stratify during summer months with the lower layers of reservoirs becoming colder and oxygen depleted compared to surface waters.

Release of cold oxygen depleted waters from deep reservoirs may have a serious effect on fish populations downstream.

Sudden releases of cold water into warmer receiving waters to which animals are acclimated can produce physiological stress and interfere with the breeding behaviour and survival of young.

The thermal tolerance of Australian freshwater native fish have not been assessed. The degree to which the dams constructed in the area influence thermal regimes in the river in months when breeding is likely to occur has not been investigated.

Effluents from sewerage treatment plants can have a significant effect on river water temperature especially during low flows. The temperature of sewerage effluent from the L.M.W.Q.C.C. can be up to 8°C higher than the receiving waters and in low flow periods cause an increase in river temperature of up to 6°C (Philp 1982). The impact of the increased river water temperature on fish in the Murrumbidgee River is not known.

The effect of increased temperatures brought about by effluent from power plants is reviewed by Castenholz and Wickstrom (1975).

Removal of bank vegetation and clear felling of forests can also alter the thermal characteristics of a water body as areas of cooler microhabitat created by overhanging vegetation are destroyed.

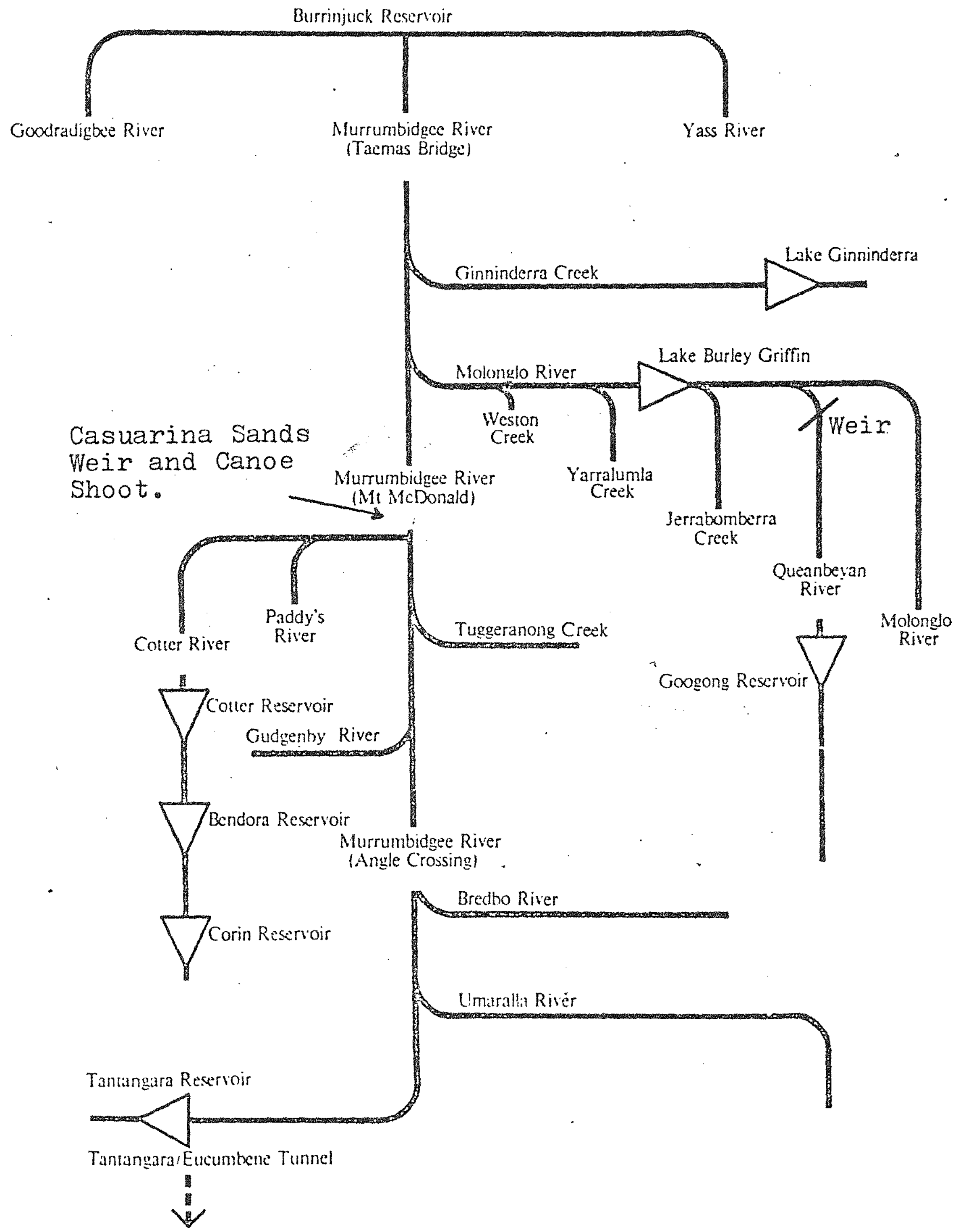
2.5 Construction of Dams and Weirs

Dams, weirs, causeways and flood gates built for a variety of purposes will prevent the free passage of fish from one part of a river system to another. This has important implications for mobile fish populations especially those which require access to streams from lentic habitats for breeding. Dams tend to isolate fish in a certain section of river and prevent movement into more favourable environments should local conditions become unfavourable for certain periods of time, as in the case of a severe regional drought for example.

The location of the major barriers to movement in the Upper Murrumbidgee are shown in Figure 2.4. It is believed that fish migrate from Burrinjuck Reservoir on annual spawning runs. The numbers and extent of these movements of native fish in the river have not been investigated. Though it is theoretically possible for fish to move from Burrinjuck past two weirs at Casuarina Sands, the efficiency of these fish passages is difficult to assess given the lack of knowledge concerning the numbers and swimming capabilities of native fish moving in the river.

Scrivener Dam prevents movements of fish from the Murrumbidgee into the Molonglo past L.B.G. Googong Reservoir and a low level weir on the Queanbeyan River near its confluence with the Molonglo obstruct movements into the Queanbeyan River. Fish in L.B.G. which require access

Figure 2.4 Major Barriers to Fish Movements in the Upper Murrumbidgee Catchment.



Source N.D.C.D. 1981 Technical Paper 30.

to breeding streams have little scope for movement. A low level crossing also exists at Sutton Road bridge on the Molonglo River and prevents fish from moving into and recolonizing this section of river which has suffered the pollution episodes from the Captain's Flat workings.

Though dams can exert detrimental effects on a fishery by altering thermal regimes as discussed in Section 2.4, or by flooding spawning sites and posing barriers to movement, they may, depending on their position in the catchment, promote a better fishery because of their high carrying capacity compared to river ecosystems. Burrinjuck Reservoir for example has probably contributed to a better river fishery upstream as fish removed from the river area are replenished from this source. It also serves as a reservoir for fish stocks during times of drought and there are sufficient inflowing streams which meet the breeding requirements for the fish species present. However it has probably had a negative impact on the downstream fishery due to a reduction in river flows and the release of cold water from low level offtakes during times when native fish would be expected to spawn in the river.

2.6 Fishing Pressure

The extent to which the stocks of fish in the Upper Murrumbidgee River are exploited by amateur anglers is not known as the prerequisite studies have not been carried out. The numbers of fish in the river may well be seasonal in occurrence and related to spawning runs. Since the reservoir at Burrinjuck is believed to be the source of fish movements into the river the status of the river fishery will be to some extent dependent on the status of the Burrinjuck Reservoir fishery. However the extent to which fish migrating from Burrinjuck are likely to use the Murrumbidgee will be dependent on favourable river conditions and therefore investigations of river stocks would prove useful.

There is a general misconception among many people that angling is an inefficient method of exploiting fish stocks and therefore not likely to result in a significant reduction in population numbers. However it has been shown that heavy angling pressure has the potential to severely reduce fish stocks. This will be especially true in rivers where the carrying capacity is low. Cooper and Wheatley (1981) estimated the rate of exploitation of the fishery by anglers on the River Trent in the U.K., under conditions where all fish caught by anglers are returned to the water. They estimated that under the fishing pressure the river was likely to experience, the rate of exploitation was 94% and stated that

> "virtually every fish available to the angler is, on average, likely to be caught once although in reality some fish are caught several times a year while others remain uncaught."

Many species of fish are rendered extremely vulnerable to angling pressure due to behaviour which tends to aggregate them in limited areas at certain times of the year. This usually occurs during spawning and is true of Macquarie perch and rainbow and brown trout.

It is logical to assume that with increased access to the Murrumbidgee River and increased population growth in the Canberra region that there has been an increase in the intensity of exploitation of fish stocks in the area under consideration.

Some indication of the fishing pressure can be gained from a tagging program conducted by the D.C.T. Of fifty five Murray cod tagged in the river a total of eight tags (14.5%) have been returned by anglers. In one popular pool in the river at Casuarina Sands three out of four Murray cod tagged in the hole were returned by anglers. Tag returns for one hundred and fourty seven fish of all species tagged to the end of

October 1982 run at 8.2% and these estimates do not take into account mortality from tagging, unreturned tags and tags lost from fish or rendered illegible (DCT unpublished data).

The extent to which illegal fishing contributes to the exploitation of fish stocks is unknown.

2.7 Introduced Species

Four species of introduced fish have established self sustaining populations in the Upper Murrumbidgee Catchment.

The rainbow and brown trout were introduced by early settlers in the area in order to establish a recreational fishery though the exact date and place of releases has not been well documented.

Gambusia and goldfish also occur in the region though the history of their introduction is not well established.

The European carp were first reported above Burrinjuck Reservoir in 1976. They were first taken from Lake Ginninderra in 1978 and are present in the Queanbeyan River System but to date do not occur in Googong Reservoir. They are now well distributed throughout the Murrumbidgee River and its tributaries upstream of Burrinjuck, where waters are suitable.

The redfin perch (*Perca fluviatilis*) has been recorded in L.B.G. on two occasions in the past ten years but have not established a population in the lake to date though self sustaining populations are known to exist in at least two dams within the Catchment.

Studies conducted overseas have provided some evidence that introduced species may have an adverse effect on the local fish fauna. Information on the effects introductions into this country have had however are fragmentary due to the lack of prior knowledge of the local flora and fauna and the many changes in land uses which have occured over the years.

The interactions between introduced and native fish species have been reviewed by Cadwallader (1978), Tilzey (1980) and Jackson (1981) and the brief summary which follows is drawn from these sources.

There is some evidence that trout have fragmented the range of some species of galaxiids in the Seven Creeks System in Victoria and the Eucumbene Catchment in N.S.W.

Trout are predators on small Macquarie perch, river blackfish and trout cod and the fry of other native species and there is considerable overlap in the diets of trout and some of the native species. Apart from the competition for food there may also be competition for space on the stream floor between trout cod and trout, for example, both of which exhibit territorial behaviour.

Habitat modifications may occur due to the presence of an introduced species which may render the environment less suitable for the local fauna. European carp may destabilize weed beds and create turbidity problems due to their spawning and feeding habits. It has also been reported that Gambusia affinis can reduce rotifer crustacean and insect populations allowing large numbers of phytoplankton to develop.

Gambusia reduce survival of native fish fry stocked in farm dams and presumably will have a similar effect in larger water bodies (Barlow 1983).

Stocking of native fish in reservoirs dominated by redfin results in large losses due to heavy predation on fry.

On the whole the interactions which occur between native and introduced species of fish have not been investigated and are not well understood.

2.8 River Flows and Runoff Volumes

Changes in land use and the construction of dams and weirs alter the volumes of runoff and patterns of flow in a river.

The total volume of runoff is governed by the infiltration characteristics of the surface over which it flows. This will be related to the type of vegetative cover and the percentage of the catchment covered in impervious surfaces. Generally both the total volume of runoff and the size of the flood peak are increased especially in urbanized catchments where large areas are covered with impermeable surfaces. Cordery (1976) showed that floods with a return period of one year are frequently increased to three times the pre-urbanized discharge level with smaller floods being influenced most.

Cordery (1976) also reports that total runoff volumes from urbanized catchments may be increased by up to two times though there is considerable variability due to differences in land use and physiography.

Since the percentage of direct runoff is increased in urban conditions, less water is available for soil moisture replenishment and ground water storage. This results in decreased low flows between storms.

A study which was conducted by the Department of Housing and Construction for the National Capital Development Commission (N.C.D.C. 1980) compared the runoff characteristics of paired rural and urban catchments (112 and 94ha respectively) in the Belconnen area of the A.C.T. in order to investigate the effects of urbanization.

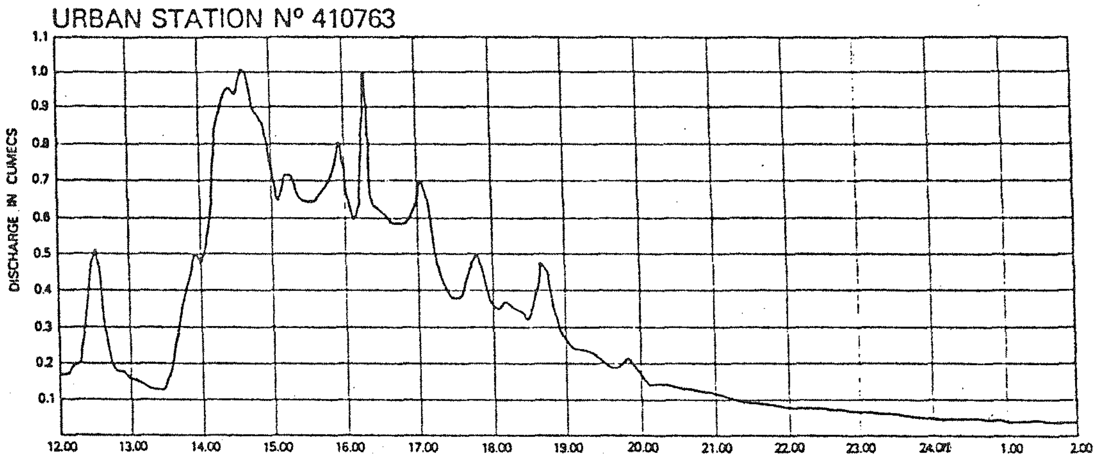
Figure 2.5 shows the hydrograph in the catchments for similar rainfall events. From this graph, one of the effects of urbanization is clearly evident. The flood peak in the urban catchment arrives earlier and is of greater magnitude than that in the rural catchment.

When monthly discharges are compared, it can be seen from Figure 2.6 that much more rainfall appeared as runoff in the urban station though rainfall patterns were shown to be similar.

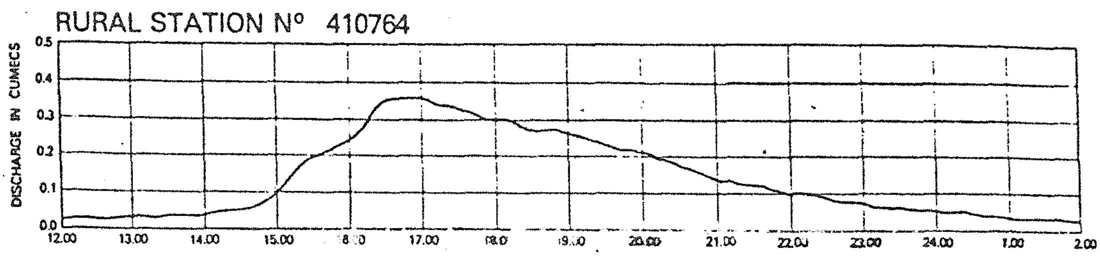
The construction of dams will also change patterns of river flow. The magnitude of the flood peak discharge is reduced as water is stored and flows are spread over longer periods. By retarding flow and creating large surface areas over which evaporation can occur the total volume of water flowing downstream may be reduced.

The Upper Murrumbidgee Basin has been subject to the influence of ruralization, urbanization and the construction of a number of dams and weirs. The alterations which have occured to patterns of flow in this section of river and the likely impacts on fish movements is the subject of the following chapters.

Figure 2.5 A Comparison of the Hydrographs in Paired Urban and Rural Catchments for the Same Rainfall Event.



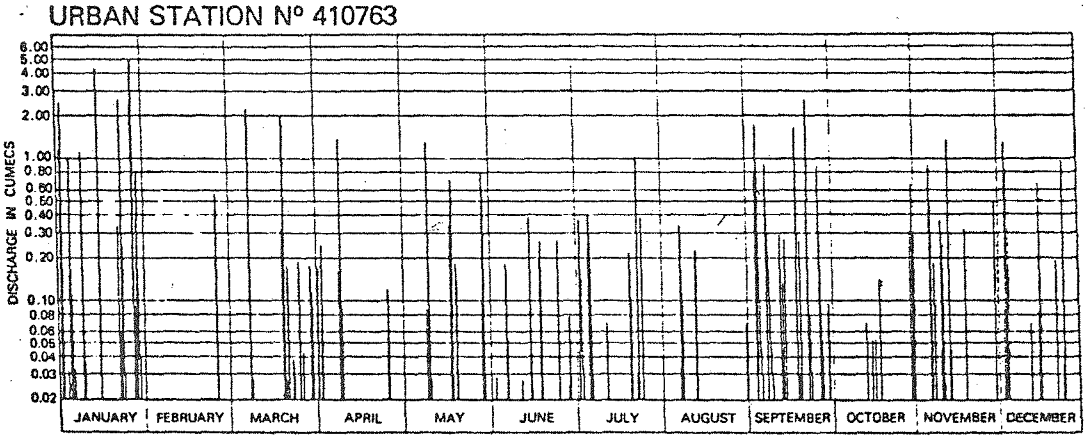
Time



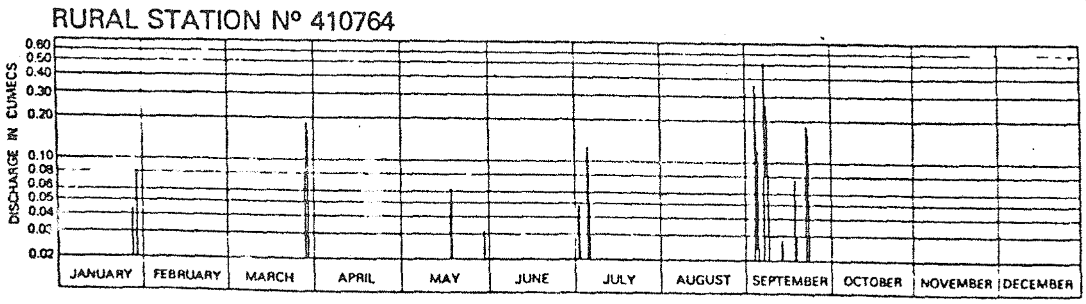
Time

Source: N.C.D.C. 1980 Technical Paper 29.

Figure 2.6 A Comparison of Daily Discharges During 1978 for Paired Urban and Rural Catchments for the Same Rainfall Events.



Month



Month

Source: N.C.D.C. 1980 Technical Paper 29.

CHAPTER 3

RESPONSE OF FISH TO RIVER FLOW

3.1 Native Species

Temperature and river height have both been shown to be important in influencing the movements of fish in a river.

From the records of fish passing through a trap in a river channel it is possible to determine the key months during which migrations take place.

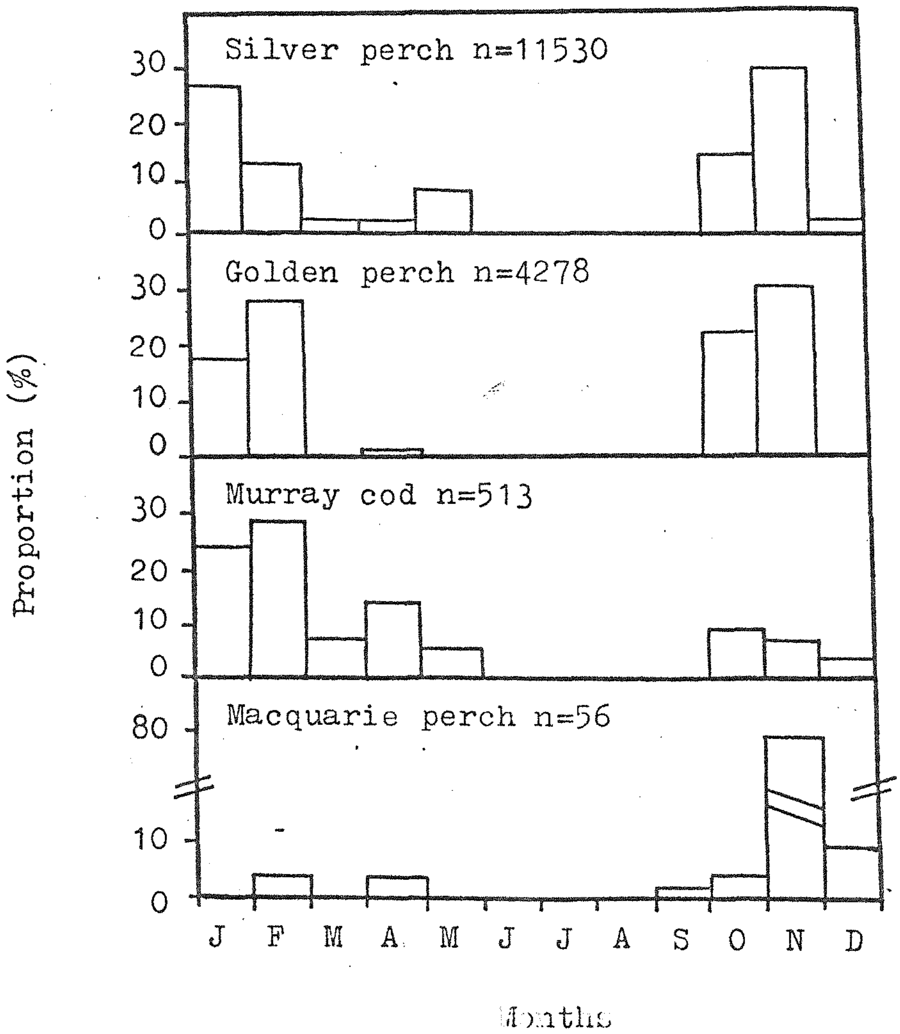
Figure 3.1 indicates the proportion of fish passing through a fish ladder on the Murray River each month between 28 May 1938 and 7 November 1942, as a percentage of the total number of fish of that species passing through (Cadwallader 1977). From these records it is clear that the major fish movements in the river occur in November for the Macquarie perch and in October, November, January and February for silver perch, golden perch and Murray cod. A trap operated at Casuarina Sands in the Upper Murrumbidgee Basin show similar monthly movements of the various species to occur though the numbers of fish observed are small (DCT unpublished data).

A study carried out in South Australia (South Australian Fisheries Industry Council 1976) found that peaks in commercial catches of golden perch corresponded to flooding three or four years previously. Strong year classes were shown to be related to spawnings which had occured in flood years (Figure 3.2).

Lake (1967) showed that spawning of golden perch required a rise

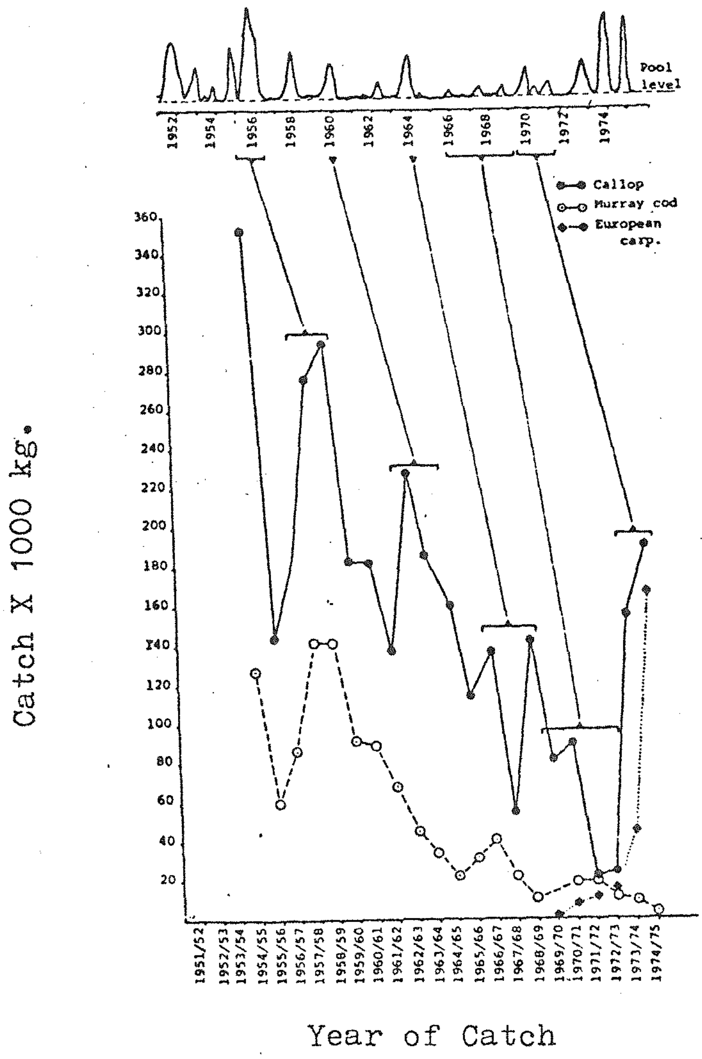
Figure 3.1 Proportion of Fish Passing Through a Fish Ladder on the Murray River in Each Month as a Percentage of the Total Number of That Species Passing Through Between May 1938 and November 1942.

n = Total number of fish



Source: Cadwallader (1977)

Figure 3.2 Commercial Freshwater Fish Catches in the Murray River Showing The Influence of River Levels on Catches of Golden Perch.



Source: South Australian Fisheries Industry Council May 1976 No. 8

in water level as well as a temperature in excess of 23°C. Floods which occur at unsuitable water temperatures would not therefore lead to recruitment to stocks. Floods which occur in months in which spawning temperatures are suitable for the species may be crucial in maintaining the population at a high level.

Llewellyn (1968) showed that movements of golden perch in the Murrumbidgee River could be related to river height. Figure 3.3 shows the relationship between river height and the upstream movements of golden perch. Most fish moved during a four day period when the river was at its peak. It was also found that fewer fish moved when the rise in river level occurred during winter.

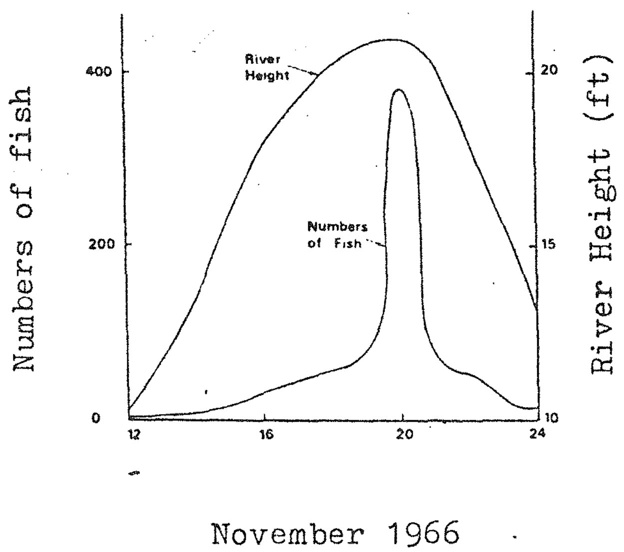
The spawning and movements of golden perch and possibly other species appear to be related to rises in river levels. Consequently any alterations to the frequency or severity of flooding may influence the spawning success of certain species.

River levels at Morgan Wharf from 1892-1974 (Figure 3.4) shows the influence of the construction of a lock in 1922. Between 1890-1922 there was a significant rise in river level each year. After the construction of the lock the annual high/low water cycle was replaced by median levels punctuated by floods. Often several years would pass without a significant rise in river level. Species which require rises in water levels to induce significant spawning may be disadvantaged reproductively by construction of structures such a locks, dams and weirs which regulate river flows.

3.2 Trout

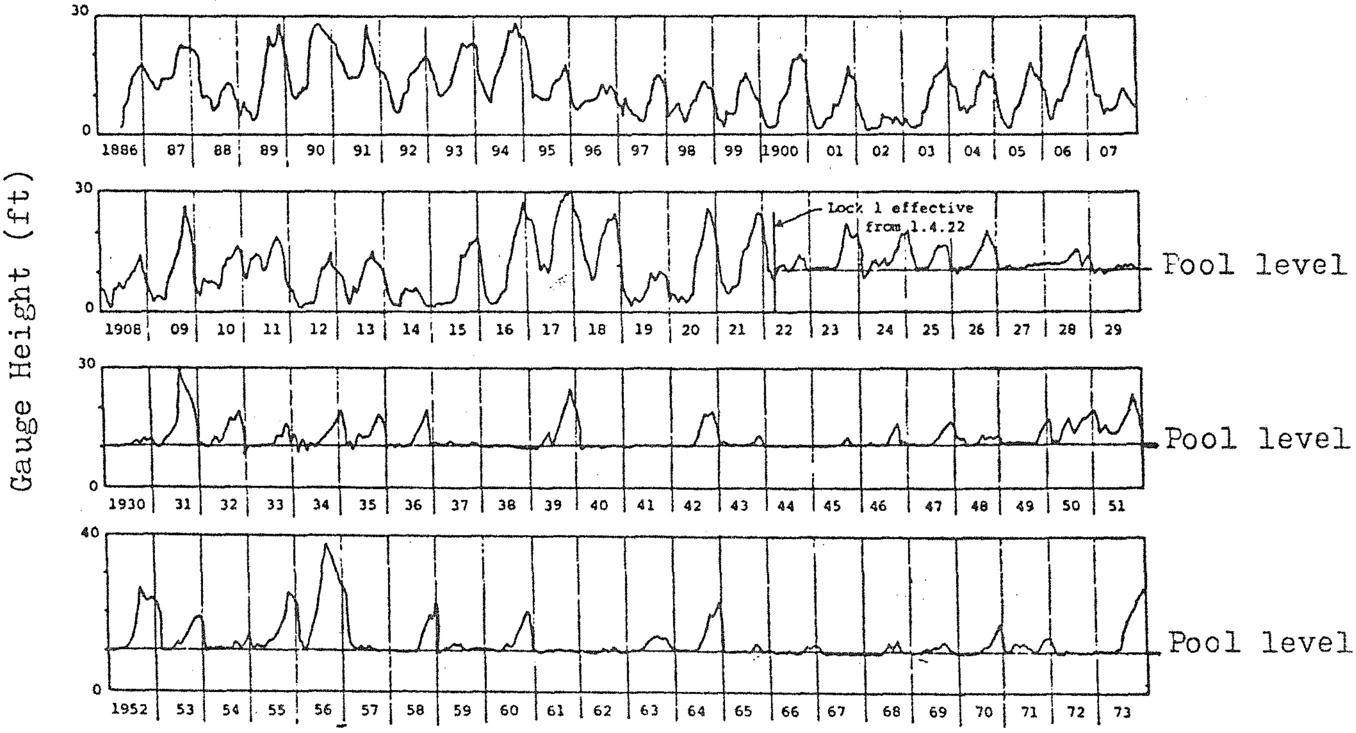
The rainbow and brown trout both occur in the regional lakes and streams. They favour cool well oxygenated water with moderate to

Figure 3.3 The Relationship Between River Height and the Numbers of Fish Migrating Upstream Over a Twelve Day Period.



Source: Cadwallader (1977).

Figure 3.4 Alterations in Flooding Brought Abought by the Construction of Lock 1 on the Murray River.



Source: South Australian Fisheries Industry Council May 1976 No. 8.

swift flows and cool clear lakes. The lakes and streams within the A.C.T. are in fact marginal for trout as high temperatures and/or low oxygen levels limit their distribution for part of the year (Cadwallader and Tilzey 1979).

The brown trout breeds between May and August and the rainbow trout somewhat later (July-October). Spawning fish migrate upstream into tributaries with swift flowing water and loose gravel beds.

In contrast to the native species, trout are winter spawners and require good flows in clear gravelly streams during winter months.

The trout populations are therefore vulnerable to high turbidities and structures which will impede their movements into suitable spawning areas. Low winter flows will also influence the fishery as low flows may not provide sufficient oxygenation of eggs or may prevent access to suitable spawning streams.

3.3 Summary

It is difficult to determine from field observations the precise stimulus which will induce spawning and movement of fish in a river. However the evidence available suggests a number of factors may be important and these are outlined below.

(i) Timing of the flood peaks. Floods which occur when temperatures are suitable for spawning in certain species result in large numbers of fish migrating and greater recruitment to stocks than floods which occur at other times of the year. Alterations in the flood cycle may therefore adversely effect spawning.

(ii) Total volume of flow. River discharges must be maintained at certain levels to allow fish free passage in the river corridor and to maintain pool levels. A reduction in river volume will result in a lowered carrying capacity of the river ecosystem and fish may experience difficulty in moving through the river corridor.

(iii) Reduction in flooding. Where an impoundment leads to a marked reduction in maximum flows, flood time scouring is reduced or prevented. (Ridley and Steele 1975). This can result in increased macrophyte growth downstream and siltation of the gravel spawning sites required by such species as the Macquarie perch and trout. Consequently reduced flooding even in non spawning months may adversely effect the fishery. Flood time scour probably plays a major role in clearing silt from the river in the Upper Catchment as no major settling areas occur between Tantangera and Burrinjuck Reservoirs.

(iv) Pattern of river rise. Figure 3.3 showed that major movements of fish occured within a four day period when the rise in the river took place over twelve days. If the pattern of river flooding is altered especially in critical months when movements are greatest, recruitment may be adversely effected. A slow sustained rise may be preferable to rapid rises and falls

CHAPTER 4

PATTERNS OF STREAM FLOW IN THE MURRUMBIDGEE RIVER (1927 - 1976)

In the previous Chapter a brief description of the changes in catchment characteristics which may have influenced the Murrumbidgee River and its recreational fishery was presented. Though a combination of factors is likely to have contributed to the perceived decline in the fishery, no detailed investigations have been carried out to determine the relative impact of each.

In this Chapter the patterns of flow and stream discharges are examined in detail for one gauging station on the Murrumbidgee River (Station No 410035/410738 Murrumbidgee River at Cotter Crossing/Mount McDonald) in order to ascertain whether any long term changes could be detected which could be related to what is known of the requirements of fish species.

4.1 Methods of Analysis

The gauging station under consideration will have had its flow influenced by the following factors:

(i) The construction of Tantangera Dam on the headwaters of the Murrumbidgee River in 1960

(ii) The construction of Corin (1968) Bendora (1961) and Cotter (1915) Dams on the Cotter River, which flows into the Murrumbidgee River upstream of the gauging station

(iii) Any changes in climatic patterns which may have occured during this period

(iv) Urbanization in the Tuggeranong Valley and urban runoff from Tuggeranong Creek (1970's)

Any of these factors may have affected flow characteristics in the past 1960 period.

In view of the above factors it was decided to divide the period under consideration into three intervals. Comparisons were carried out for the years 1928 - 1959 and 1960 onwards as these represented a pre and post dam construction period. Tantangera Reservoir was completed in 1960 and Corin and Bendora Reservoirs came into operation after this date. The Cotter Dam built in 1915 would have had only a minor impact on flows due to its small volume.

A further breakdown in the time intervals was made in order to consider the periods 1928 - 1943 and 1944 - 1959 as these two periods differ in rainfall characteristics, the period between 1928 - 1943 being much drier climatically. This is in accordance with observed climatic trends in south eastern Australia (Pittock, 1975; Cornish, 1977). Rainfall data from several regional gauging stations, for the periods under consideration are presented in Chapter 5.

As seasonal flow characteristics are important in the context of fish migration and spawning, data were analysed on a seasonal basis, grouping the months October to March for comparison with the period April to September. Alterations in flow patterns which have occured in the critical migration and spawning months will be more informative than annual trends.

The data for the three periods were compared using the following criteria: (i) mean annual and mean monthly flows in megalitres (ii) flow duration curves (iii) frequency of flows (per cent of days spent in a certain flow range) (iv) seasonal flood recurrence intervals (v) plots of daily flows.

The megalitre (ML) was used as the unit of flow in the analysis carried out in this report. However, a rating curve for the Cotter Crossing/Mt McDonald gauging station indicating the depth represented by this unit of flow is given in Appendix 11.

4.2 Annual Discharges at Cotter Crossing/Mt McDonald

Annual discharges at the Cotter Crossing Mount McDonald gauging station for the three periods between 1928 and 1976 are listed in Appendix 2. A summary of mean annual discharge and mean runoff is presented in Table 4.1.

The period between 1928 - 1959 consists of a relatively dry cycle between 1928 - 1943, with a mean annual discharge of 782, 692 megalitres compared to 1, 307, 696 megalitres for the period 1944 - 1959.

The mean annual discharges and runoff for the period 1960 - 1976 is remarkably similar to that of the 1928 - 1943 dry period.

The values calcula ed in this study contradict the values reported in the A.C.T. Region Water Quality Study (NCDC Report 1978). In this report the value of the mean annual discharge for the fourty nine year period between 1928 - 1976 was calculated to be 787,000 megalitres and 811,000 megalitres for the period 1960 - 1976 (Table B 5.1 in that report).

Table 4.1 Mean Annual Discharge (ML) at Cotter Crossing/Mt McDonald Gauging Station for Various Periods Between 1928 - 1980.

Period	Flow (ML)	Runoff (mm)
1928 - 1943	782 692	118.5
1944 - 1959	1 307 696	198.0
1928 - 1959	1 045 194	158.2
1928 - 1976	964 190	145.5
1960 - 1976	811 711	121.5
1960 - 1980	776 342	113.8
1928 - 1980	938 668	-

If this were the case and the mean value for the entire period was elevated by the post 1960 discharges, the years in the post 1960 period must have experienced higher flows than those in the period prior to 1960. This in fact contradicts the flow duration curves presented in the same report (as Figure B5.4) which indicated the flows after 1960 to be lower especially in the median flow range. This was attributed in the report to the effect of the construction of Tantangera Reservoir, without taking into consideration any of the other factors, already outlined, which may have affected flows in the post 1960 period.

A recalculation of the data by the author has shown that the mean annual discharge for the period 1928 - 1976 was underestimated in the ACT Region Quality Study. A comparison of the recalculations to those of the earlier report are shown in Table 4.2.

Discharges for the period after 1960 are further depressed when data for 1977 - 1980 are included (Table 4.1).

To summarize then, for the period 1960 - 1976, the mean annual flows are lower than in the previous sixteen years but not unlike those experienced from 1928 - 1943, which was a relatively dry period climatically. Therefore it is possible that the depressed flows experienced in the period following 1960 could be the result of climatic influences. The rainfall effect is considered in detail in Chapter 5.

4.3 Monthly Discharges

The mean monthly flows for the Murrumbidgee River at Cotter Crossing/Mount McDonald are presented in Figure 4.1. The actual values are listed in Appendix 3.

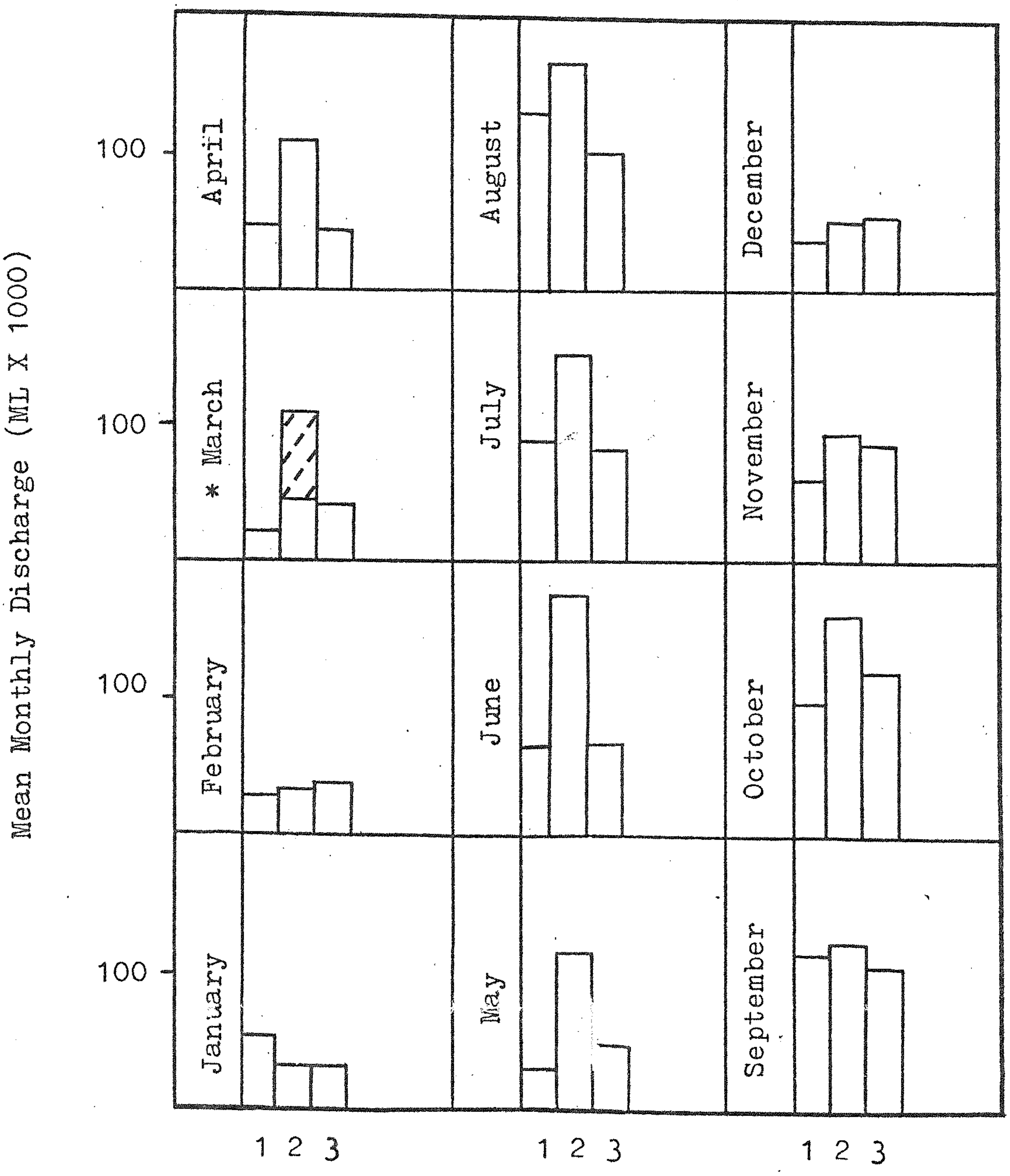
Table 4.2 Mean Annual Discharges (ML) at Cotter Crossing/Mt McDonald for the Periods Indicated as Calculated in the A.C.T. Region Water Quality Study and by the Author.

Period	ACT Region Water Quality Study (NCDC 1978)	Recalculation
1928 - 1976	787 000	964 00
1960 - 1976	823 000	811 711

The mean discharges for each of the months during the dry/wet cycle experienced between 1928 - 1959 parallel the annual trends (ie flows for each month in the wet period were higher than flows for the same months during the dry period) with the exception of January. The differences for the months of September, December and Febraury are not as pronounced. Mean flows in Januarys during the wet cycle were in fact lower than January flows during the dry cycle.

In the period from 1960 onwards, six of the months have mean flows which were nearly equal to or less than flows experienced in the

Figure 4.1 Mean Monthly Discharges at Cotter Crossing/ Mt. McDonald Gauging Station.



1. 1927–1943
2. 1944–1959
3. 1960–1976

*March 1950

not included

included

dry cycle (1927 - 1943). However for the remaining six months mean flows were in excess of those experienced in the dry cycle and nearly equalled, or exceeded, as in the case of December and February, those experienced during the wet cycle (1944 - 1959). These include the months which were shown to be critical for the movements and spawning of native fish (October, November, February and March) as well as December.

In summary mean flows during the months between October and March for the period 1960 - 1976 nearly equalled flows during the wet years 1944 - 1959. However mean winter flows (April - September) were significantly lower and more nearly approached those experienced during the dry years 1927 - 1943.

The mean discharges for each of these six monthly periods is shown in Table 4.3.

The extent to which the construction of dams has contributed to lowered winter flows, and the relative influence of climatic changes are assessed in Chapter 5.

Table 4.3[+] Mean Monthly Discharges (ML) for the Periods April - September and October - March.

	April-September	October-March
1928 - 1943	80245	50200
1944 - 1959	138533	·68975
1960 - 1976	74734	60647

. March 1950 flow omitted

+ Values were obtained by averaging the mean monthly discharges for the six months within each period.

4.4 Flow Duration Curves

The flow duration curve is a comulative frequency curve that shows the percentage of time during which specified discharges were equalled or exceeded in a given period and the flow characteristics of a stream throughout the range of discharge (Searcy 1959). It does not show the chronological sequence of flows and is an average curve for the period on which it was based.

To prepare the curve flows are arranged according to order of magnitude and the percent of time during which the flow equalled or exceeded specified values is computed. The curve is drawn to average the plotted points of specified discharges versus the percentage of time during which they were equalled or exceeded. This then represents the average for the period under consideration.

In this study annual flow duration curves were constructed by ranking daily flows (Figure 4.2 a-b). Seasonal flow durations were also plotted separately for the six monthly periods April - September and October - March for each of the three intervals under consideration.

The plots were drawn on logarithmic probability paper and the daily discharge in megalitres was used as the unit of flow.

4.4.1 Annual trends

The flow duration curves for the period 1960 - 1976 and 1927 - 1959 are compared in Figure 4.2a. From these curves it can be seen that flows which occured during the period 1960 - 1976 are reduced and that the flows most affected are those which lie between 200 - 10,000 megalitres.

However when the two periods in which the runoff was nearly equal are compared (1927 - 1943, 1960 - 1976), the curves are very similar in this range (Figure 4.2b).

4.4.2 Seasonal trends

Seasonal flow duration curves are shown in Figure 4.3 a-b.

The flow duration curve for the months October - March between 1960 - 1976 lies above the curve for 1927 - 1943 over most of its range (4.3a).

The curve for April - September for the post 1960 period lies below that of 1927 - 1943 except at flows above 5000ML. (Figure 4.3b).

The median flows (flow at the 50% probability level) are compared in Table 4.4.

This data suggests that the depression in the annual median flow for the period 1960 - 1976 was in fact brought about by depressed flows between the months April - September for this period.

4.5 The Frequency Distribution of Daily Flows

The frequency distribution of daily flows between the months April and September and from October to March can be compared by referring to Fiqure 4.4 a-b.

The distribution of flows for the period 1960 - 1976 was compared to that which occured between 1928 - 1959. This latter interval was further broken down for comparison into the wet and dry cycle of 1928 - 1943 and 1944 - 1959.

Figure 4.2 Flow Duration Curves for the Gauging Station at Cotter Crossing/Mt. McDonald Comparing the Period 1960-1976 to (a) 1928-1959 and (b) 1928-1943.

(a) 1928-1959

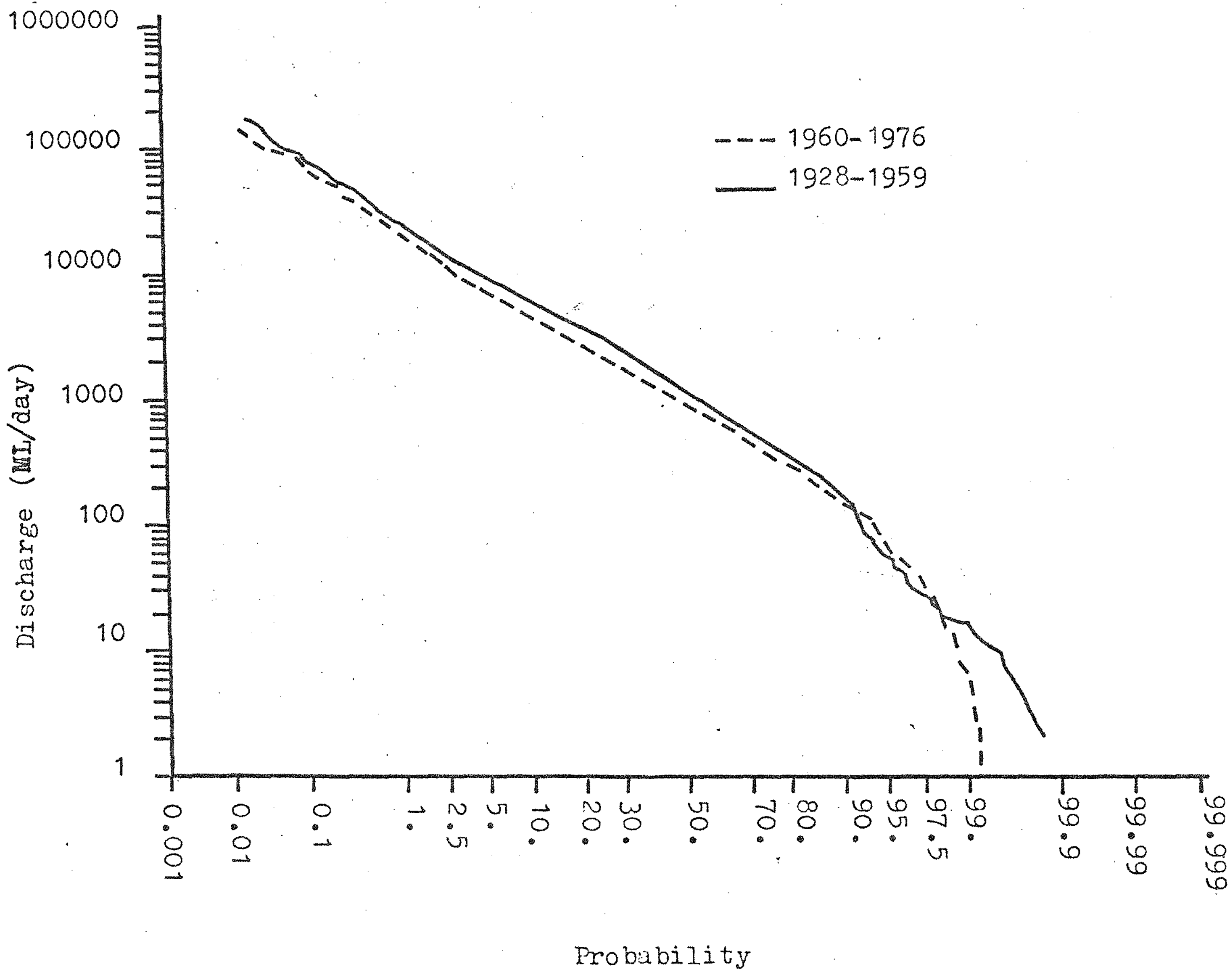


Figure 4.2 con't

(b) 1928-1943

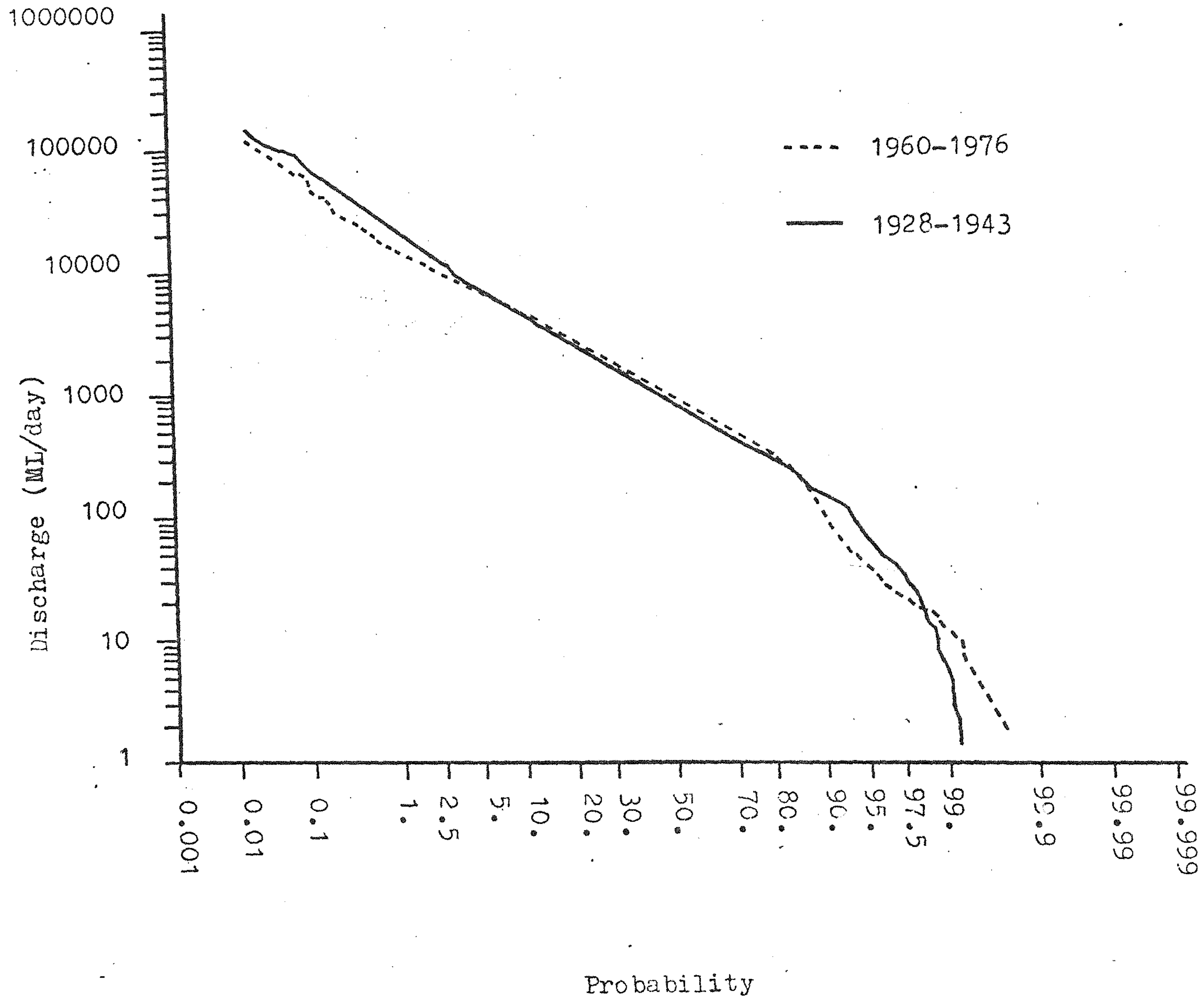


Figure 4.3 Flow Durations for the Six-monthly Intervals (a) October to March and (b) April to September.

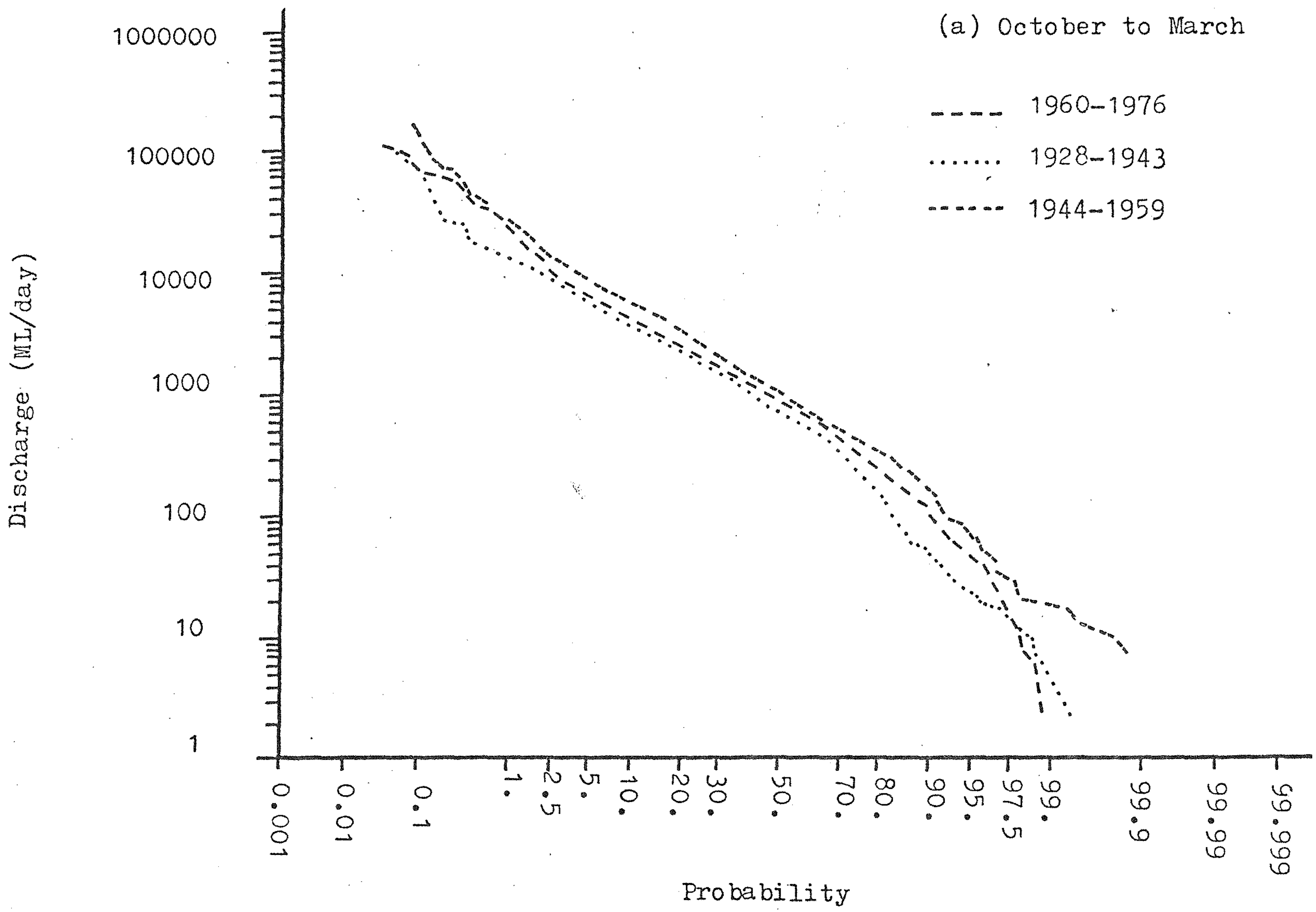


Figure 4.3 con't.

(b) April to September

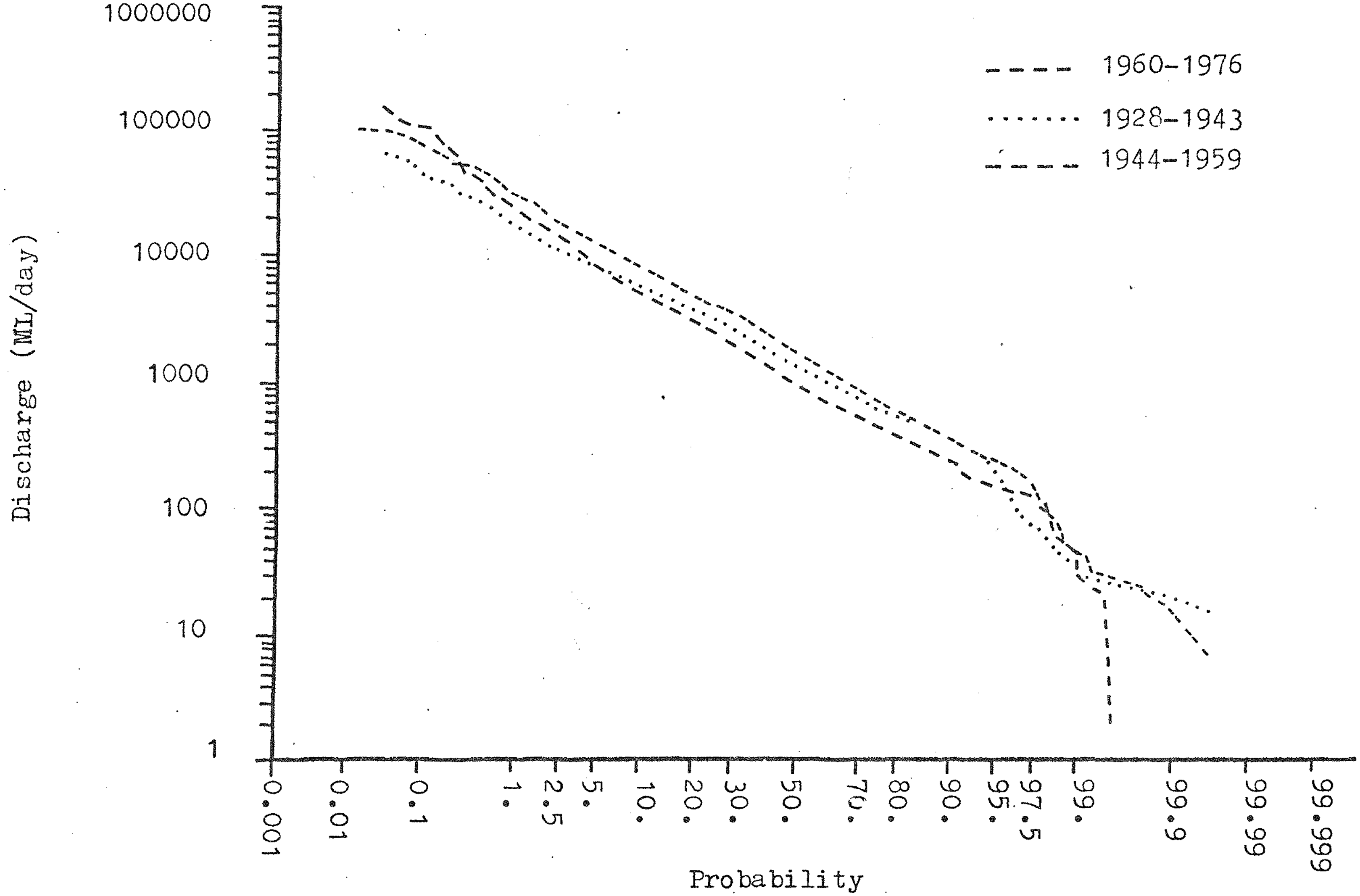


Table 4.4 Seasonal and Annual Median Flows Taken from the Flow Duration Curves for the Various Periods under Consideration.

Month	Year	Median Flow (ML)
Annual		
Jan - Dec	1928 - 1959	1170
Jan - Dec	1960 - 1976	870
Jan - Dec	1928 - 1943	1025
Seasonal		
April - Sept	1928 - 1943	1420
	1944 - 1959	2190
	1960 - 1976	896
Oct - March	1928 - 1943	705
	1944 - 1959	920
	1960 - 1976	840

The flow distribution in the region exceeding 5000 megalitres and in the ranges 1000-5000 megalitres and 0-1000 megalitres were compared for each of the periods outlined above. For ease of discussion these will be referred to as the high medium and low flow regions. The cumulative percentage of days occuring in each flow range is indicated on the graph.

The frequency distribution of flows which occurred in the period following 1960 for the months October to March do not differ markedly from the flow distributions which occurred between 1928 - 1959. The comulative frequencies of flows in the range 0-1000 megalitres were nearly identical, (55.9% vs 55.5%) and the distribution and cumulative frequencies within the remaining two cycles were similar.

For the months April to September in the period prior to 1960 about 35% of days fell in the low flow and 46% in the medium flow range. Most flows which exceed 5000 megalitres occur during these months (19.2% vs 8.7% for the months October to March).

In the period after 1960 however the flow frequencies have been altered dramatically with 19.3% more days occuring in the low flow range and 10% fewer days occuring in each of the middle and high flow intervals. Moreover when the post 1960 period is compared to the dry cycle of 1928 - 1943 during which mean flows for the two periods were similar, the distribution of the flows is quite different. During the drought cycle of 1927 - 1943 only 3.9% more days occured in the 0-1000 megalitre range when compared with the 1928 - 1959 period. A similar comparison for the post 1960 period shows that 19.3% more days occured in the low flow range. There is also a major reduction in the number of days which occur in the high flow range in the post 1960 period (9.7% fewer days occur in this interval).

To sumamrise then, high medium and low flows which occur between October and March are relatively unaffected in the period following dam construction in the 1960's. Flows which occur between April and September however have an altered frequency distribution with many more days experiencing flows between 0-1000 megalitres, and consequently fewer days in the high and medium range.

This is understandable given the patterns of rainfall in the catchment, with high falls occuring in the Tantangera Catchment in winter and high falls in the Monaro district in summer (Chapter 5). One would not therefore expect summer flows to be as affected by diversions from Tantangera Reservoir.

Figure 4.4 Frequency Distributions of Daily Flows for the Months (a) April-September and (b) October-March at Cotter Crossing/Mt. McDonald.

(a) April - September

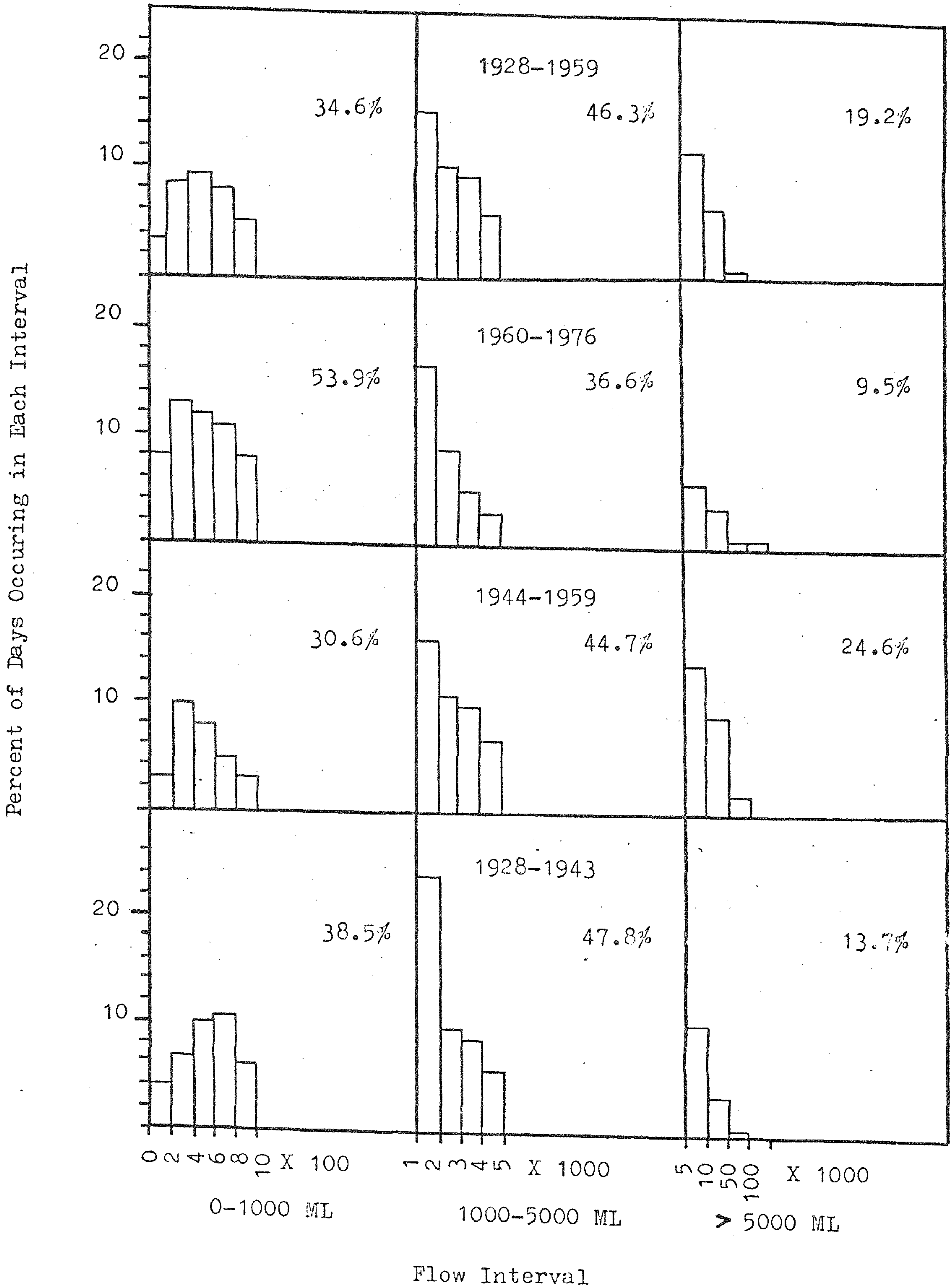
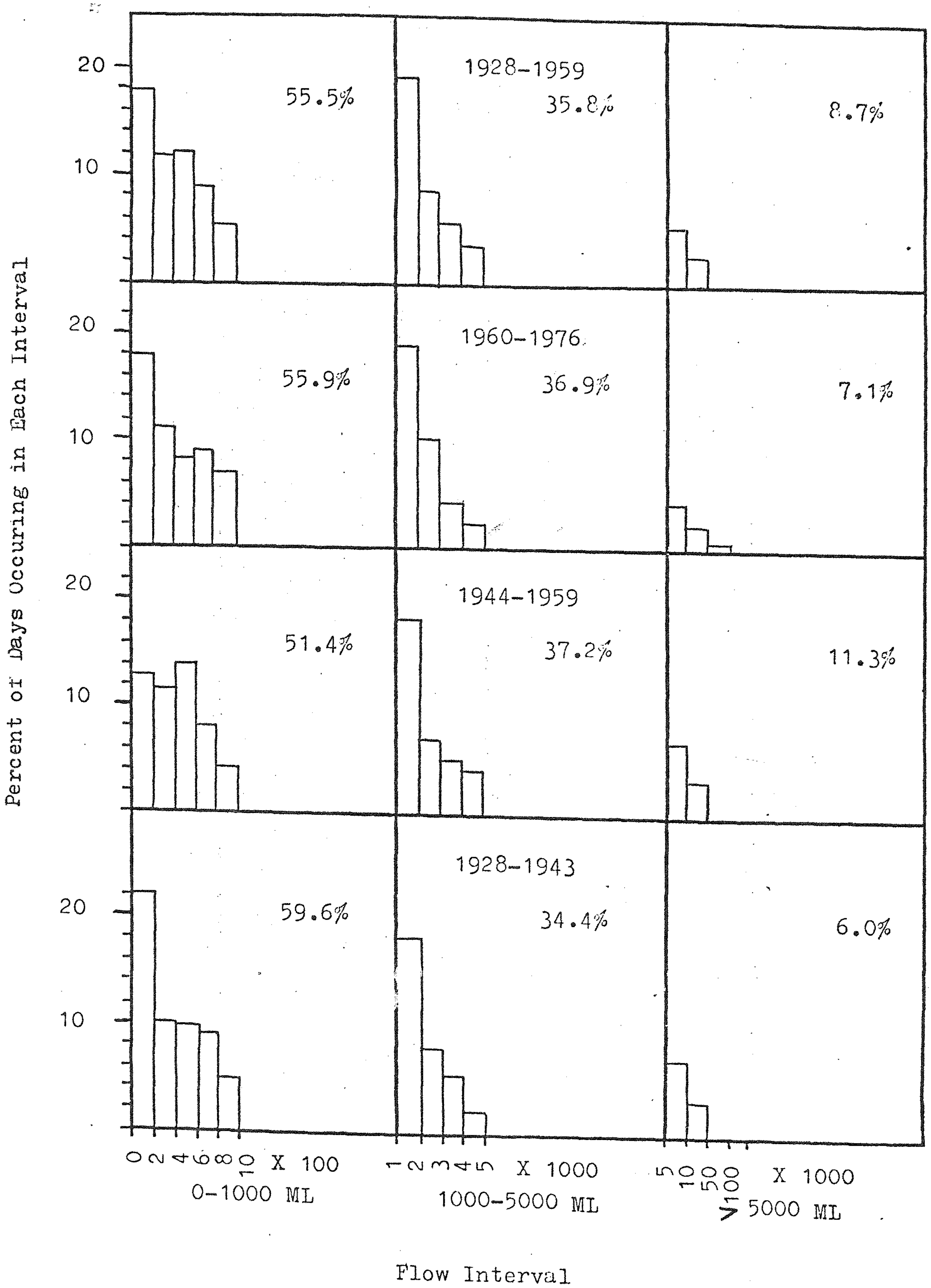


Figure 4.4 con't

(b) October - March



4.6 Recurrence Intervals of High Flow Events

There is some evidence that rises in river levels are correlated with the spawning of golden perch (Section 3.1). It may be anticipated then that a reduction in the frequency and severity of flooding would have an impact on the breeding success in this species, and other species in which flooding in believed to be a stimulus to spawning.

Since high flow days are aggregated into flood events, it is the distribution of flood events rather than the distribution of daily flows that are more relevant for these species.

To determine the probability of the recurrence of floods of a certain magnitude normally requires a flood record of long duration, a minimum of 30 years being recommended in order to obtain some degree of accuracy. In the present analysis however, if comparisons are to be made at all, the three intervals to be compared are of the relatively short duration of sixteen years. It is the high flow which occurs each year or every two years that is important in the context of fish breeding. Determining the probability of a two year flood form a sixteen year record would not be expected to be much more biased statistically than determining the probability of a five year flood from a fourty year record.

Flood recurrences in the hydrological context are normally calculated for yearly intervals without regard to the time of year in which the flood occurred.

In the context of the breeding of native fish in the Upper Murrumbidgee River however it is the flood which occurs in the months between October and March that is most relevant. Therefore for the three periods under consideration the flood recurrences were calculated seasonally ie. the probability of the recurrence of an event of a certain magnitude for the period April to September or October to March in any year. These will be referred to as the winter and summer periods for ease of discussion.

The standard procedure for calculating the flood recurrence is to rank the highest flow in each event in excess of a chosen value for the length of the record, or for extended periods of record to rank the values of the highest flow in each year.

In the present analysis the probabilities and recurrence intervals were determined as follows using the six monthly seasonal intervals described earlier rather than yearly intervals:

(a) The highest flow for each season was ranked form highest to lowest over the sixteen years of record for the three periods under consideration

(b) The highest flow in each event in excess of 9000ML was ranked from highest to lowest for each season for the three periods under consideration. If more than one event of this magnitude occurred in a single month, only the highest was used. It was assumed that two events is close proximity would not be perceived as separate events by migrating fish.

(c) The probability (p) was calculated using the formula $P = \frac{R}{n-1}$ where R = rank and n = number of flows.

In case (b) the cutoff value of 9000ML was chosen as it was the value of the two year flood during the natural dry cycle which occurred between 1928 - 1943. Since this cycle included the severest drought on record up until 1976, it can be regarded as having provided only the minimal breeding requirements required to sustain the fishery. This assumes that fish have evolved so that breeding can occur under the most severe naturally occurring climatic cycles, not an unreasonable assumption if the continuity of populations is to be assured.

If we also assume that under the minimal breeding conditions breeding must occur at least once every two years to sustain the fishery, then the discharge of 9000 megalitres per day at Cotter Crossing/Mt McDonald can be considered an index of the flow level which should be ensured in this section of river at least every other summer, for flood induced spawning to occur.

The probabilities of the recurrence of flows of a certain magnitude were plotted on logarithmic probability paper (assuming a log-normal distribution). If the data are log normally distributed a straight line plot should result.

Regression lines were fitted to the plots. The details of the regression analysis are given in Appendix 8. Flows at each probability level were derived from the regression line equations.

4.6.1 Flood recurrence using the highest flow in each season

The probability plots for the recurrence of flows of a certain magnitude using only the highest flow in each season as a data base are shown in Appendix 9.

Between April and September there appears to be a discontinuity of flows below 8000ML. For this reason a straight line was fitted only to flows which lie above this value.

The flows which occured at the probabilities of 50%, 33.3% and 25% (ie. had a recurrence interval of two, three and four years) are listed in Table 4.5.

For the winter months there is no statistically significant difference at the 95% probability level between the distribution of floods for the periods 1944 - 1959 and 1960 - 1976. The distribution of flood events for the period 1928 - 1943 is significantly different from the other two periods at the 95% probability level but not at the 90% level.

The lines for the three periods converge towards flows above 30,000ML, suggesting the probability of recurrence of flows in this region are less affected than those in the lower ranges.

For the months October to March there is a significant lowering of peak flows which occured between 1928 - 1943. There is no significant difference at the 95% probability level between the remaining two periods.

Though recurrence intervals were not significantly different for the period April - September (except marginally for 1928 - 1943), the number of flows in excess of 9000ML was nearly one and a half times higher for the period 1944 - 1959 when compared to the remaining two periods (Table 4.7).

The converse is true for the period October - March. The

Table 4.5 The Recurrence Intervals of High Flow Events (ML) Using Only the Highest Flow in Each Season for the Period (a) October - March and (b) April - September.

(a) October - March

Recurrence (years)	Probability %	Period 28-43	44-49	60-76
2	50.0	8,666	15,782	18,741
3	33.3	12,274	27,131	31,730
4	25.0	14,927	36,795	42,664

(b) April - September

Recurrence (years)	Probability %	Period 28-43	44-59	60-76
2	50.0	19,181	25,685	20,984
3	33.3	30,023	36,769	33,846
4	25.0	38,630	44,988	44,403

period 1928 - 1943 though experiencing significantly lower flows at each probability level when compared to the remaining two periods, had just as many flow events in excess of 9000ML.

4.6.2 Flood recurrence using all flow events in excess of 9000ML

The probability plots based on all flow events which peaked above 9000 megalitres are shown in Appendix 10.

The flows at each probability level are noticeably higher when compared to those derived using the previous method (Table 4.6). However the comparisons are similar. The only statistically significant difference at the 95% level of probability was the distribution for October - March 1928 - 1943.

The difference between the two methods can be accounted for by the fact that high flow events are not randomly distributed between years. That is when one high flow occurs in a season there is a good chance that other high flows will occur as well.

From the point of view of a fishes response to flooding the first comparison is most relevant as it is the occurence of at least one flood event in the season that is most important. Multiple rises in a single season may supplement spawning in any one year but do not contribute to recruitment of new year classes necessary for the long term survival of the population.

To summarise then, the probabilities of flood recurrences of a certain magnitude in the October - March period after 1960 were not significantly different to those which occurred between 1944 - 1959. Individual flow values for the 1928 - 1943 period at the same probabilities were lower than for the other two cycles. The total

Table 4.6 The Recurrence Intervals of High Flow Events (ML) Using all Events Which Peaked Above 9000 Megalitres for the Period (a) October - March and (b) April - September.

(a) October - March

Recurrence (years)	Probability (%)	Period 28-43	44-59	60-76
2	50.0	14,571	29,666	26,571
3	33.3	16,553	38,851	38,274
4	25.0	17,784	45,215	46,994

(b) April - September

Recurrence (years)	Probability (%)	Period 28-43	44-59	60-76
2	50.0	28,388	41,095	33,296
3	33.3	37,332	50,953	41,814
4	25.0	43,556	57,503	57,529

number of flows above 9000 megalitres for the three periods were similar.

The native fish species which require a significant rise in water level between October and March in order to spawn should not have been adversely affected by a reduction in the frequency or severity of flooding in the post 1960 period as conditions in the post 1960 period for these months resembled those of the wet cycle of 1944 - 1959.

For the winter months the frequency of flooding above 9000 megalitres for the post 1960 period was similar to that of dry cycle of 1928 - 1943. The flood recurrences in the post 1960 period however were not significantly different to those which occurred between 1944 - 1959.

Trout which are winter spawners may have been adversely affected by the reduced number of high flows in winter months after 1960, though recurrence intervals between periods were not significantly different. There may have been an indirect effect due to a reduction in flood time scour because of the lowered frequency of high flows. In addition to the lowered frequency of high flows, mean flows for this period were also lower (Section 4.3).

4.7 Plots of Daily Flow

In order to determine the pattern of river rise and fall, daily flows were plotted for each of the months for the three periods under consideration. Appendix 4 contains representative graphs for the summer months of October, November and January and the winter months June, July and August.

Visual observation of the graphs showed no detectable differences in the pattern of river rise and fall over the three periods under consideration, though wet periods and dry periods may be evident. This is especially true for Junes between 1960 - 1976 where low river flows dominated.

Table 4.7 Total Number of Flow Events Above 9000 Megalitres for Each Season in the Three Periods Under Consideration.

	October-March	April-September
1928 - 1943	17	27
1944 - 1959	18	43
1960 - 1976	19	26

CHAPTER 5

THE RELATIVE IMPACT OF DAM CONSTRUCTION AND CLIMATIC FACTORS ON FLOWS IN THE MURRUMBIDGEE RIVER AT COTTER CROSSING/ MT. McDONALD

The flows at the gauging station under consideration will have been influenced by Tantangera Dam, completed in 1960, which diverts water from the headwaters of the Murrumbidgee River to Lake Eucumbene for the purpose of hydroelectric power generation in the Snowy Mountains scheme.

The Cotter River, which discharges into the Murrumbidgee, has had three dams constructed on it for the purpose of supplying water to Canberra. The completion dates for the dams were Cotter (1915), Corin (1968) and Bendora (1961).

The catchment areas and storage capacities are outlined in Table 5.1. The relative influence of Tantangera Reservoir and the Cotter System are outlined in this Chapter.

5.1 The Cotter System

In order to determine the effect on flows in the Murrumbidgee that diversion from the Cotter System may have had, stream discharges at the Cotter River Kiosk (Department of Transport and Construction Station Number 410700) have been analysed. This gauging station is below the Cotter Dam Wall, the lowest dam in the catchment, and would experience the effects of all three dams on the River.

Table 5.1 Completion Dates and Relative Sizes of Various Impoundments in the Upper Murrumbidgee Catchment.

LAKE OR RESERVOIR	SURFACE AREA (ha)	VOLUME ($10^6 m^3$)	MAX. DEPTH (m)	MEAN DEPTH (m)	CATCHMENT AREA (ha)	DATE COMPLETED
Tangangera Reservoir	2065	240	38	12	46,600	1960
. Corin Reservoir	320	75	70	24	19,700	1968
. Bendora Reservoir	75	11	43	14	29,000	1961
. Cotter Reservoir	51	5	28	9	48,200	1915
. Googong Reservoir	688	119	-	17.3	87,300	1978
. Lake Burley Griffin	704	33	17.4	4.7	186,500	1964
. Lake Ginninderra	105	3.7	10.1	3.5	9,200	1973
Burrinjuck Reservoir	5540	1026	53	18.5	1,300,000	1912

Appendix 5 lists the annual flows in the Cotter River at this station as well as the total flows that would have occured had no water been pumped from the dams. The percentage of river flow to total flow has also been calculated. The mean annual river flows and the river flows as percentage of total flows are outlined in Table 5.2.

The percentage, of inflowing water reaching the downstream gauging station has progressively declined from a mean of 99.9% in the 1910-1926 period to an average of 81.6% (range 27.1% - 93.9%) in the post 1960 period. In some years more than half of the flow of water in the Cotter River never reaches downstream of Cotter Dam.

The contribution of the Cotter River flow to flows in the Murrumbidgee was estimated by calculating the ratio of the annual total inflow into the Cotter River to flows in the Murrumbidgee at Cotter Crossing/Mt McDonald on a percentage basis for each year. These are listed in Appendix 6.

The percent reduction in flows in the Murrumbidgee brought about by abstraction of water from the Cotter System are also listed in Appendix 6 and mean values are shown in Table 5.3. These values range from 0.1% to 15.9% as occured in 1972. Between the years 1960 - 1976 the average reduction in flow brought about by diversions from the Cotter System was 3.6% (range 1.1% - 15.9%).

All of the calculations assume that all of the Cotter River flow would have eventually reached the gauging station at Cotter Crossing/ Mount McDonald on the Murrumbidgee. The effects of evaporation have not been considered and reduction in flow may be greater than calculated due to evaporation occuring over large surface areas in the post 1960 period with the construction of Corin and Bendora Dams.

Table 5.2 Mean Annual River Flows (ML) as Percentage of *Total Flows for the Cotter River.

Period	River Flow at Cotter Kiosk	Total Inflow	River Flow / Total Flow %	Range %
1910 - 1926	167 852	168 523	99.9	99.5-100
1927 - 1943	116 182	118 765	97.8	91.4-99.4
1944 - 1959	160 600	167 894	92.0	69.6-97.7
1910 - 1959	147 850	151 404	97.7	69.6-100
1960 - 1976	128 378	157 305	81.6	27.1-93.9

* Total Inflow = River flow + megalitres pumped from dams

Table 5.3 Mean Annual Total Flow and River Flow (ML) of the Cotter River as Percentage of Murrumbidgee Flow at Cotter Crossing/Mt McDonald for the Equivalent Period.

Period	Cotter River Flow	Cotter River Flow as % of Murrumbidgee Flow	* Cotter River Total Inflow	Inflow as % of Murrumbidgee Flow	X Reduction in Annual Inflow %
+ 1910-1926	167 852	-	168 523	-	-
1928-1943	116 182	14.8	118 765	15.2	0.4
1944-1959	160 306	12.2	167 894	12.8	0.6
1910-1959	147 850	-	151 404	-	-
1960-1976	128 378	15.8	157 305	19.4	3.6

* Total Inflow = River flow at Station + amount pumped from Cotter and Bendora Dams.

X % reduction in annual flow is obtained by subtracting column 2 from column 4.

+ No data is available on Murrumbidgee River Flows Prior to 1927.

5.2 Tantangera Reservoir

Tantangera Reservoir has an estimated mean annual runoff of 294,440 megalitres and a storage capacity of 354,000 megalitres. Most of the water entering the dam is diverted to Lake Eucumbene for use in hydroelectric schemes. The average annual flow from Tantangera downstream is 5,000 megalitres. The mean annual diversion from Tantangera represents 27.7% of the mean annual flow at the Cotter Crossing/Mt McDonald gauging station. Consequently the construction of Tantangera Reservoir may be expected to have had a significant effect on the total volume of flow reaching the downstream gauging station.

However the lower mean flows experienced at Cotter Crossing/ Mt McDonald after the construction of the dam in 1960 when compared to those of the previous sixteen years, could have occured as the result of a dry climatic period, as annual discharges are not dissimilar to those expereinced between the dry cycle of 1927 - 1943.

The relative impact of Tantangera therefore cannot be assessed unless consideration is given to long term variability in rainfall patterns throughout the catchment.

5.2.1 Rainfall patterns

In order to determine the extent to which the low flows experienced in the years following 1960 were due to temporal changes in rainfall patterns, the rainfall data from a number of gauging stations was analysed in order to assess regional trends. Unfortunately the number of rainfall stations for which records are complete for the entire period under consideration are limited especially at the higher altitudes.

Seven gauging stations were selected for which records were available. The mean monthly and annual rainfall for each of these stations is listed in Appendix 7.

The stream discharges in the Murrumbidgee River at the Cotter Crossing/Mt McDonald gauging station will be a reflection of rainfalls occuring at both higher altitudes and those occuring in the lower reaches of the catchment, each of these areas being subject to different climatic influences.

An account of the features of the climate of the Snowy Mountains Area which have hydrological significance is presented in a report by the Snowy Mountains Hydroelectric Authority (1957). The following description is drawn from this source.

The Snowy Mountains Area experiences a predominance of westerly weather in winter and spring and most of the annual rainfall occurs during these months as a result of orographic lifting. Orographic precipitation of this type tends to be prolonged but of low or moderate intensity which mitigates the severity of flooding. The summer and autumns are drier and with the weakening of the westerly circulation there are occasional intrusions of moist air and moderate thunder storm activity. Summer rainfall tends to be of shorter duration and higher intensity.

When air in a westerly stream descends from the region over the Snowy Mountains into the Monaro the formation of rain is suppressed. The winter rainfall pattern extends as far as Yaouk down the Murrumbidgee Valley. Below here the winter rains vanish and the Monaro climate becomes dominant. In the Monaro region there is a higher proportion of summer to winter rainfall and the total annual precipitation is lower.

As an example of the high winter rainfall pattern the stations of Kiandra, Argalon and Tumut were chosen. Mean monthly rainfalls for these stations are shown in Figure 5.1 a-c. As examples of the Monaro climate the stations at Uriarra, Cooma and Michelago show the pattern of higher summer rainfall (Figure 5.2 a-c). The rainfall for the station at Adaminaby was also considered. Though at an elevation of 1006m the rainfall reflects more the pattern of the Monaro Stations (Figure 5.3).

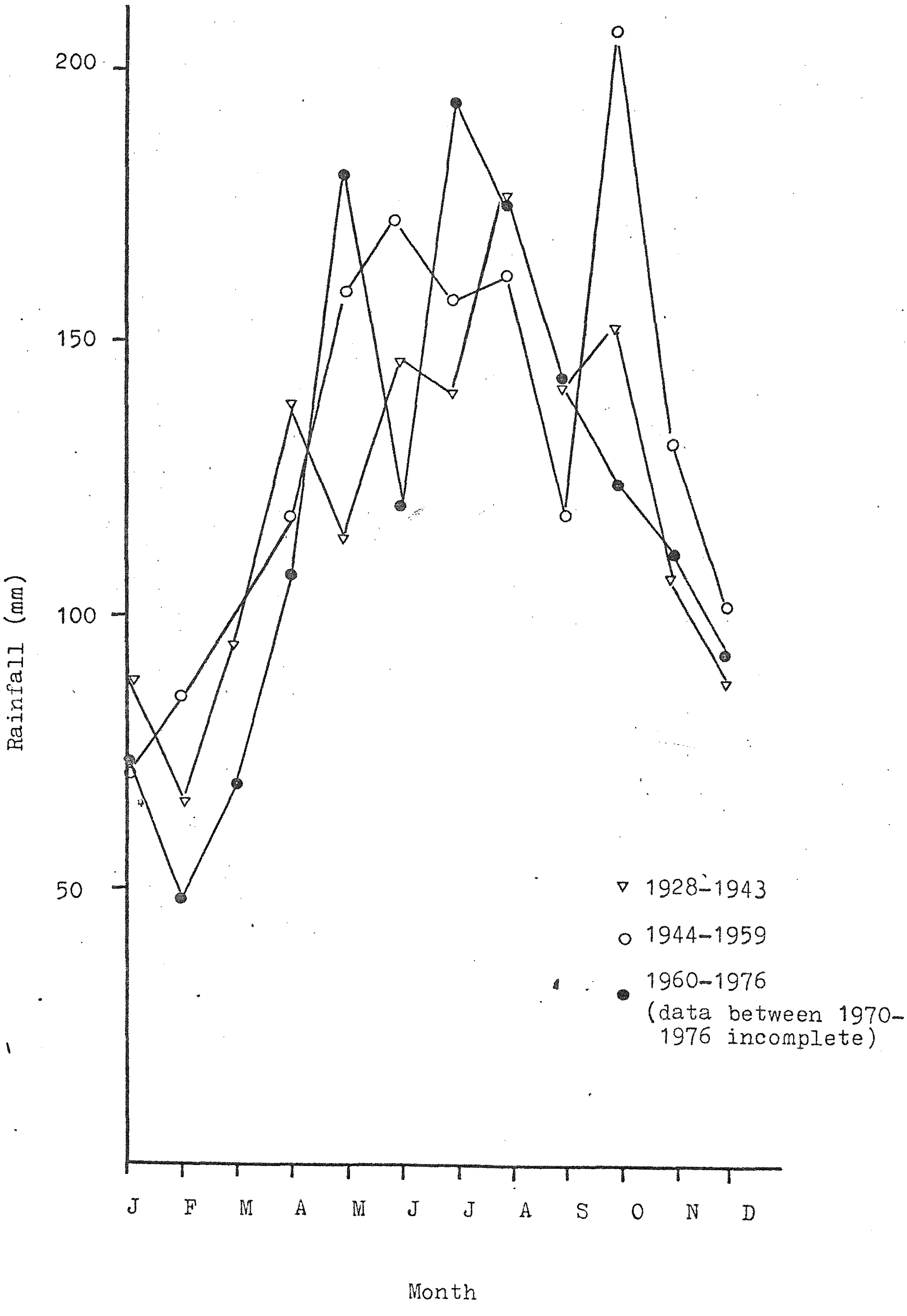
The peaks in stream flow reflect the cycles of precipitation. At high elevations the stream flow peaks in November with a secondary minima in July and August as the proportion of snow is higher and snow melt is later. At lower elevations the peak in stream flow occurs in August (Snow Mountains Hydroelectric Authority 1957). The peak in stream flows at Cotter Crossing/Mt McDonald has occured in some month between May and October depending on the period under consideration (Figure 5.4). Thus the peak in stream flow occurs in winter reflecting rainfall patterns at the higher altitudes at this time.

Since the flows between October and March were considered to be the flows which were crucial for the spawning of native fish, the rainfalls and streamflows for these months were examined separately and compared to those which occured between April and September. The period April - September also represents the period when westerly weather and high rainfalls dominate the higher altitudes.

The mean monthly rainfalls of the selected stations for the combined months April - September and October - March were calculated for the three periods under consideration and compared to mean streamflows for the same periods. These are shown in Tables 5.4 and 5.5. The mean rainfalls for the seven stations are used as an index regional trends

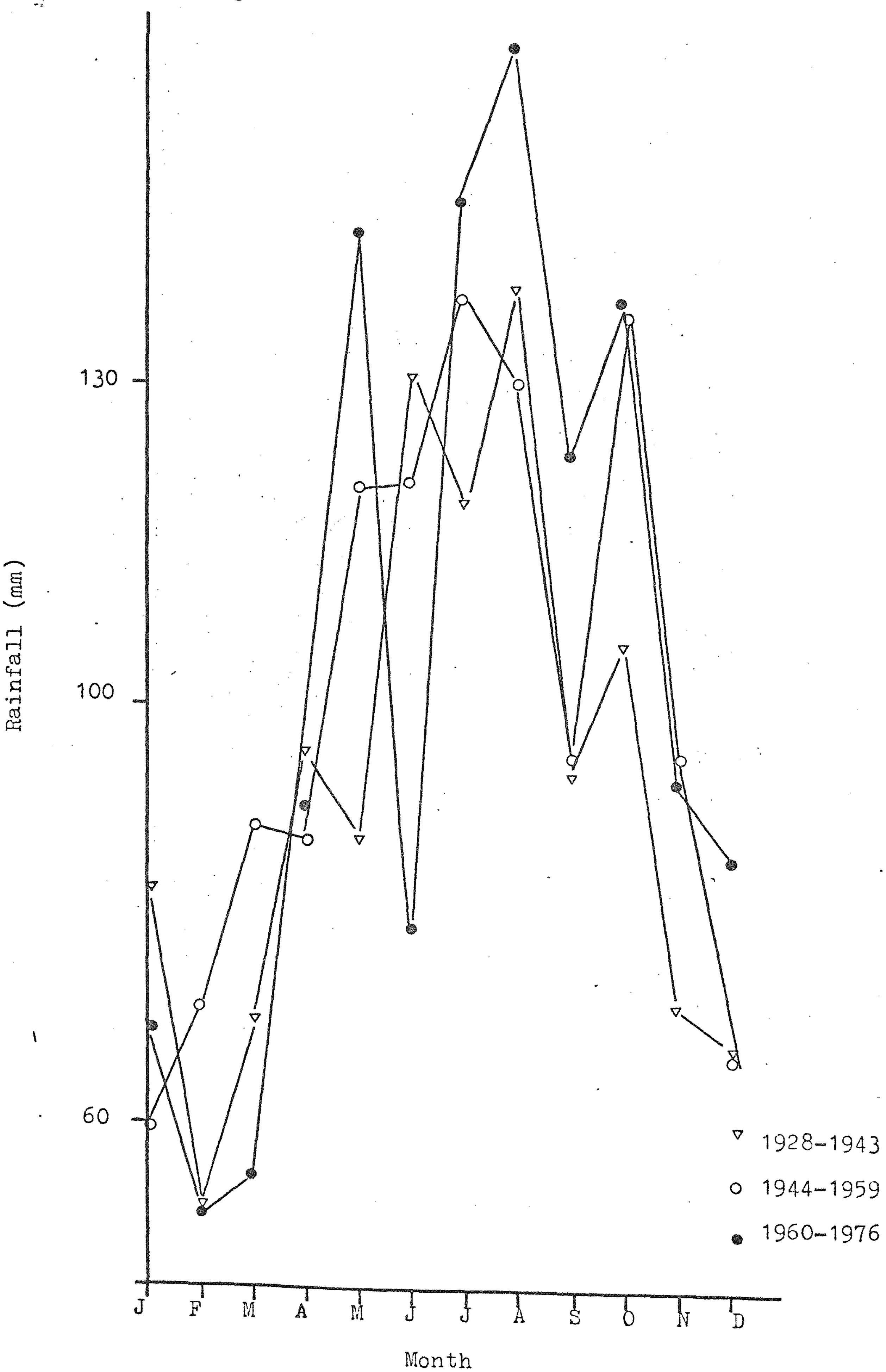
Figure 5.1 Mean Monthly Rainfalls for Gauging Stations at (a) Kiandra (b) Argalon and (c) Tumut.

(a) Kiandra



5.1 con't

(b) Argalon



5.1 con't.

(c) Tumut

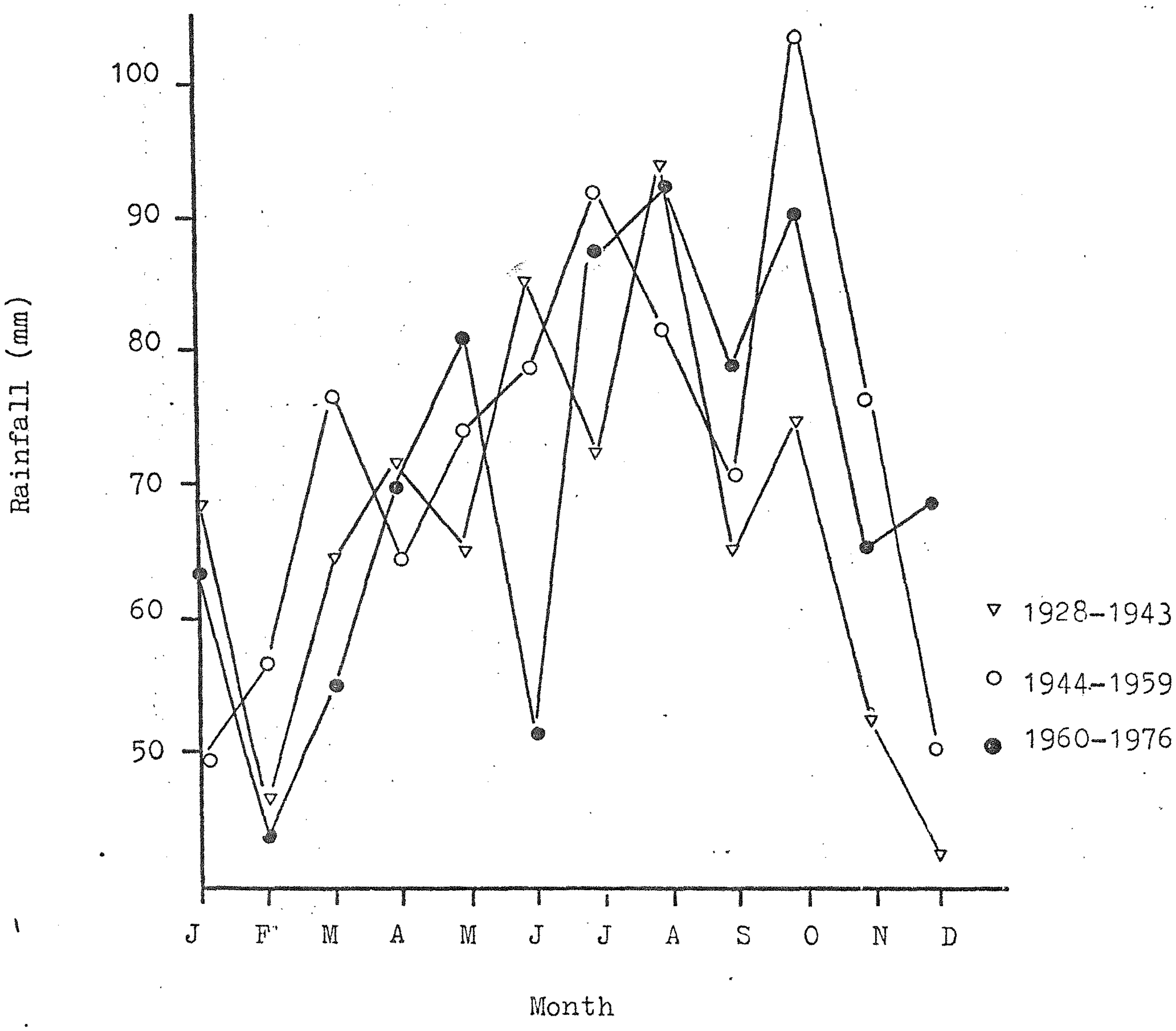
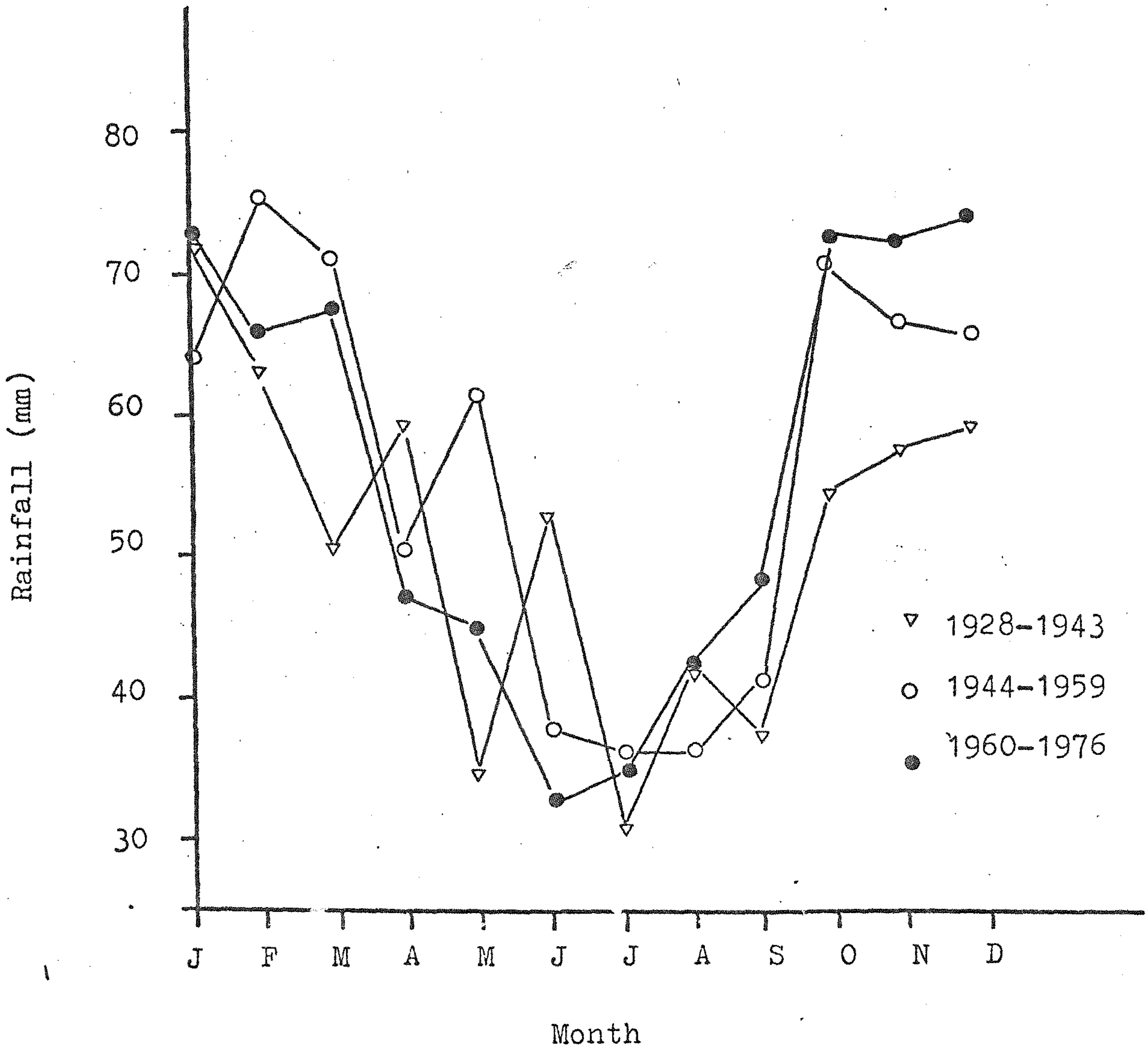


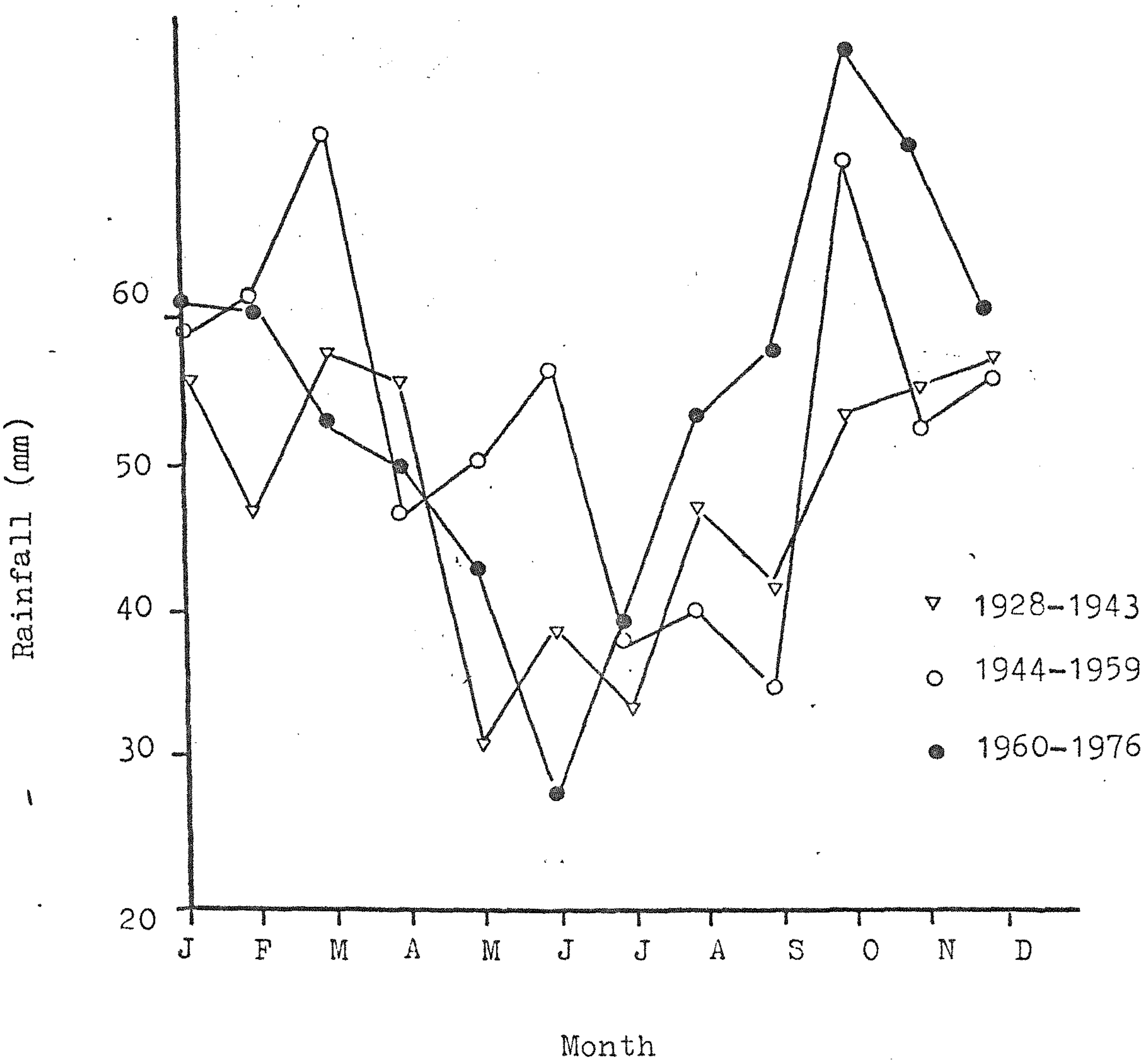
Figure 5.2 Mean Monthly Rainfalls for Gauging Stations at (a) Cooma (b) Michelago and (c) Uriarra Forest.

(a) Cooma



5.2 con't

(b) Michelago



5.2 con't

(c) Uriarra

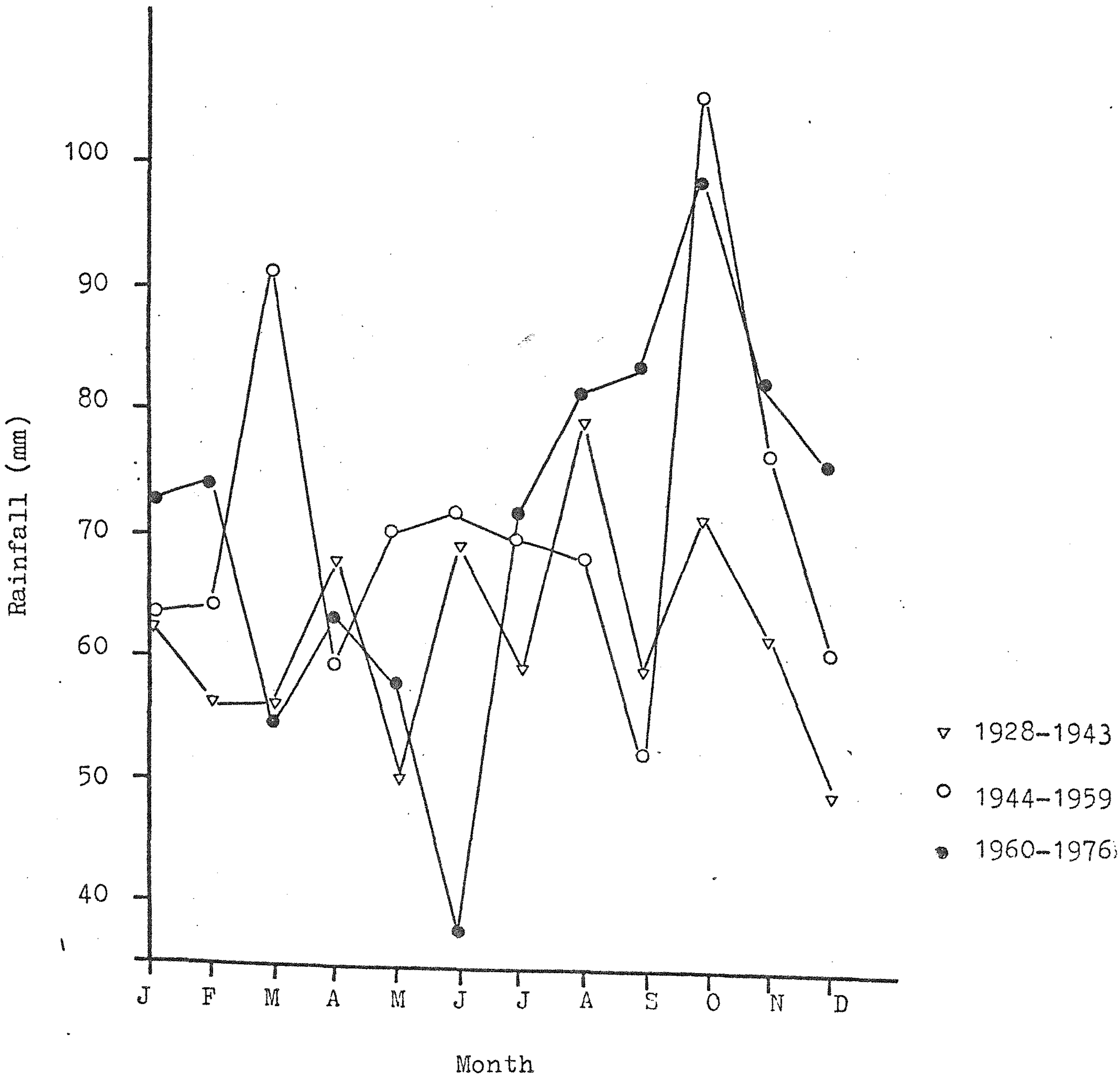


Figure 5.3 Mean Monthly Rainfalls for the Gauging Station at Adaminaby.

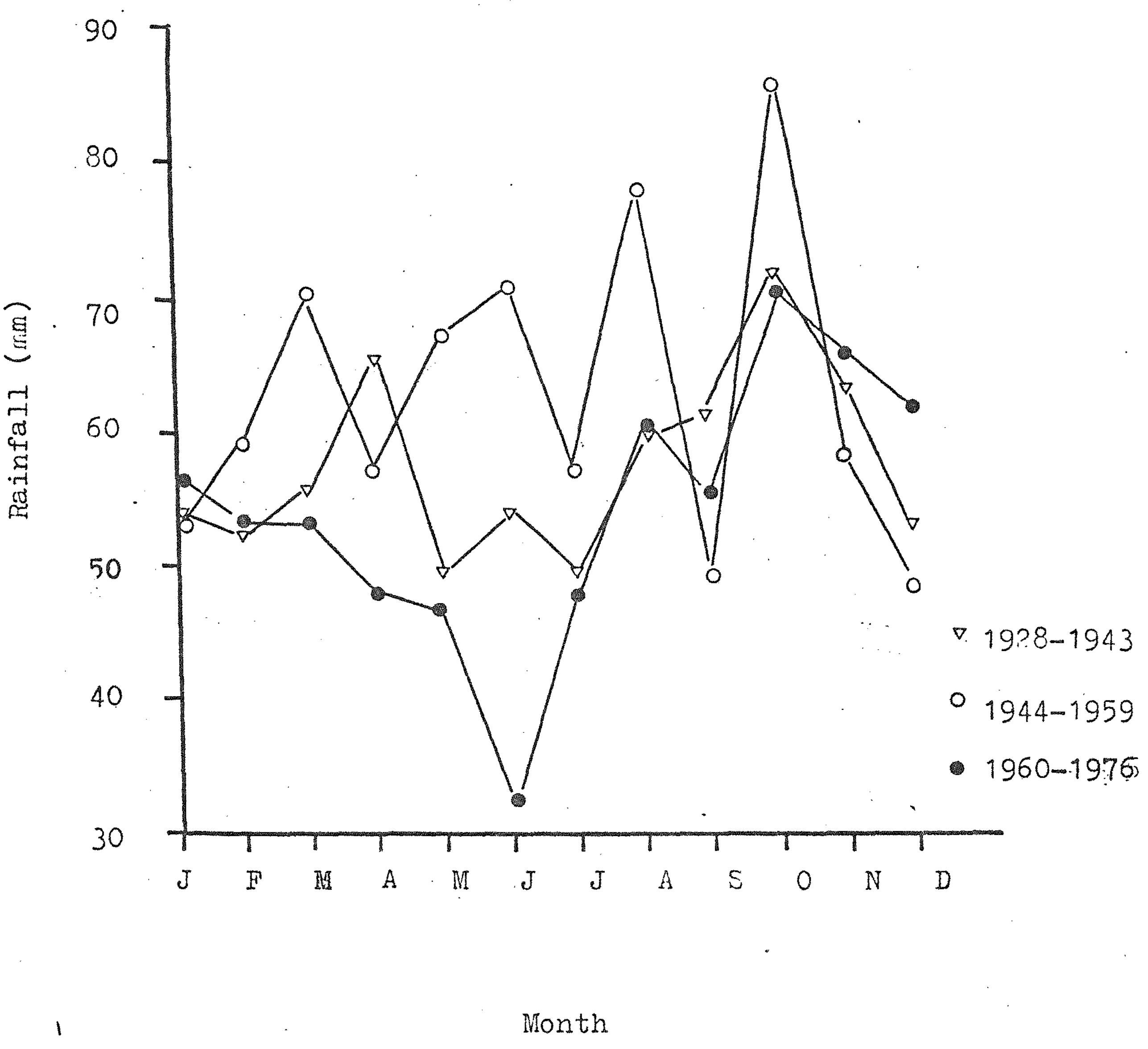
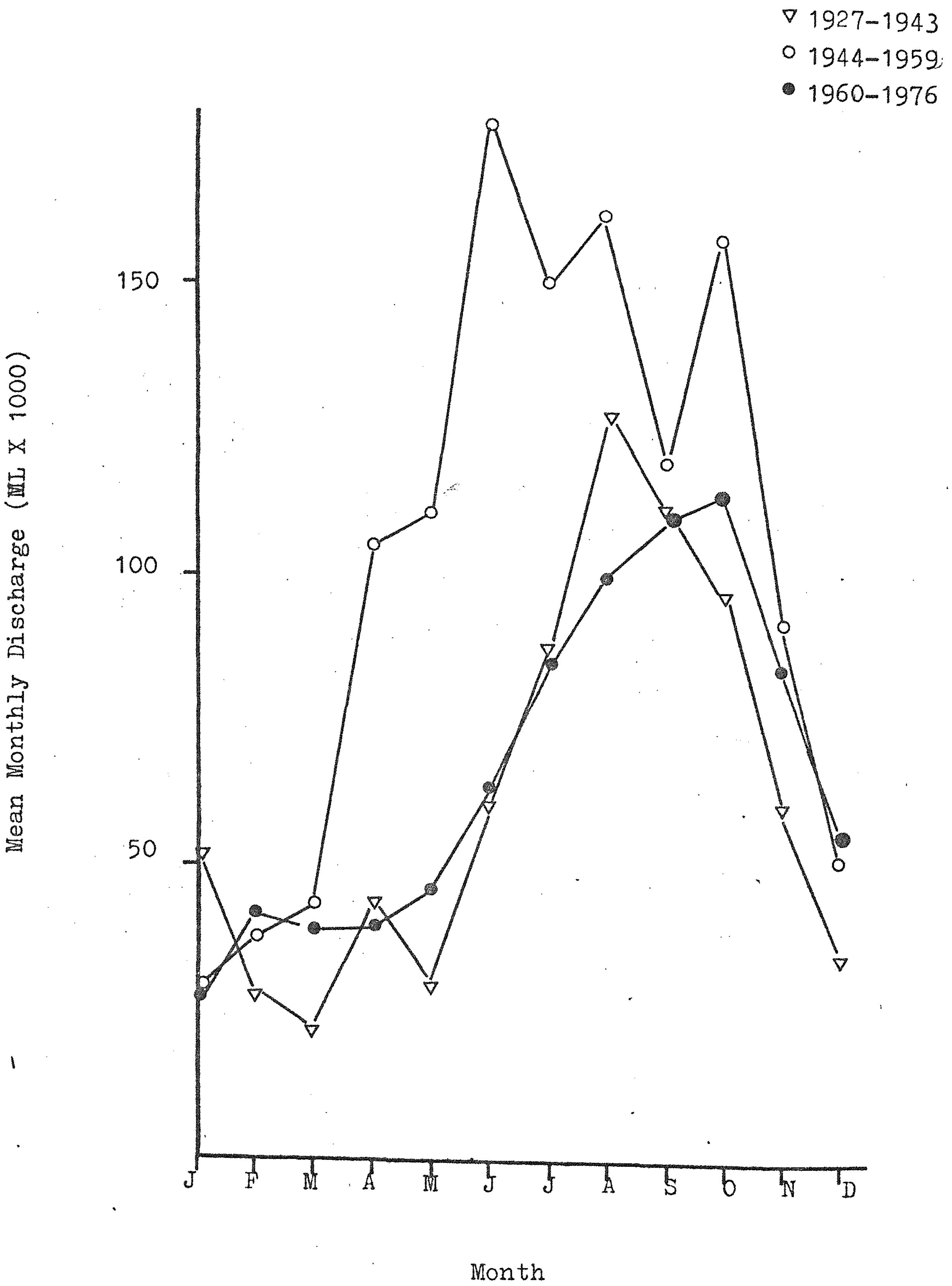


Figure 5.4 Mean Monthly Flows in the Murrumbidgee River at Cotter Crossing/Mt. McDonald.



and are not meant to be a mean rainfall for the catchment in the strict hydrological sense.

The mean monthly rainfall of the index stations for the six months between April and September from 1928 - 1943 was 3.6% lower than for the same months from 1944 - 1959. Streamflow for the comparable period was 42% less. However, though stream flow for the period 1960 - 1976 was 46% lower than for the 1944 - 1959 period, the rainfalls for the two periods were nearly identical (Table 5.4).

These rainfall/stream flow data suggest that the operation of Tantangera Reservoir from 1960 onwards has had a significant effect on stream flows between April - September. The effects of farm dams and irrigation practices have not been considered however, and part of the discrepancy may be related to these practices. Also on average approximately 3.6% of the annual reduction in flow in the post 1960 period would be due to water extraction from the Cotter System.

A similar comparison was made for the months October - March (Table 5.5). Between 1928 - 1943 rainfall was 11.1% less than for the period 1944 - 1959 and stream flows 27.2% lower. For the period 1960 - 1976 the index rainfall was 3.9% less and stream flows 12% lower. It would appear that summer flows are less affected by the construction of Tantangera Reservoir as some of the lowered stream flow in the period after 1960 must be accounted for by lower rainfalls which occured during this time and abstraction of water from the Cotter System.

Consequently though one would expect an average annual reduction in stream flow of 27.7% at Cotter Crossing/Mt McDonald in the post 1960 period due to the operation of Tantangera Reservoir, in fact a 46% reduction in flow has occured between the months April -

Table 5.4 Mean Monthly* Rainfall and Stream* Discharges at Cotter Crossing/Mt McDonald for the Months April - September.

	STATION	1928-1943	1944-1959	1960-1976
	Kiandra	145.7	148.6	157.8
	Argalon	112.6	115.6	125.5
	Adaminaby	60.0	60.4	48.7
	Cooma	30.4	36.6	32.3
	Michelago	42.1	44.2	45.2
	Uriarra forest	66.3	65.7	66.4
	Tumut	77.0	77.2	77.0
Mean Rainfall (mm)		76.3	78.3	79.0
Mean Discharge (ML)		80,245	138,533	74,734

* Values for March 1950 omitted.

Table 5.5 Mean Monthly Rainfall and Stream Discharges at Cotter Crossing/ Mt McDonald for the Months October - March.

	STATION	1928-1943	+ 1944-1959	1960-1976
	Kiandra	101.7	115.8	87.1
	Argalon	77.1	83.3	82.6
	Adaminaby	58.6	62.1	60.2
	Cooma	49.3	57.9	62.5
	Michelago	54.6	59.6	64.8
	Uriarra forest	59.2	74.1	76.8
	Tumut	61.5	67.2	64.8
Mean Rainfall (mm)		66.0	74.2	71.3
Mean Discharge (ML)		50200	*68975	60647

*Discharge for March 1950 omitted from calculations.

+ Rainfall for March 1950 omitted from calculations.

September with only negligible reductions in flow occuring between October - March which could be attributable to the operation of the dam.

5.3 Other Impoundments in the Catchment

In the previous section it was shown that flows in the Murrumbidgee River at the Cotter Crossing/Mt McDonald gauging station have been significantly lower in the post 1960 period between the months of April and September. It was also shown that the Cotter River dams could divert from between 1.1% and 13.3% of the flow from the Murrumbidgee on an annual basis.

Downstreams of the gauging station under consideration are the impoundments of Lake Ginninderra on Ginninderra Creek, Lake Burley Griffin on the Molonglo River and Googong Reservoir on the Queanbeyan River all of which will further reduce the flows in the Murrumbidgee. The relative size of these storages and their catchments are shown in Table 5.1 along with the other impoundments in the catchment.

The percentage reduction in flow that is caused by the diversion from a reservoir will depend on which parts of the river are being compared and the years which were used to derive the mean flow from which the reduction is being calculated. In the previous section the mean flow at Cotter Crossing/Mt McDonald from which the reduction in river flow brought about by the Cotter System and Tantangera Dam was computed was the mean discharge at this station for the length of record prior to 1960 (1928 - 1959). Use of the annual flows after this date will artificially reduce mean values as the effect of the dams are being felt.

The Department of Housing and Construction has compared the mean annual natural flow to the mean annual regulated flow for the

Burrinjuck Catchment (Figure 5.5). It is not clear however on which years the mean river flows were based. For example the mean annual discharge for the Cotter Crossing/Mt McDonald Station between 1928 - 1959 was calculated to be 1,045,194 megalitres by the author. However Figure 5.5 shows the mean annual flows in the Murrumbidgee after the entrance of the Cotter River to be 704,000 megalitres. The authors values only consider the period up to 1959.

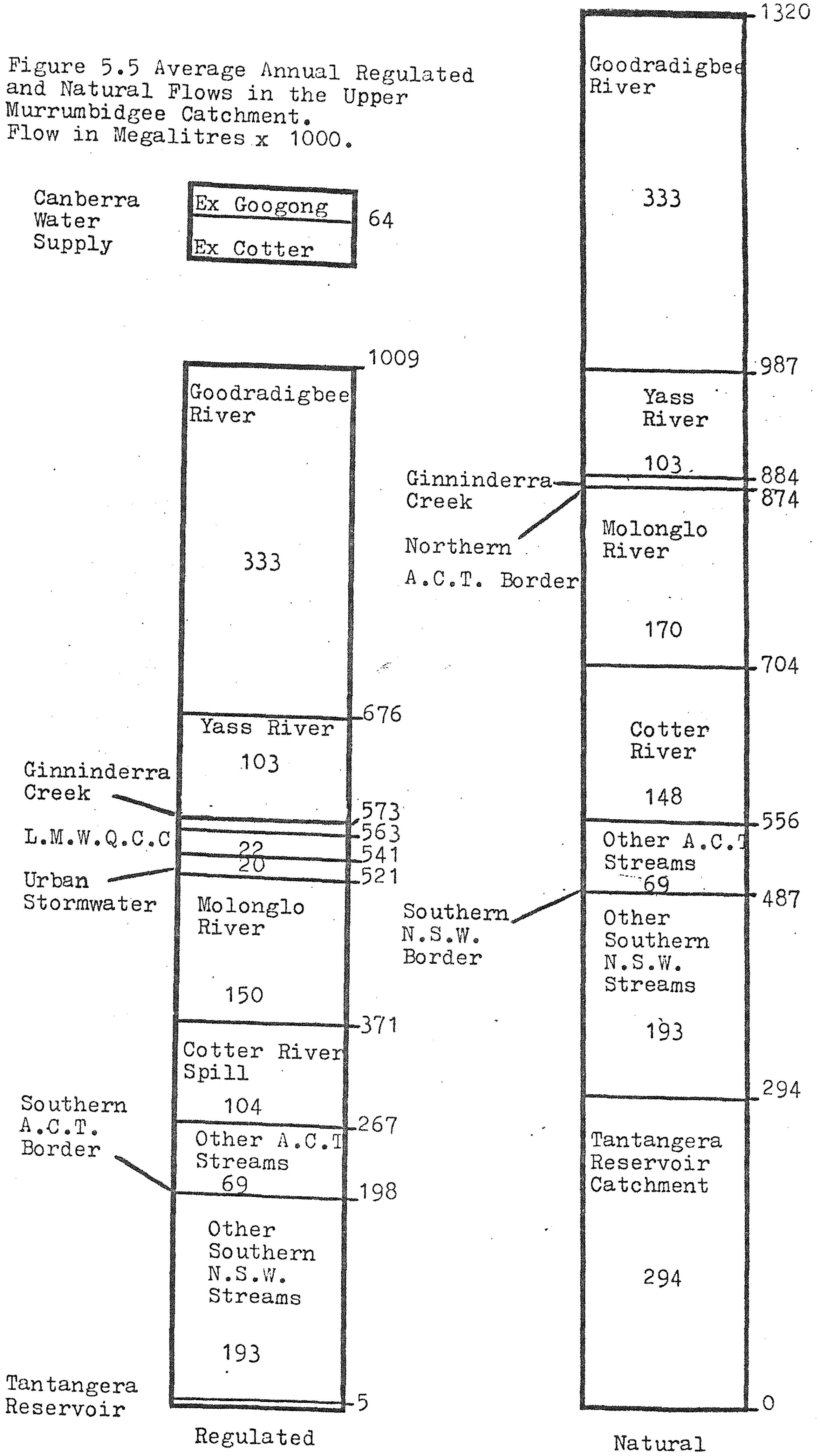
Despite these discrepencies it is instructive to note the percentage reduction in flows experienced in the Murrumbidgee as it passes from the southern to the northern ACT border based on the Transport and Construction figures. As it enters the ACT at the southern end there is an average annual reduction in flow of 59.3% brought about by the diversion from Tantangera Reservoir. After entrance of the Cotter River the reduction is 47.3% and at the northern border 35.6%. As the river reaches Burrinjuck its flow is 23.5% less than the natural flow.

Dam construction in the catchment has had a significant impact on river flows and much of the effect is felt within the ACT boundary.

Though Tantangera Reservoir has had the greatest impact it was shown earlier that most of its effect was experienced between April and September. Though it represented an average annual reduction of 27.7% of the mean annual flow at Cotter Crossing/Mt McDonald (calculations by author) or 35.6% of the mean annual natural flow at the ACT Northern border (Transport and Construction figures) most of this effect was experienced between April and September when reductions in flow were shown to be in excess of 45%. (See section 5.2).

The Cotter and Molonglo River diversions represented only 7.3% of the natural flow at Northern NSW border (based on Figure 5.5). The

Figure 5.5 Average Annual Regulated and Natural Flows in the Upper Murrumbidgee Catchment.
Flow in Megalitres x 1000.



Source: Department of Transport and Construction.

effect however may not be distributed evenly throughout the year and may in fact be higher for certain months and lower for others.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Summary of Main Seasonal Hydrological Changes

The principle changes in the seasonal hydrological criteria which were investigated are shown in Table 6.1 for each of the periods under consideration.

6.2 Potential Significance of Hydrological Changes for the Fishery

6.2.1 Mean flows

The mean monthly discharge at Cotter Crossing/Mt McDonald for the months October - March combined was only slightly lower between 1960-1976 than the mean discharge for the period 1944-1959. This difference could be accounted for by a slightly lower catchment rainfall during this time.

The construction of Tantangera Reservoir and the dams in the Cotter Catchment in the post 1960 period appear to have had a relatively minor impact on flows during the months which are critical for the movement and spawning of native fish.

There is no evidence that the perceived decline in the native fishery can be attributed to low flows between October and March brought about by the construction of Tantangera Reservoir.

The mean monthly discharge for the months April - September combined has been significantly lower in the period between 1960-1976 and is comparable to the mean flow experienced during the drought cycle 1927-1943. Rainfall for the period 1960-1976 however was similar to that which occurred during the relatively wet climatic cycle which occurred between 1944-1959.

Table 6.1 A Comparison of the Seasonal Hydrological Features of the Murrumbidgee River at Cotter Crossing/Mt McDonald for the Periods 1928-1943, 1944-1959, 1960-1976 for the Months (a) October - March and (b) April - September.

(a) October - March

Criteria Being Compared		1928-1943	1944-1959	1960-1976
Mean Monthly Rainfall (mm)		66.0	74.2	71.4
Mean Discharge (ML/month)		50 200	68 975	60 646
Frequency Distribution of Daily Flows (ML)	% of days between			
	0 - 1000ML	59.6	51.1	55.9
	1000-5000ML	34.4	37.2	36.9
	5000ML	6.0	11.3	7.1
Flood Recurrence	Flow (ML/day) which recurred every			
	2 years	9 000	15 000	18 000
	3 years	13 000	30 000	36 000
	4 years	15 500	42 000	46 000
Median Discharge (ML/day)		705	920	840

Table 6.1 con't

(b) April - September

Criteria Being Compared		1928-1943	1944-1959	1960-1976
Mean Monthly Rainfall (mm)		76.3	78.3	79.0
Mean Discharge (ML/month)		80 245	138 532	74 734
Frequency Distribution of Daily Flows	% of days between			
	0 - 1000ML	38.5	30.6	53.9
	1000-5000ML	47.8	44.7	36.6
	5000ML	13.7	24.6	9.5
Flood Recurrence	Flow (ML/day) which recurred every			
	2 years	18 000	25 000	21 000
	3 years	30 000	31 000	33 000
	4 years	40 000	42 000	44 000
Median Discharge (ML/day)		1 420	2 210	896

Consequently much of the reduction in flow, for the April to September period post 1960 can be attributed to the construction of Tantangera Reservoir. The Cotter Dam system was shown to exert a relatively small effect on flows (mean of 3.6%) when compared to the total reduction in mean flow of over 45% for these months.

The reduction in mean winter flows would not be expected to have an effect on native fish whose main feeding and breeding behaviours are adapted to lower summer flows.

However rainbow and brown trout are cold water species which actively feed and spawn through the winter months. This may have resulted in decreased spawning and survival of young due to the decreased carrying capacity brought about by the Tantangera diversion.

Under these conditions it is unrealistic to expect the trout numbers to return to their formal level of abundance.

6.2.2 Frequency and severity of flooding

The probability of the recurrence of a flow of a given magnitude for the period 1960 - 1976 did not differ significantly from that which occurred between 1944 - 1959, for either the period April to September or October to March. However, for the period April to September the number of flow events in excess of 9000 megalitres was only 60% of that which occurred between 1944 - 1959 and was comparable to the number which occurred between 1928 - 1943.

There was no reduction in either the frequency or severity of flooding during the months critical for spawning and movement of native fish in the post 1960 period.

The period 1928 - 1943 was the driest on record to 1976 and the flood level which could be expected to recur every two summers was 9000 megalitres (per day). In the remaining two periods the flood which had a two year recurrence interval was much greater in magnitude.

Managing the Upper Murrumbidgee River so that a fishery is at least sustained under conditions of lowered flow would involve manipulating flows so that flooding is not reduced below that which occurred during the dry cycle 1928 - 1943 - ie a rise of 9000 megalitres per day at least once every other summer as measured at Cotter Crossing/Mt McDonald.

This flood level however does not take into consideration the benefit that may be derived from the scouring effect of more numerous high flows or the fact that under these minimal conditions the fishery may be sustained at a much lower level of abundance than would otherwise occur.

During the April - September period between 1960 - 1976 many more days occurred in the low flow range 0-1000ML/day and there were fewer flows in excess of 9000ML/day. These lower flows may have had significance for the trout fishery as mentioned earlier.

6.2.3 Pattern of river rise

Visual examination of daily plots of river flows did not show any obvious differences in the pattern of river rise between the three periods.

6.2.4 Siltation and turbidity

Though the problem of siltation was not investigated as a major part of this study, its effects should not be overlooked. Though empirical evidence is lacking, the effect of deposition of silt in the rivers and streams of the region is one of the most obvious changes which has occurred over the years. The filling in of deep holes in the river and the siltation of spawning sites has resulted in a marked reduction in habitat available for the various species.

This may in part be due to the reduction in the number flood flows in the post 1960 with a consequent reduction in flood time scour, but is also linked to changes in the quality of the runoff. Runoff originating from urban and grazing areas is associated with higher turbidities for longer periods when compared to woodland habitats. As was pointed out earlier, golden perch appear to require a rise in river level in order to spawn. Though native to warm turbid waters it is questionable whether their pelagic eggs can withstand the prolonged and high turbidities associated with floods which do occur.

Moreover many other inputs are associated with high flow events which lower the quality of water available to the fish at this critical time.

Consequently though neither changes in flow volumes nor in the severity of flooding could be shown to be associated with the perceived decline in the native fishery, the impact of changes in water quality parameters associated with flood flows and the effects of the many other factors outlined only briefly in the overview warrant further investigation.

BIBLIOGRAPHY

Alabaster, J.S. and R. Lloyd 1980. Water Quality Criteria for Freshwater Fish. London: Butterworths.

Barlow, C. 1983. Paper presented at the First Freshwater Aquaculture Workshop held at Narrandera 22 - 25 February 1983 on survival of fish in farm dams.

Beinssen, K.H.H. 1978. Recreational and commercial estuarine fishing in Victoria: a preliminary study. Victorian Fisheries and Wildlife Division: Fish. Wildl. Pap. 16, 40pp.

Beer T., Young, P.C., Humphries, R.B., and J.S. Burgess 1982. Environmental Water Quality: A Systems Study in Tuggeranong Creek and Kambah Pool. Canberra: A.N.U. Press.

Bryan, E.H. 1972. Quality of stormwater drainage from urban land. Wat. Res. Bull. 8: 578-588.

Cadwallader, P.L., 1977. J.O. Langtry's 1949 - 1950 Murray River investigations. Victorian Fisheries and Wildlife Division: Fish. Wildl. Pap. 13, 70pp.

Cadwallader, P.L. 1978. Some causes of the decline in range and abundance of native fish in the Murray-Darling River System. Proc. Roy. Soc. Vic. 90: 211-224.

Cadwallader, P.L., and R.O.J. Tilzey 1979. Paper presented at Symposium on "Dammed Waters" held during the 18th Annual Conference of the Australian Society for Limnology at Tallangatta 19-20 May 1979.

Castenholz, R.W. and C.E. Wickstrom 1975. 'Thermal Streams'. In B: A. Whitton B.A. Studies in Ecology, Volume 2. River Ecology: 264-285. London: Blackwell Scientific Publications.

Collins, A.J. 1976. Inland Angling in N.S.W. N.S.W. State Fisheries Research Bulletin No. 14.

Cooper, M.J. and G.A. Wheatley 1981. An examination of the fish population in the River Trent, Nottinghamshire using angler catches. J. Fish Biol. 19: 539-556.

Cordery, I. 1976. Some effects of urbanisation on streams. Institute of Engineers, Australia. CE 18(1): 7-11.

Cornish, P.M. 1977. Changes in seasonal and annual rainfall in N.S.W. Search 6: 504-508.

Costin, A.B. 1980. Runoff and soil and nutrient losses from an improved pasture at Ginninderra, Southern Tablelands N.S.W. Australia. J. Agr. Res. 31: 533-546.

Cullin, P., Rosich, R.S. and P. Bek 1978. A phosphorous budget for Lake Burley Griffin and management implications for urban lakes. A.W.R.C. Technical Paper No. 31.

Cullin, P. and R.S. Rosich 1979. Effects of rural and urban sources of phosphorous to L.B.G. Prog. Water Rech. 11: 219-230.

Dawdy, D.R. 1967. Knolwedge of sedimentation in urban environments. Proceedings of the A.S.C.E. J. Hydraul Div. 93: 235-245.

Greenham, P. 1981. Murrumbidgee River Aquatic Ecology Study. School of Applied Science, Canberra College of Advanced Education, Australia.

Gutteridge, Haskins and Davey Pty. Ltd. and the Environmental Protection Authority of Victoria 1981. Characterisation of pollution in urban stormwater runoff. A.W.R.C. Technical Paper No. 60.

Hart, B.T. 1974. A compilation of Australian water quality criteria. A.W.R.C. Technical Paper No. 7.

Hobby, J.E. and G.E. Likens 1973. Output of phosphorous, dissolved organic carbon and five particulate carbon from Hubbard Brook watersheds. Limnol. Ocean 18: 734-742.

Holmes, A.N. 1978. Studies of Forms of Nitrogen in Streams Near Adelaide, South Australia. MSc thesis, University of Adelaide.

Jackson, P.D. 1981. Trout introduced into South-Eastern Australia - Their interactions with native fishes. Victorian Naturalist 98: 18-23.

Kendall, P. 1980. Murrumbidgee Ecological Survey: Resources and Land Use Evaluation for the River Corridor in the A.C.T. N.C.D.C. Internal Report No. 1/80.

Kluesnar, J.W. and G.F. Lee 1974. Nutrient loading from a separate storm sewer in Madison, Wisconsin. J. Watter Poll. Control Fed. 46, 920-936.

Lake, J.S. 1967. Rearing experiments with five species of Australian Freshwater fishes; Inducement to spawning. Aust. J. Mar. Freshwat. Res. 18: 137-153.

Llewellyn, L.C. 1968. Tagging gives answers to fish growth queries. Fisherman (N.S.W.) 3: 1-5.

McColl, R.H.S. 1979. Factors affecting downslope movement of nutrients in hill pastures. Prog. Water Tech. 11: 271-285.

Menzel, R.G., Rhoades, E.D., Olness, A.E. and Smith S.J. 1978. Variability of annual nutrient and sediment dishcarges in runoff from Oklahoma cropland and rangeland. J. Env. Qual. 7, 401-412.

N.C.D.C. 1978. A.C.T. Region Water Quality Study.

N.C.D.C. 1980. Monitoring stormwater flow water quality in paired rural and urban catchments in the A.C.T. Technical Paper No. 29.

N.C.D.C. 1981. Waters of the Canberra Region. Technical Paper No. 30.

Nicholaichuk, W. and D.W.L. Read 1978. Nutrient runoff from fertilized and unfertilized fields in Western Canada. J. Env. Qual. 7: 542-544.

Olness, A., Rhoades, E.D., Smith, S.J. and R.G. Menzel 1980. Fertilizer nutrient losses from rangeland watersheds in Central Oklahoma. J. Envir. Qual. 9: 81-86.

Philp, D.M. 1982. Waste disposal to Australian inland rivers. Proc. of a Symposium on the Prediction in Water Quality (Australian Academy of Science): 417-435.

Pittock, A.B. 1975. Climatic changes and patterns of variation in Australian rainfall. Search 6: 498-504.

Ridley, J.E. and J.A. Steel 1975. 'Ecological Aspects of River Impoundments'. In B.A. Whitton, River Ecology: 565-587. London: Blackwells.

Rosich, R.S. and P. Cullen 1981. Water Quality in Canberra's Urban Lakes. Water Studies Group, School of Applied Science, Canberra College of Advanced Education, Canberra, Australia.

Searchy, J.K. 1959. Flow Duration Curves - Manual of Hydrology: Part 2 - Low Flow Techniques. Washington: U.S. Government Publishing Service.

Sharpley, A.N. and J.K. Syers 1979. Phosphorous inputs into a stream draining an agricultural water shed. II Amounts contributed and the relative significance of runoff types. Water Air Soil Poll. 11: 417-428.

South Australian Fisheries Industry Council 1976. Decline of Native Fish in the River Murray, No. 8.

Snowy Mountains Hydro Electric Authority 1957. Report on Hydrology and Meteorology of the Murrumbidgee Eucumbene Diversion.

Tilzey, R.D.J. 1980. 'Introduced Fish'. In W.D. Williams, A Ecological Basis for Water Quality Management: 271-279. Canberra A.N.U. Press.

Uttormark, P.D., Chapin, J.D. and K.M. Green 1974. Estimating nutrient loadings of lakes from non point sources. Report No. PA 660/3-74-020, Environmental Protection Agency, Washington.

Weatherley, A.H., Beevers, J.R., and P.S. Lake 1967. 'The Ecology of a Zinc Polluted River'. In A.H. Weatherley, Australian Inland Waters and Their Fauna: 252-278. Canberra: A.N.U. Press.

Wolman, M.G. 1964. Problems posed by sediment derived from construction activities in Maryland. Report to the Maryland Water Pollution Control Commission, Annapolis Md.

Wolman, M.G. 1967. A cycle of sedimentation and erosion in urban river channels. Geographisker Annaler. 49D: 385-395.

Appendix 1

Tabulation of Existing Land Uses in the Upper Murrumbidgee Basin

Basin	Description	Area ha.	Existing Land Use: Forest %	Rural %	Urban %
Mbgee	Tantangera - Mittagang Rd	189 600	58.3	41.7	
	Mittagang Rd - ACT Border	320 300	45.4	54.2	0.4
	Angle Crossing - Molonglo (excluding Naas/Gudgenby, Tuggeranong, Cotter and Paddy's catchments)	28 400	19.7	79.9	0.4
	Molonglo R - ACT Border	9 800	44.9	55.1	
	ACT Border - Taemas Br. (excluding Ginninderra)	46 500	6.3	93.7	
Gudgenby	Naas Gudgenby Rivers	68 800	81.0	19.0	
Cotter	Headwaters - Murrumbidgee	48 300	100.0		
Paddy's	Headwaters - Cotter River	24 600	65.4	34.6	
Tugger-anong	Melrose Valley - Mbgee	6 400	4.6	36.9	58.5
Molonglo	Headwaters - East Basin (excluding Queanbeyan R)	66 920	30.5	64.7	4.1
	East Basin - Scrivener Dam (excluding Jerrabomberra, and Sullivans Creek)	4 730	3.2	6.3	77.2
	Scrivener Dam - Mbgee (excluding Yarralumla and Weston Creeks)	7 080	16.9	76.8	6.3
Quean-beyan	Headwaters - Molonglo R	96 900	50.6	47.2	1.4
Jerrab-omberra	Headwaters - East Basin	13 000	6.2	87.3	6.3
Sullivans	Headwaters - West Lake	5 030	0	23.8	76.2
Yarralumla	Headwaters - Molonglo R	3 450	4.3	2.9	92.1
Weston	Headwaters - Molonglo R	1 750	1.4	0	98.6
Ginnind-erra	Headwaters - ACT Border	13 425	0	52.3	47.7
	ACT Border - Murrumbidgee (excluding Gooromon Pd)	570	8.8	91.2	
Gooromon	Hall - ACT Border	8 279	0	92.1	7.9

Source: N.C.D.C. Draft Water Use Plan for the A.C.T.

Appendix 2

Annual Discharges at Cotter Crossing/ Mt. McDonald Gauging Station

Year	Annual flow (megalitres)	Annual Runoff (mm)	Year	Annual flow (megalitres)	Annual Runoff (mm)
1928	564 010	85.3	1944	371 490	56.2
1929	578 940	87.7	1945	720 280	109
1930	345 720	52.3	1946	886 710	134
1931	871 260	132	1947	692 220	105
1932	796 430	120	1948	1 060 200	160
1933	542 015	82.2	1949	1 030 800	156
1934	2 556 300	387	1950	3 505 500	531
1935	1 102 100	167	1951	1 423 500	215
1936	811 200	123	1952	2 622 950	397
1937	579 500	87.7	1953	908 800	138
1938	344 120	52.2	1954	344 040	52.1
1939	1 079 120	163	1955	981 790	149
1940	258 084	39.1	1956	3 797 100	575
1941	462 290	70.0	1957	365 380	55.3
1942	859 067	130	1958	783 970	119
1943	772 910	117	1959	1 428 400	216
TOTAL	12 523 066	1896	TOTAL	20 923 130	3168
MEAN	782 692	118.5	MEAN	1 307 696	198
1960	1 153 750	175	1977	278 000	40.9
1961	1 490 400	226	1978	1 600 000	235
1962	742 200	112	1979	250 000	36.7
1963	857 100	130	1980	81 611	12.0
1964	1 019 720	154	TOTAL	2 209 612	324.6
1965	190 530	28.8			
1966	668 830	101			
1967	260 050	39.4			
1968	173 070	26.2			
1969	572 890	86.8			
1970	659 980	99.9			
1971	737 400	112			
1972	251 170	38			
*1973	327 000	48			
1974	2 140 000	314			
1975	1 760 000	258			
1976	795 000	116			
TOTAL	13 799 090	2065			
MEAN	811 711	121.5			

* From 1973 onwards discharges are at Mt McDonald

Appendix 3

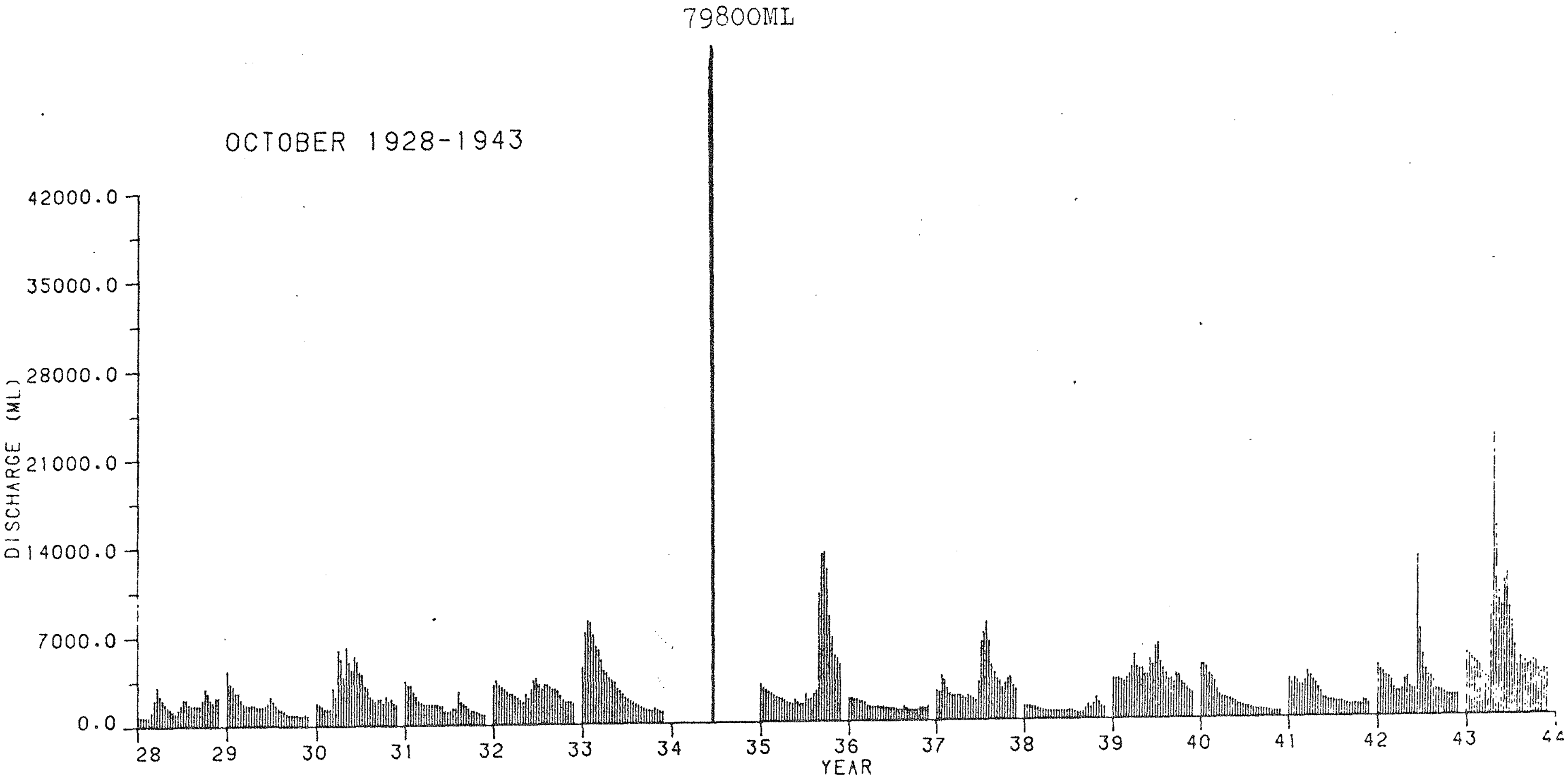
Mean Monthly Flows (ML) in the Murrumbidgee River at Cotter Crossing/Mt. McDonald (Station No. 410035/410738).

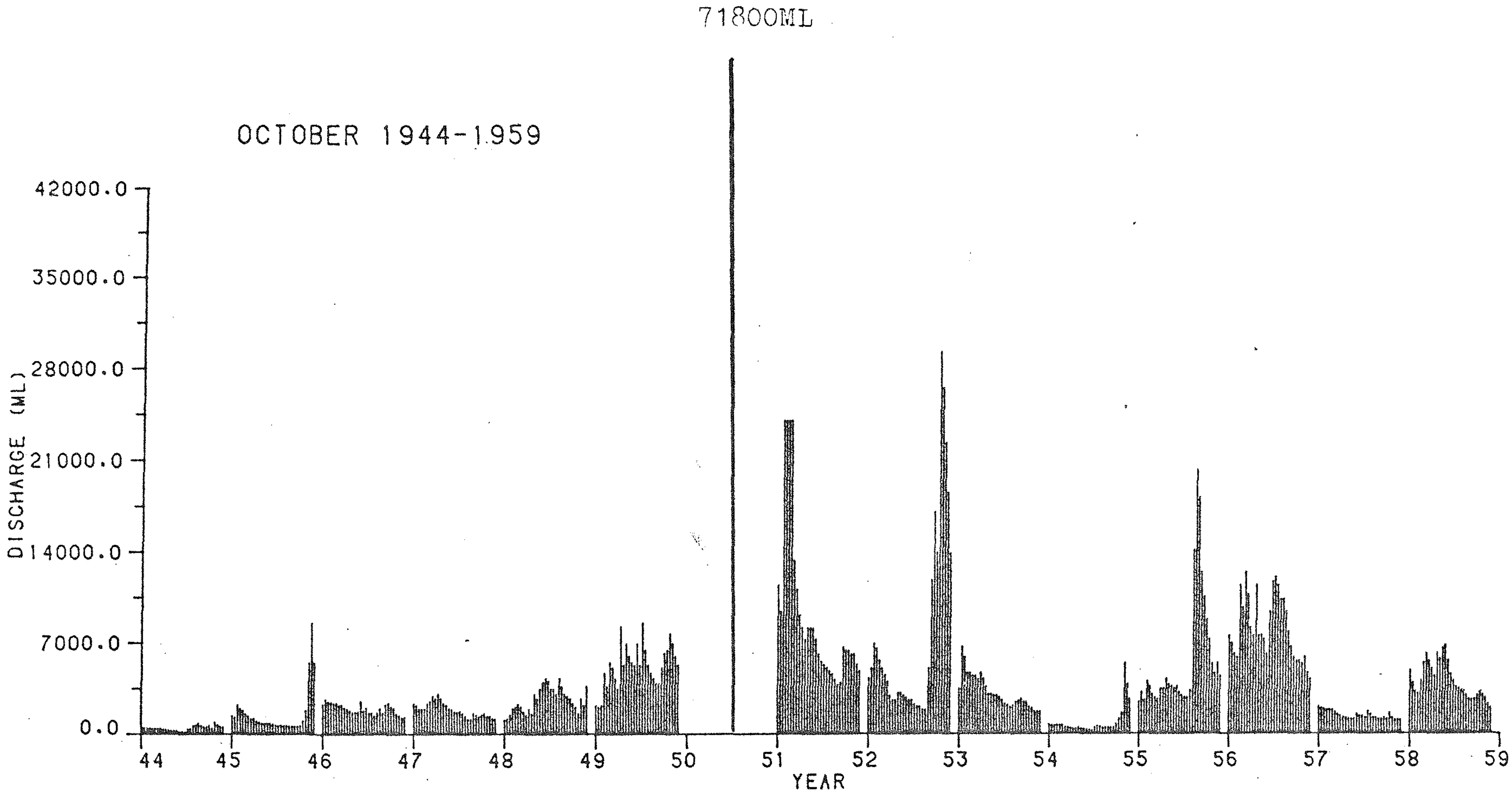
Month	1928-1943	1944-1959	1928-1959	1960-1976	1960-1980	1928-1976
January	52 520	29 656	41 088	28 250	24 980	36 634
February	30 640	31 878	31 628	42 172	36 005	35 039
March	24 154	*47 607	*35 508	39 640	46 344	*36 972
April	46 746	106 471	76 608	40 673	38 756	64 141
May	31 658	111 836	71 747	46 498	44 710	62 987
June	64 093	178 475	121 284	63 488	76 724	101 233
July	91 856	150 963	121 409	85 404	81 471	108 917
August	132 808	162 475	147 640	100 386	82 290	131 238
September	114 311	120 975	117 653	111 931	107 721	115 668
October	96 519	159 325	121 921	114 056	97 979	123 111
November	60 563	93 218	76 890	84 461	73 900	79 517
December	36 803	52 167	44 485	55 300	47 049	48 237
Mean Annual Flow	782 692	1 307 696	1 045 194	811 711	776 342	964 190

* March 1950 flow omitted

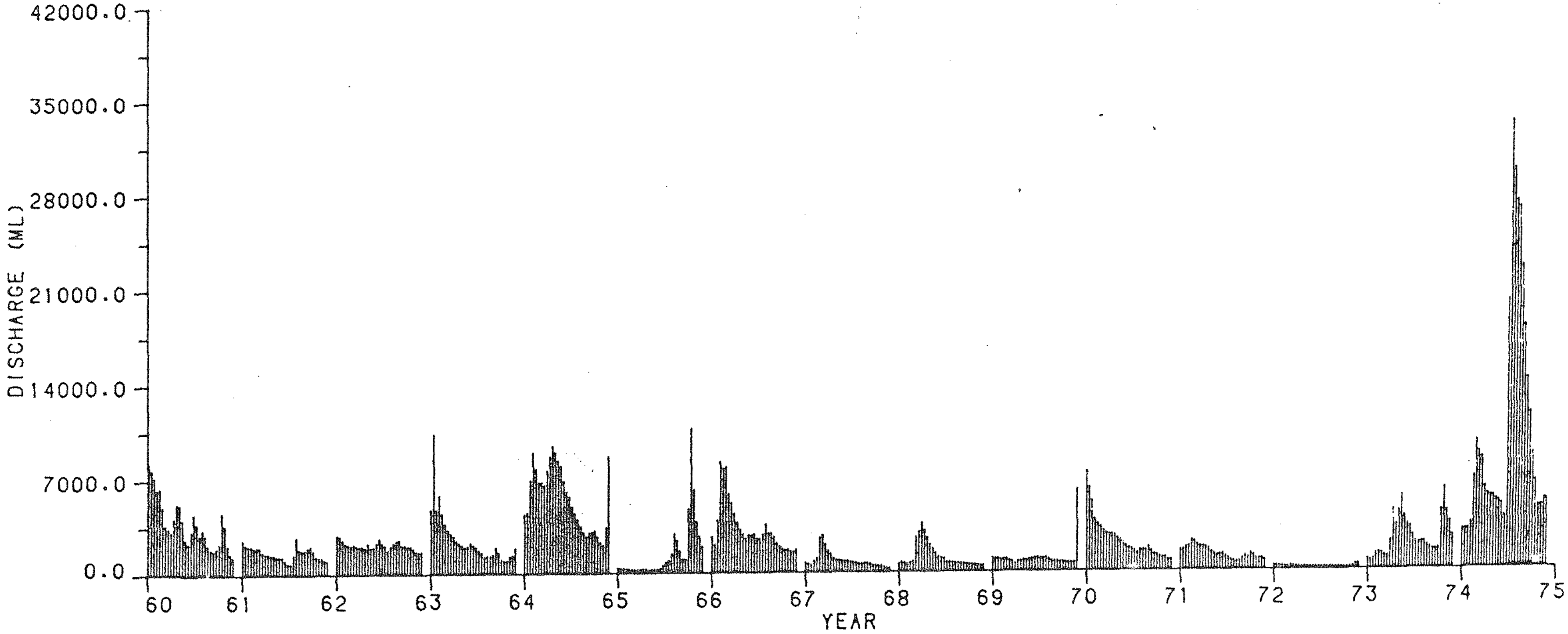
Appendix 4

Plots of Daily Flows (ML) at Cotter Crossing/ Mt McDonald (Station No. 410035/410378) for the Months October, November, January, June, July and August.

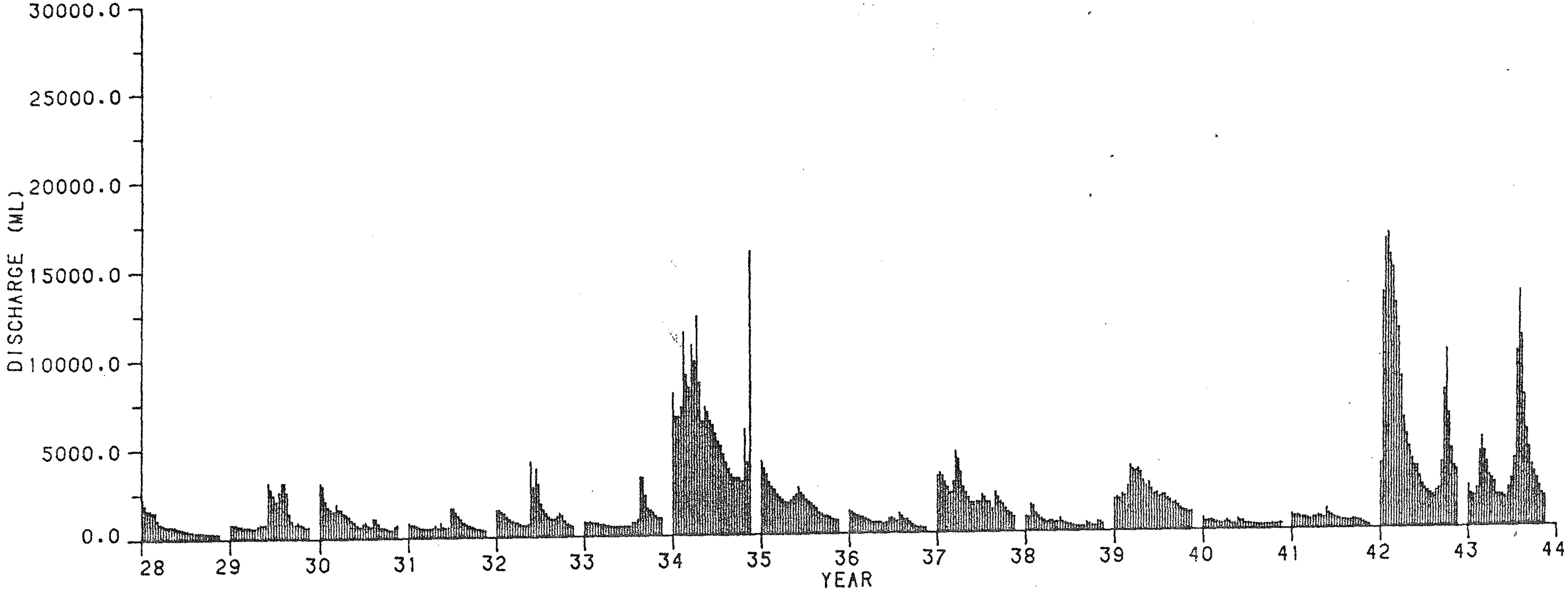

79800ML
OCTOBER 1928-1943
DISCHARGE (ML)
42000.0
35000.0
28000.0
21000.0
14000.0
7000.0
0.0
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
YEAR


71800ML
OCTOBER 1944-1959
42000.0
35000.0
28000.0
21000.0
14000.0
7000.0
0.0
DISCHARGE (ML)
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
YEAR

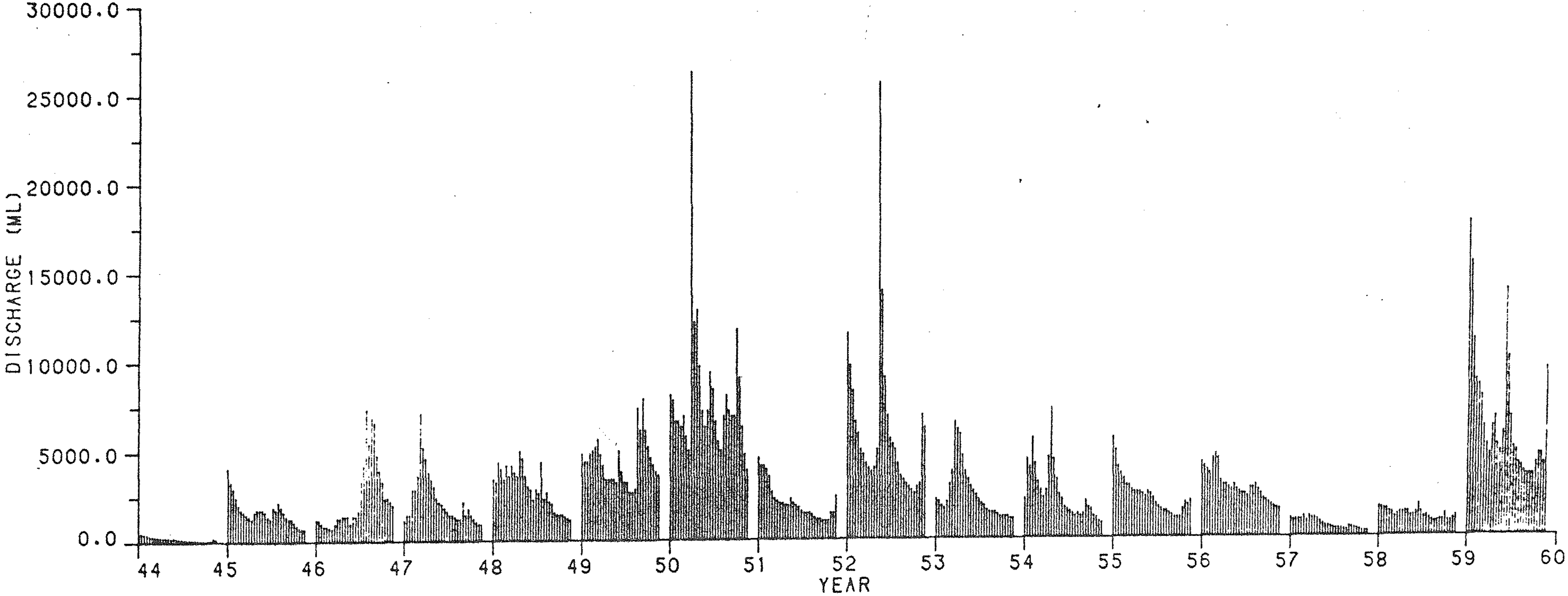
OCTOBER 1960-1976

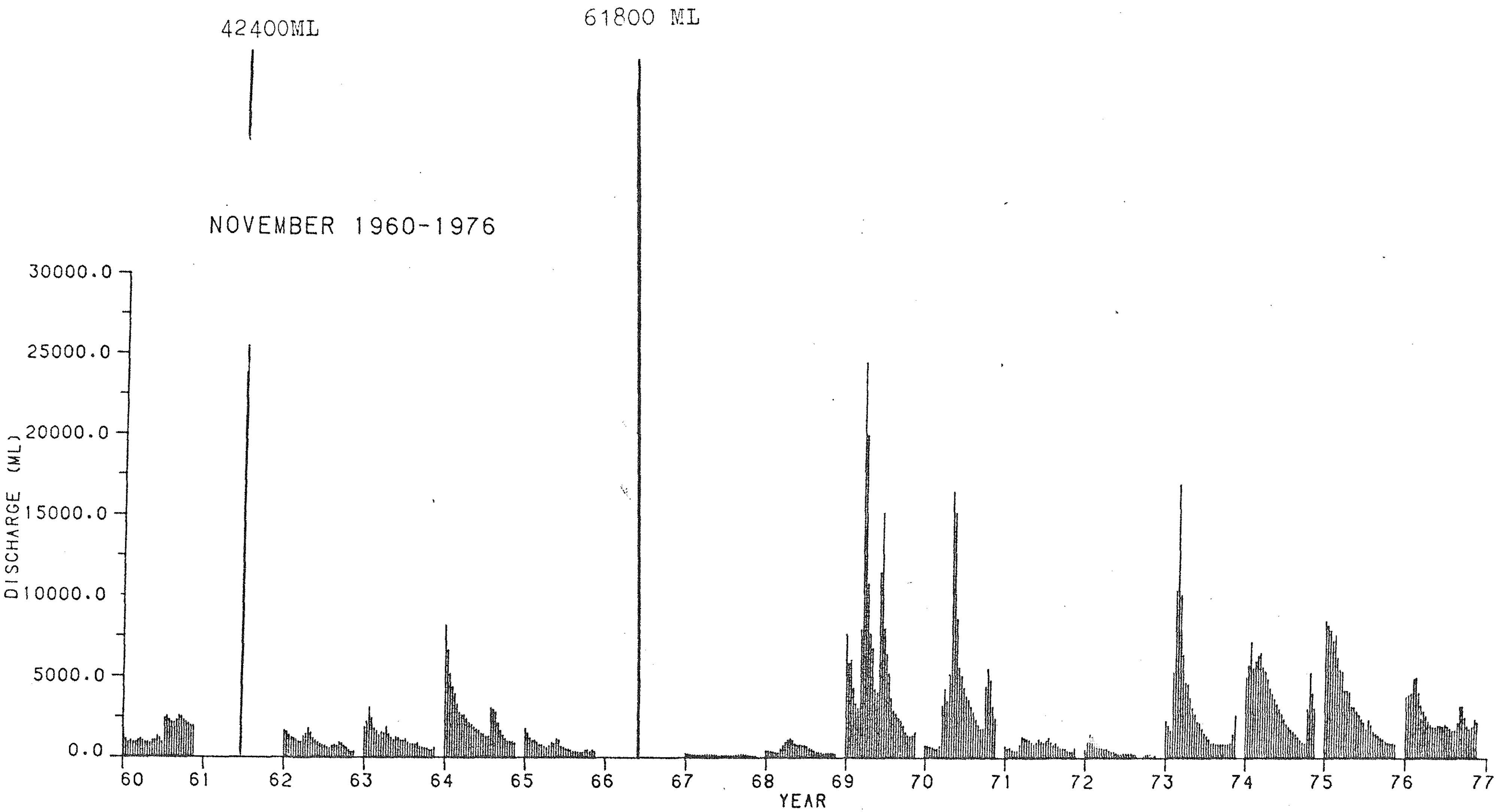


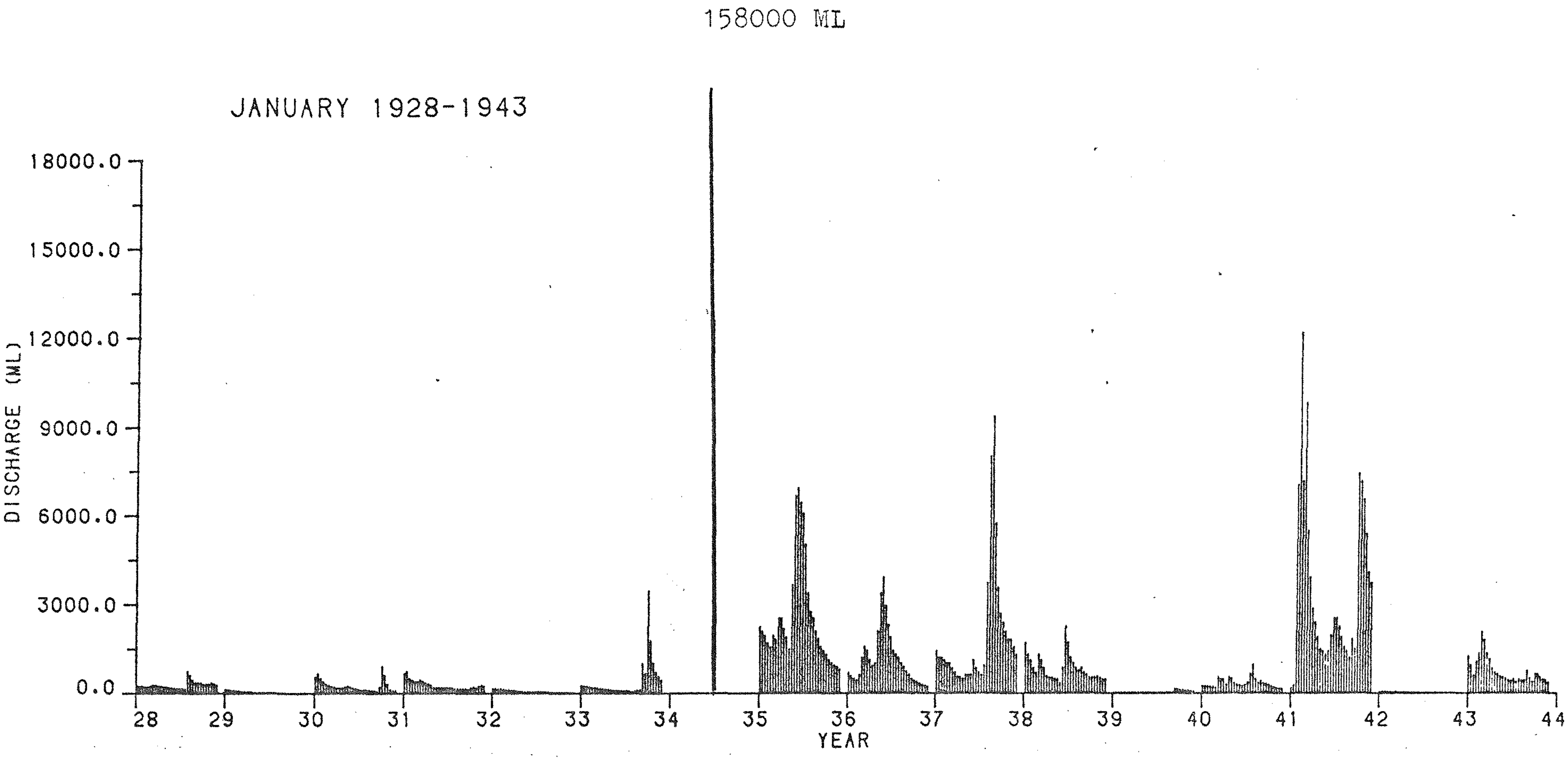
NOVEMBER 1928-1943



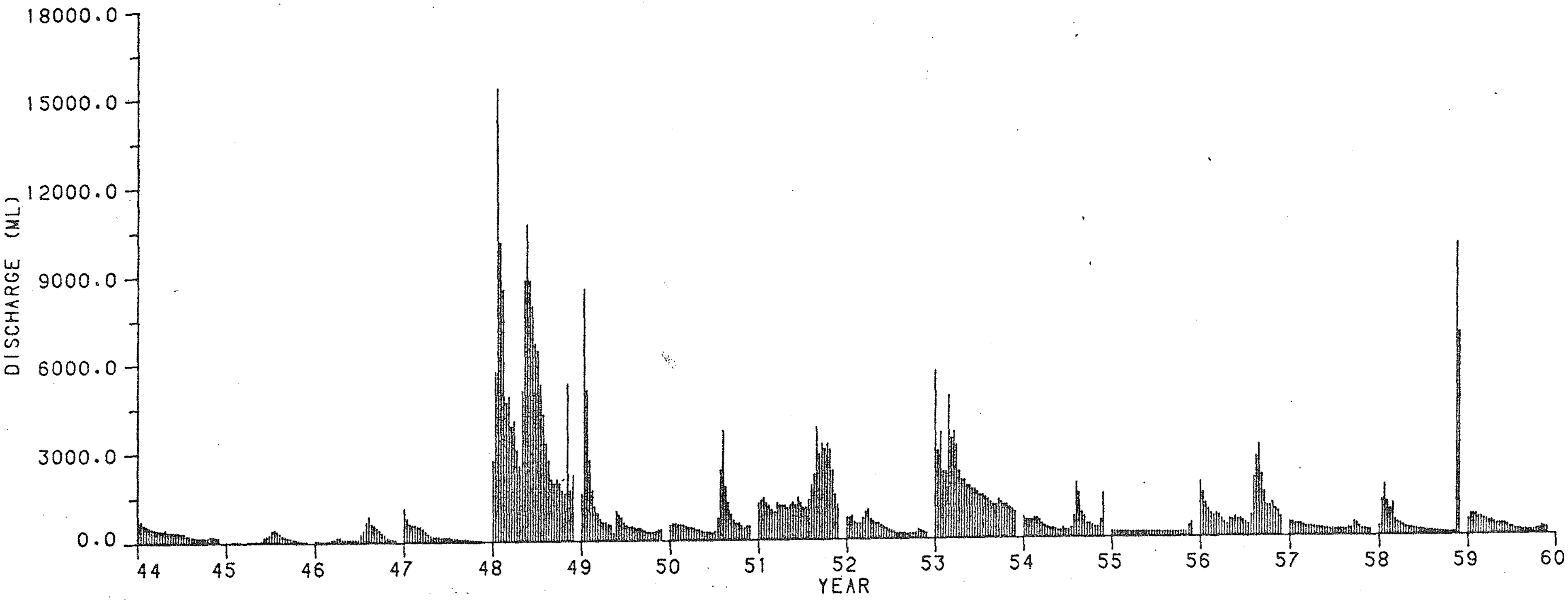
NOVEMBER 1944-1959



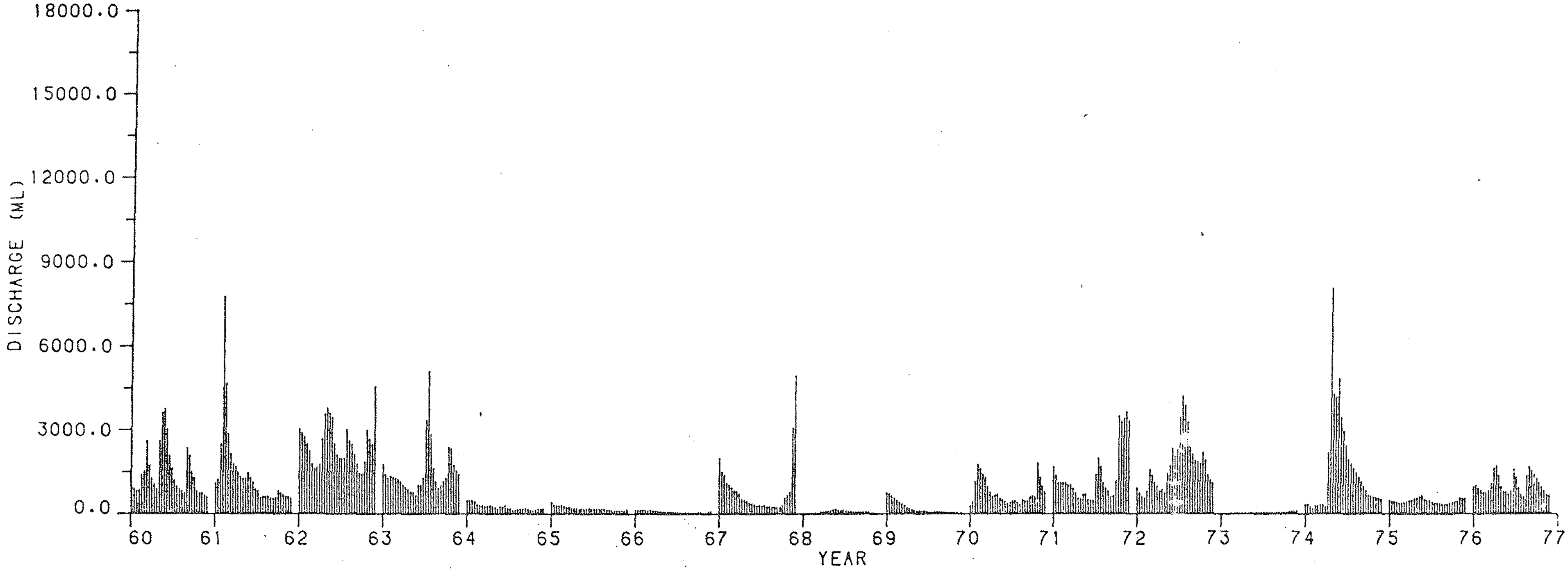

42400ML
61800 ML
NOVEMBER 1960-1976
DISCHARGE (ML)
30000.0
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
YEAR


158000 ML
JANUARY 1928-1943
18000.0
15000.0
12000.0
9000.0
6000.0
3000.0
0.0
DISCHARGE (ML)
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
YEAR

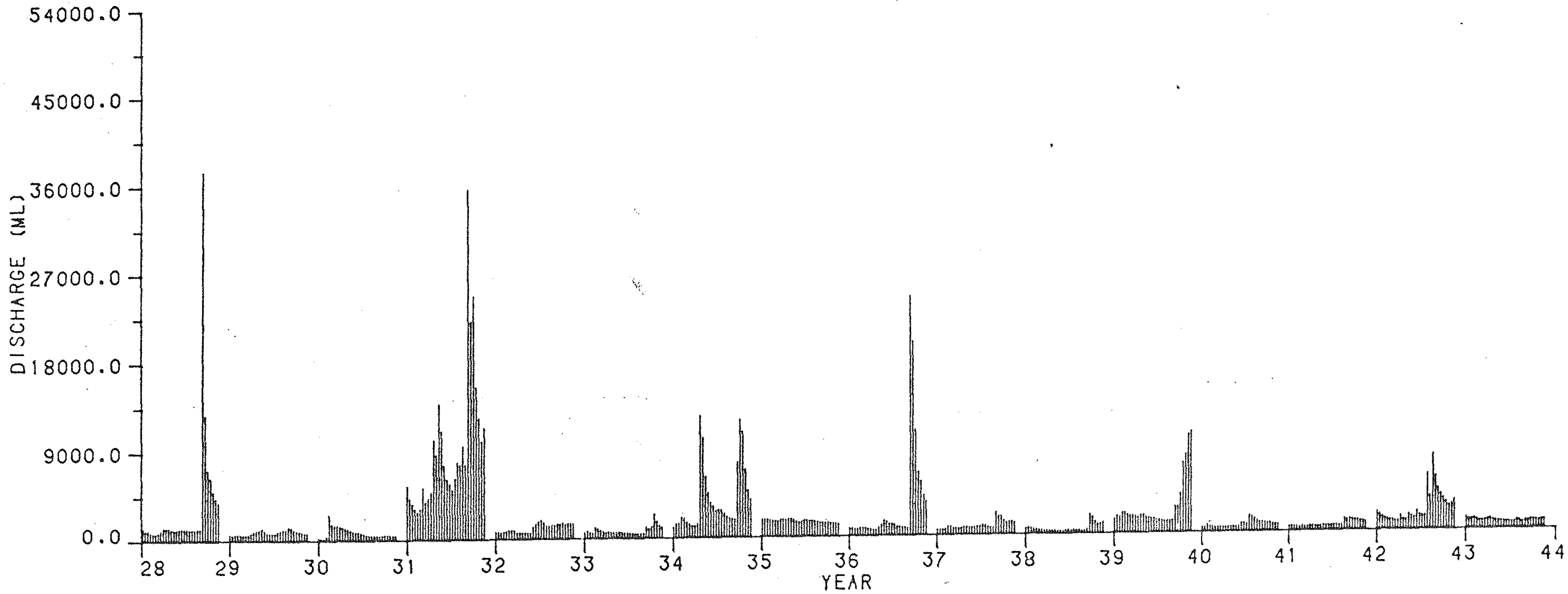
JANUARY 1944-1959

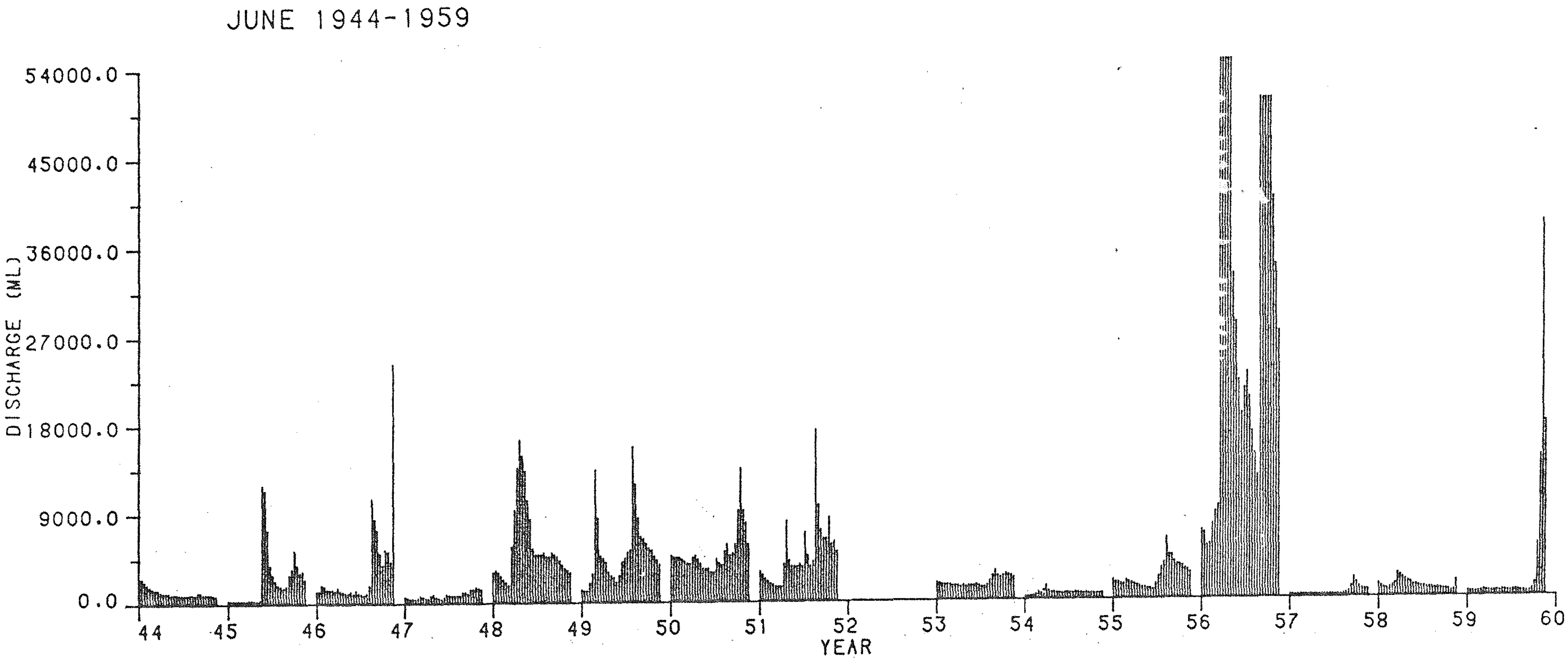


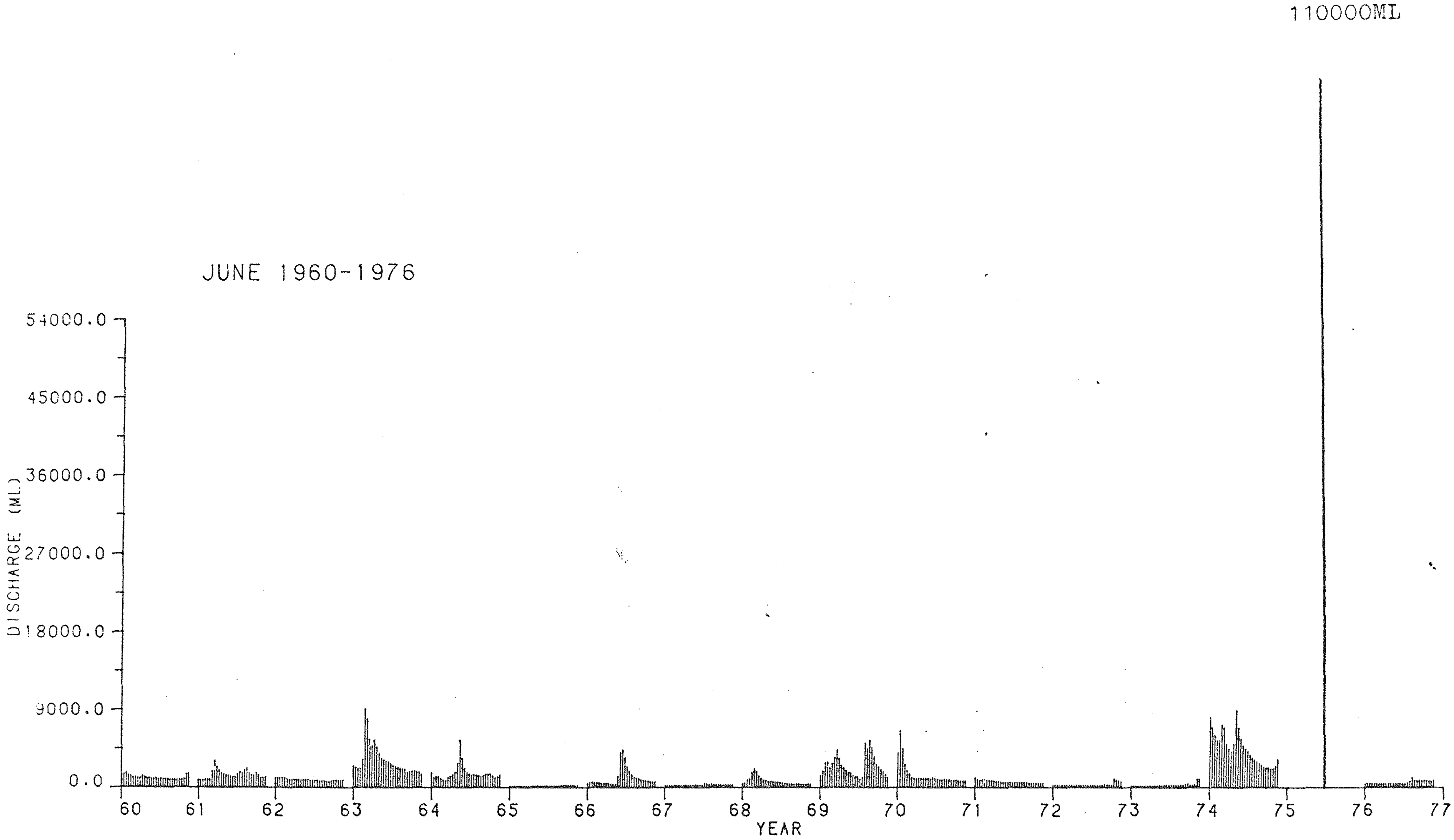
JANUARY 1960-1976

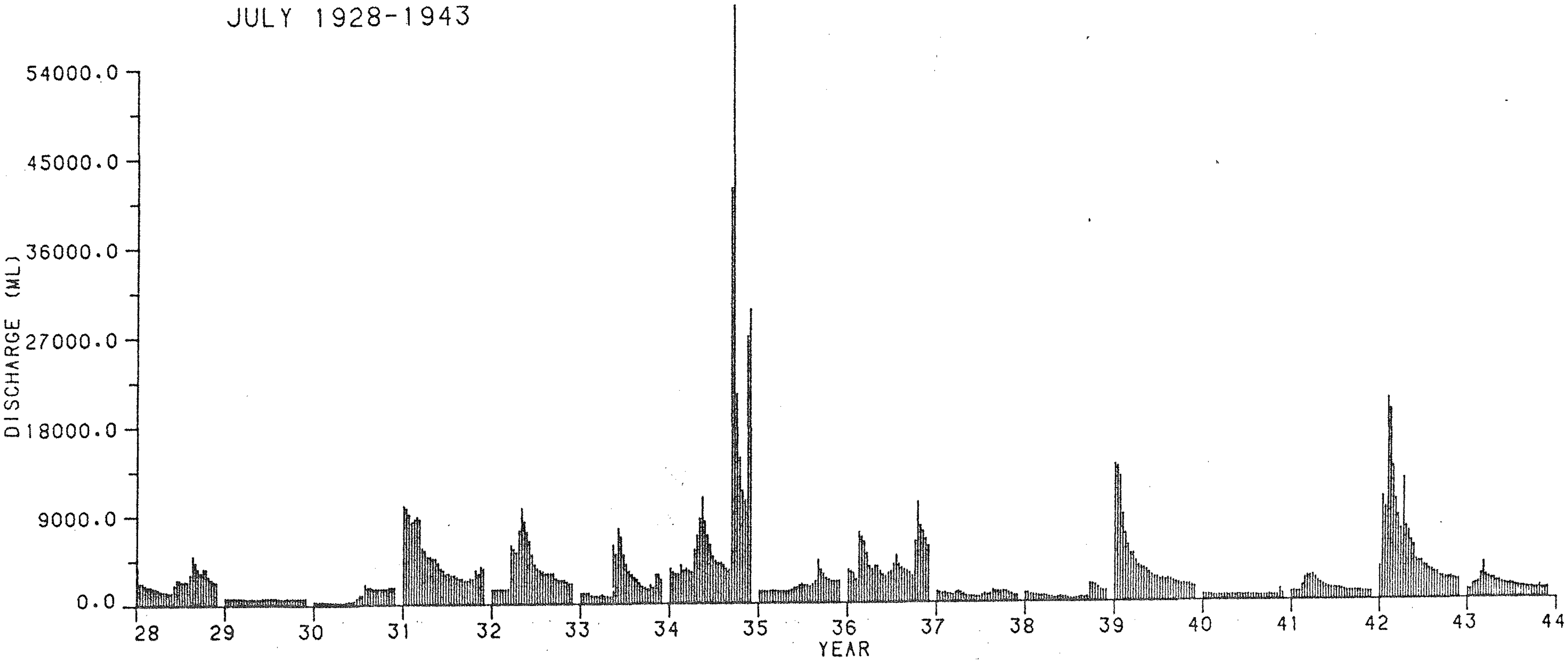


JUNE 1928-1943

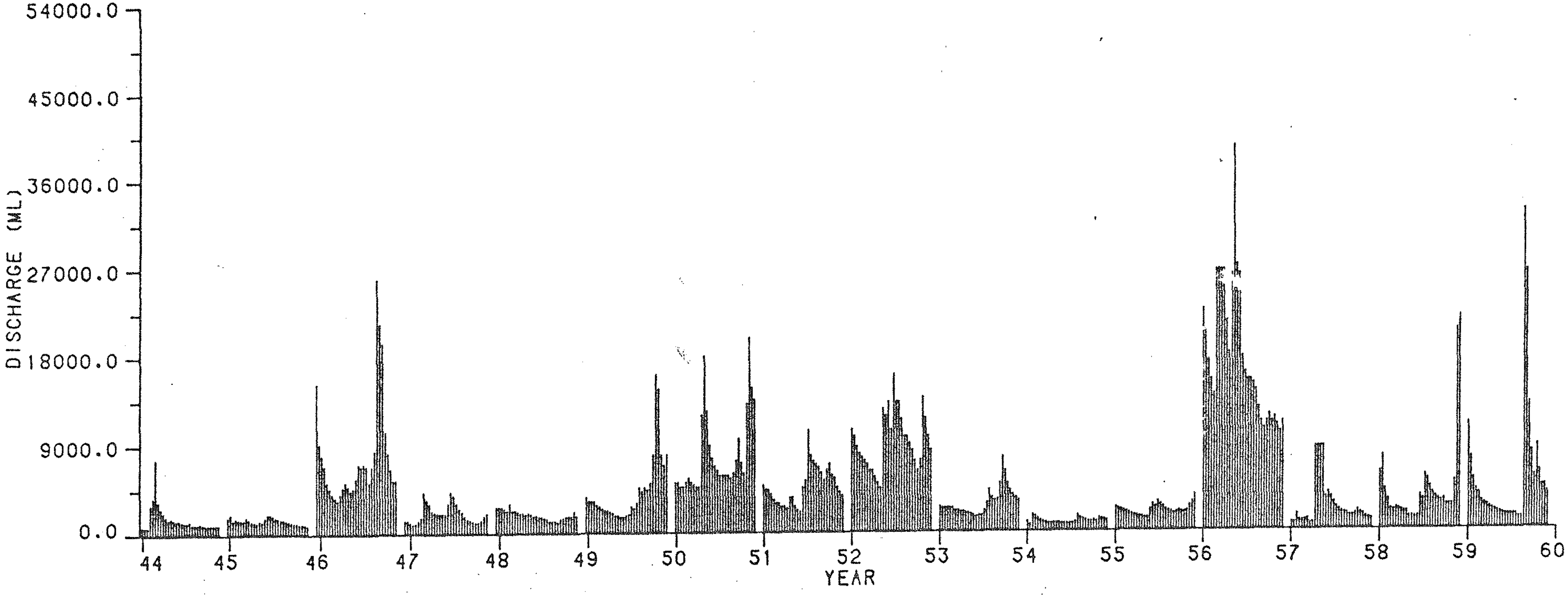


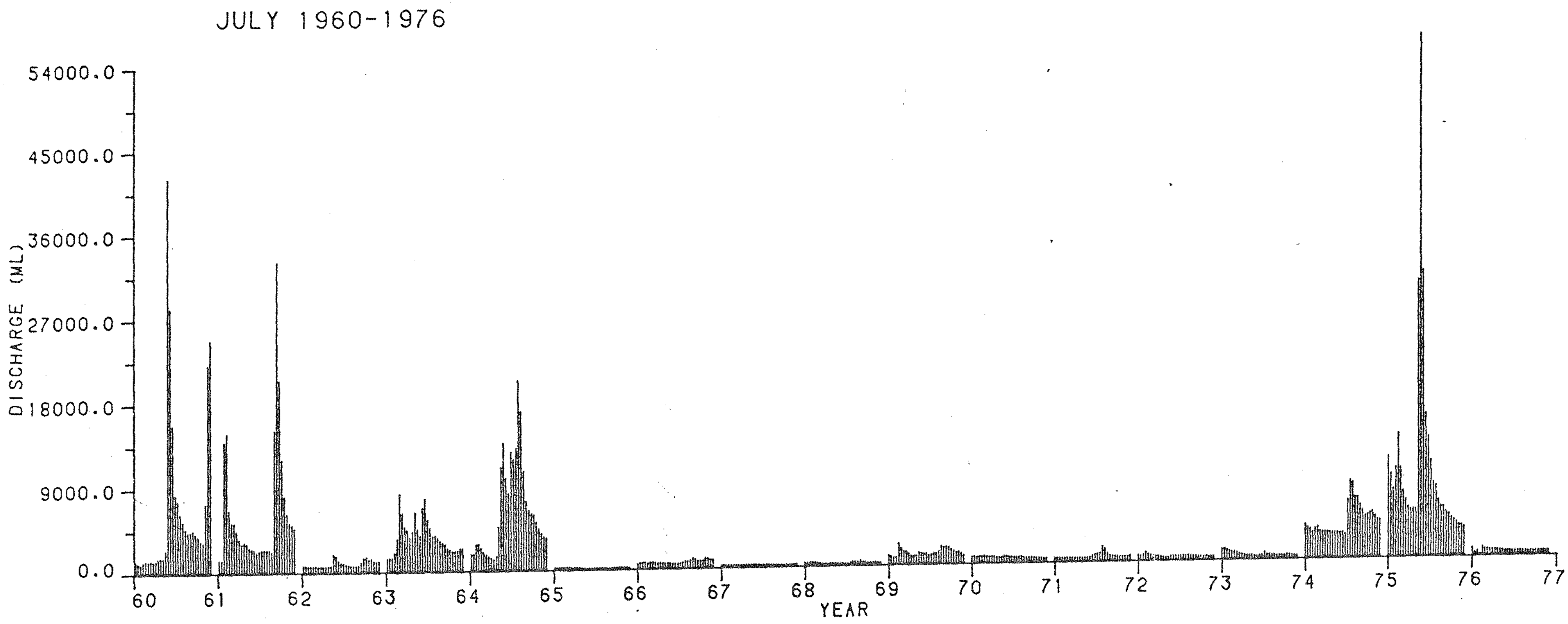

JUNE 1944-1959
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
DISCHARGE (ML)
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
YEAR

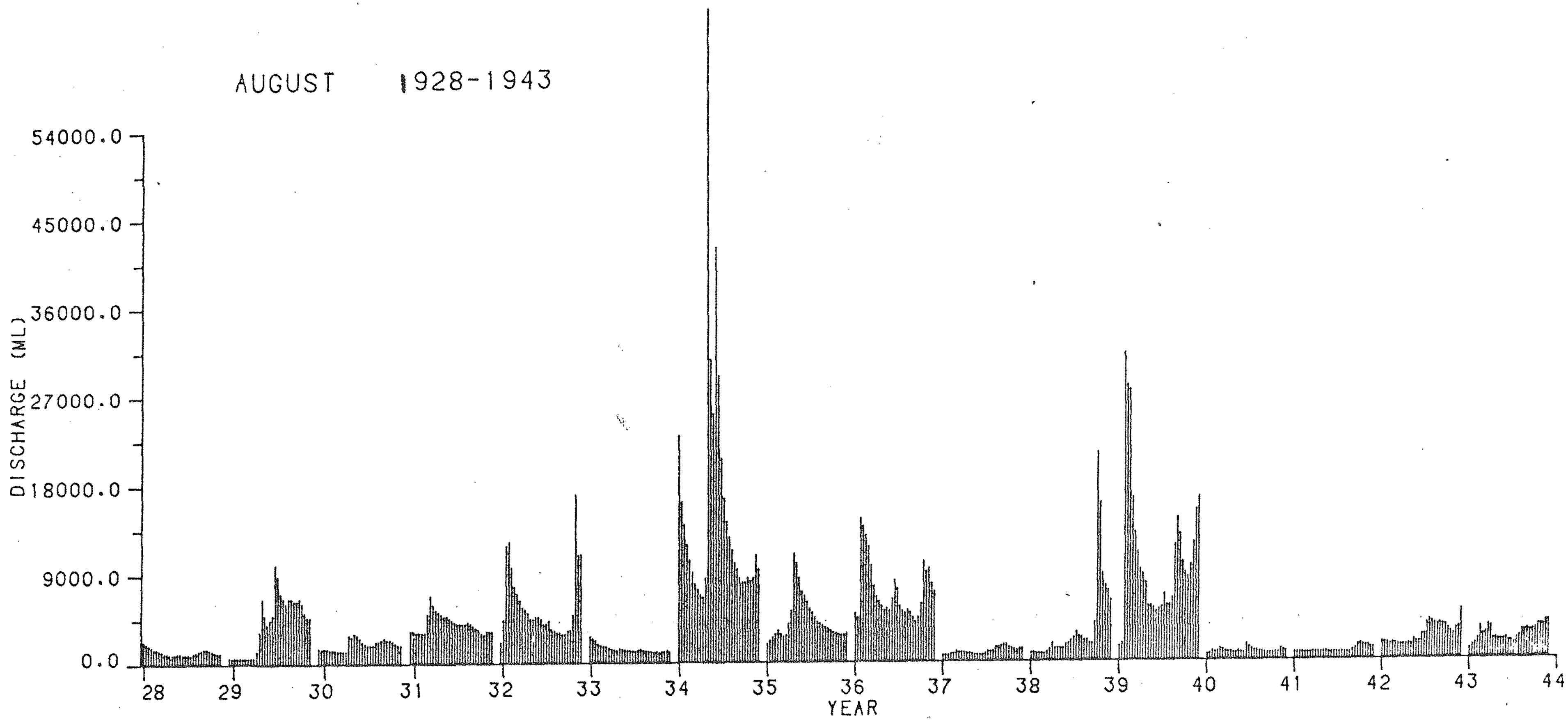

110000ML
JUNE 1960-1976
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
DISCHARGE (ML)
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77
YEAR

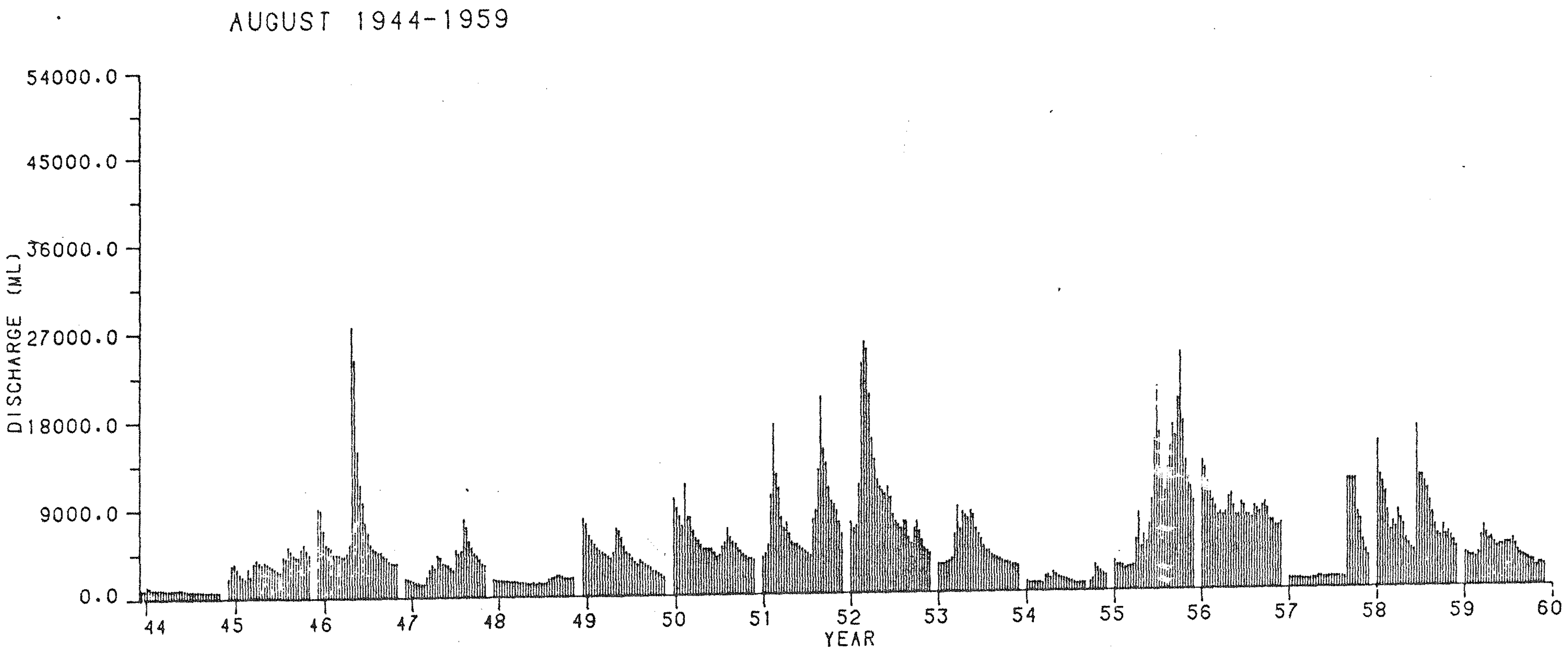

JULY 1928-1943
DISCHARGE (ML)
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
YEAR

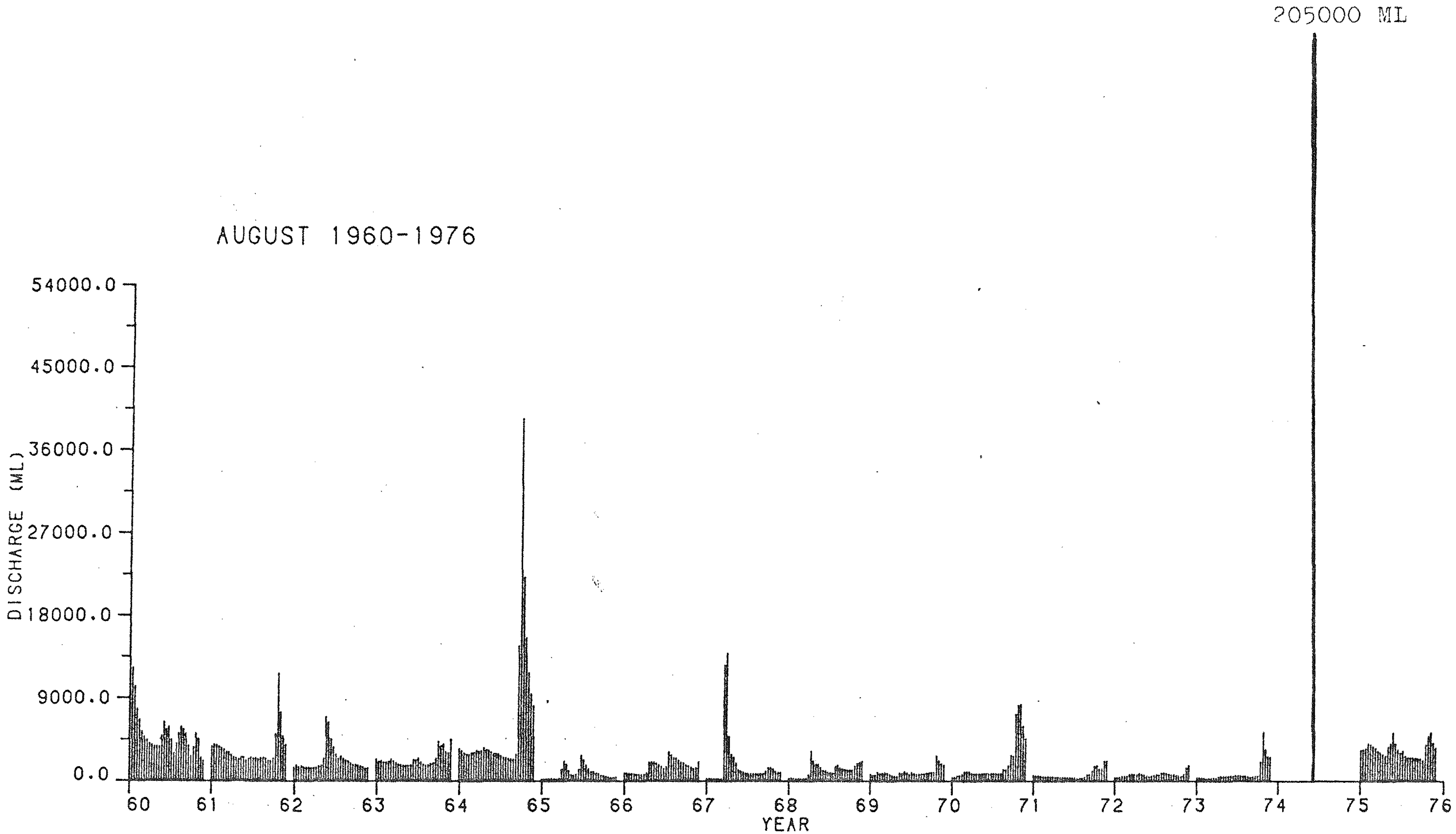
JULY 1944-1959




JULY 1960-1976
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
DISCHARGE (ML)
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
YEAR


AUGUST 1928-1943
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
DISCHARGE (ML)
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
YEAR


AUGUST 1944-1959
DISCHARGE (ML)
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
YEAR


205000 ML
AUGUST 1960-1976
54000.0
45000.0
36000.0
27000.0
18000.0
9000.0
0.0
DISCHARGE (ML)
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
YEAR

Appendix 5

Annual Flows (ML) at the Cotter Kiosk Gauging Station (Station No. 410700) Expressed as a Percentage of Total Flow.

Year	River Flow	* Total Flow	River Flow / Total Flow
1910	72 500	72 500	100%
1911	139 800	139 800	100
1912	141 300	141 300	100
1913	62 800	62 800	100
1914	27 600	27 600	100
1915	204 500	204 500	100
1916	317 600	317 600	100
1917	510 000	510 000	100
1918	154 200	154 200	100
1919	36 000	36 000	100
1920	159 300	159 300	100
1921	188 400	188 400	100
1922	87 100	87 300	99.8
1923	166 000	166 300	99.8
1924	121 300	121 600	99.8
1925	257 300	257 900	99.8
1926	216 800	217 800	99.5
TOTAL	2 852 500	2 864 900	
MEAN	167 852	168 523	99.9

* Total flow = river flow + amount pumped from dams.

Appendix 5

(con't.)

Year	River Flow	Total Flow	River Flow / Total Flow
1927	55 400	56 700	97.7
1928	69 900	71 500	97.8
1929	91 300	93 100	98.1
1930	60 600	62 500	97.0
1931	200 400	202 400	99.0
1932	94 200	96 400	97.7
1933	114 500	116 600	99.0
1934	342 200	344 200	99.4
1935	124 200	126 400	98.3
1936	115 000	117 200	98.1
1937	86 100	88 800	97.0
1938	50 700	54 000	93.9
1939	233 500	236 700	98.6
1940	42 600	46 600	91.4
1941	67 800	71 600	94.7
1942	119 100	122 900	97.0
1943	107 600	111 400	96.6
TOTAL	1 975 100	2 019 000	
MEAN	116 182	118 765	97.8

Appendix 5

(con't.)

Year	River Flow	Total Flow	River Flow / Total Flow
1944	19 300	24 200	79.8
1945	49 200	53 700	91.6
1946	103 100	107 900	95.6
1947	117 300	122 200	96.0
1948	159 300	164 100	97.1
1949	152 300	157 500	96.7
1950	306 300	313 500	97.7
1951	139 000	147 500	94.2
1952	332 500	339 400	98.0
1953	104 800	113 000	92.7
1954	49 500	58 500	84.6
1955	165 000	173 100	95.3
1956	569 300	578 000	98.5
1957	28 600	41 100	69.6
1958	143 200	155 100	92.3
1959	126 200	137 500	91.8
TOTAL	2 564 900	2 686 300	
MEAN	160 306	167 894	92.0

Appendix 5

(con't.)

Year	River Flow	Total Flow	River Flow / Total Flow
1960	190 100	202 500	93.9
1961	185 100	208 900	88.6
1962	130 400	144 800	91.0
1963	109 600	126 400	86.7
1964	249 700	271 200	92.1
1965	31 108	56 343	55.2
1966	122 500	142 000	86.2
1967	11 640	42 197	27.1
1968	28 383	51 460	55.1
1969	120 000	146 461	81.9
1970	152 000	180 287	84.3
1971	113 000	145 539	77.6
1972	47 531	87 491	54.3
1973	110 824	149 632	74.1
1974	350 120	388 782	90.1
1975	169 583	218 619	77.5
1976	60 839	111 579	54.5
TOTAL	2 182 428	2 674 190	
MEAN	128 378	157 305	81.6

Appendix 6

Annual Flows (ML) at the Cotter Kiosk Gauging Station (Station Number 410700) Expressed as Percentage of Annual Flows at Cotter Crossing/ Mt McDonald (Station No. 410035/410738)

Year	Cotter *River Flow	% of Murrumbidgee Flow	Cotter *Total Flow	% of Murrumbidgee Flow	% Reduction in Flow
1928	69 900	12.4	71 500	12.6	0.2
1929	91 300	15.8	93 100	16.1	0.3
1930	60 600	17.5	62 500	18.1	0.6
1931	200 400	23.0	202 400	23.2	0.2
1932	94 200	11.8	96 400	12.1	0.3
1933	114 500	21.1	116 600	21.5	0.4
1934	342 200	13.4	344 200	13.5	0.1
1935	124 200	11.3	126 400	11.5	0.2
1936	115 000	14.2	117 200	14.4	0.2
1937	86 100	14.9	88 800	15.3	0.4
1938	50 700	14.7	54 000	15.7	1.0
1939	233 500	21.6	236 700	21.9	0.3
1940	42 600	16.5	46 600	18.1	1.6
1941	67 800	14.7	71 600	15.5	0.8
1942	119 100	13.9	122 900	14.3	0.4
1943	107 600	13.9	111 400	14.4	0.5
MEAN	119 981	15.3	122 643	15.7	0.4

* Total flow = river flow + amount pumped from dams

Appendix 6

(con't.)

Year	Cotter *River Flow	% of Murrumbidgee Flow	Cotter *Total Flow	% of Murrumbidgee Flow	% Reduction in Flow
1944	19 300	5.2	24 200	6.5	1.3
1945	49 200	6.8	53 700	7.5	0.7
1946	103 100	11.6	107 900	12.2	0.6
1947	117 300	16.9	122 200	17.6	0.7
1948	159 300	15.0	164 100	15.4	0.4
1949	152 300	14.8	157 500	15.3	0.5
1950	306 300	8.7	313 500	8.9	0.2
1951	139 000	9.8	147 500	10.4	0.6
1952	332 500	12.7	339 400	12.9	0.2
1953	104 800	11.5	113 000	12.4	0.9
1954	49 500	14.4	58 500	17.0	2.6
1955	165 000	16.8	173 100	17.6	0.8
1956	569 300	15.0	578 000	15.2	0.2
1957	28 600	7.8	41 100	11.2	3.4
1958	143 200	18.3	155 100	19.7	1.4
1959	126 200	8.8	137 500	9.6	0.8
MEAN	160 306	12.2	167 894	12.8	0.6

Appendix 6

(con't.)

Year	Cotter *River Flow	% of Murrumbidgee Flow	Cotter *Total Flow	% of Murrumbidgee Flow	% Reduction in Flow
1960	190 100	16.5	202 500	17.6	1.1
1961	185 100	12.4	208 900	14.0	1.6
1962	130 400	17.6	144 800	19.5	1.9
1963	109 600	12.8	126 400	14.7	1.9
1964	249 700	24.5	271 200	26.6	2.1
1965	31 108	16.3	56 343	29.6	13.3
1966	122 500	18.3	142 000	21.2	2.9
1967	11 640	4.5	42 197	16.2	11.7
1968	28 383	16.4	51 460	29.7	13.4
1969	120 000	20.9	146 461	25.6	4.7
1970	152 000	23.0	180 287	27.3	4.3
1971	113 000	15.3	145 539	19.7	3.8
1972	47 531	18.9	87 491	34.8	15.9
1973	110 824	33.9	149 632	45.8	11.9
1974	350 120	16.4	388 782	18.2	1.8
1975	169 583	9.6	218 619	12.4	2.8
1976	60 839	7.6	111 579	14.0	6.4
MEAN	128 378	15.8	157 305	19.4	3.6

Appendix 7

le 1 *Monthly and Annual Rainfalls (mm) at seven Regional Rainfall Gauging Stations.

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNU.
ADAMINABY (071000) 36 01 S 138 46 E 1006m elevation													
28-43	53.6	55.3	58.0	69.1	45.7	55.9	48.4	77.4	63.4	70.2	58.9	55.8	710
44-59	53.4	59.3	56.5	57.3	67.9	71.3	57.2	59.5	49.3	91.7	63.0	48.9	764
60-76	56.1	52.9	53.5	48.6	46.9	32.4	48.5	59.8	55.8	70.8	65.6	62.2	653
KIANDRA (071010) 35 53 S 148 30 E 1395.4m elevation													
28-43	87.8	69.2	98.7	146.1	110.8	152.0	140.2	177.6	147.3	150.1	110.8	93.6	1484
44-59	70.4	85.8	93.2	118.5	160.3	173.2	158.9	163.4	117.5	209.5	133.8	102.1	1601
60-76	73.4	48.2	69.4	108.5	181.5	121.8	214.6	176.1	144.4	124.6	112.8	94.3	1464
ARCALON (072003) 35 18 S 148 24 E 527.3m elevation													
28-43	83.4	56.0	74.4	100.9	83.4	136.6	119.4	137.8	97.3	102.2	74.9	71.8	1138
44-59	59.8	71.1	68.7	87.6	120.9	121.1	138.1	130.2	95.8	137.1	95.5	67.7	1214
60-76	69.7	52.7	55.9	90.8	144.9	79.9	148.8	163.5	124.8	138.	93.1	86.2	1245
UT (072044) 35 18 S 148 13 E 280.4m elevation													
28-43	73.0	48.6	67.1	74.5	63.8	89.0	73.1	94.0	67.6	73.9	57.1	49.2	826
44-59	49.9	56.8	59.1	64.8	74.1	78.8	92.9	82.1	70.6	110.5	76.7	50.3	884
60-76	63.8	43.9	55.6	69.5	81.5	51.9	87.5	92.1	79.5	90.2	66.7	68.7	851
OOMA (Lambre Street) (070023) 36 45 S 149 07 E 812m elevation													
28-43	60.7	55.9	42.3	50.7	22.8	28.7	19.6	32.8	27.8	41.3	50.9	44.7	481
44-59	54.8	65.4	50.9	40.9	51.6	43.1	26.7	26.6	30.4	60.4	56.9	58.9	584
60-76	62.8	56.2	57.5	37.5	35.5	23.0	25.5	33.7	38.3	62.8	69.2	66.3	568
IC ELAGO (SOGLIO) (070064) 35 41 S 149 09 E 762m elevation													
28-43	56.1	49.2	60.5	57.4	29.1	40.8	34.5	48.9	41.8	50.5	52.0	59.2	580
44-59	58.9	61.3	57.5	46.9	49.3	56.3	37.8	40.0	34.8	80.8	52.8	56.1	639
60-76	60.8	60.8	56.8	50.3	43.0	28.1	38.5	53.1	57.9	78.4	71.1	60.8	660
RI RRA FOREST (070085) 35 18 S 148 55 E 626m elevation													
28-43	62.1	56.2	56.1	68.6	50.3	69.1	59.2	79.6	59.1	69.4	60.6	50.9	746
44-59	63.9	64.7	71.8	59.9	70.6	72.4	70.1	68.3	52.6	106.1	77.1	60.8	858
60-76	72.7	74.4	54.9	63.5	58.1	38.0	72.4	82.1	84.4	99.5	82.7	76.7	859

*Values for March 1950 omitted from calculations

Appendix 8: Parameters for Regression Lines Fitted to Flood Recurrence Probabilities.

(a) Using highest flow in each season

Period		Intercept	Slope	S.E. of Intercept	S.E. of Slope	S.E. of Estimate	R^2
October - March							
1928 - 1943	mean ± S.D	7.2929 ± .4179	1.7359 ± .3026	.1935	.0465	.1298	.9781
	range	6.8750 - 7.7108	1.4333 - 2.0385				
1944 - 1959	mean ± S.D	10.5681 ± 1.3396	1.7434 ± .3416	.6007	.1532	.3150	.9284
	range	9.2285 - 11.9077	1.4018 - 2.0850				
1960 - 1976	mean ± S.D	10.5954 ± .6790	1.6942 ± .1633	.3173	.0763	.2224	.9723
	range	9.9164 - 11.2744	1.5309 - 1.8575				
April - September							
1928 - 1943	mean ± S.D	9.6165 ± .7029	1.4420 ± .1775	.3195	.0807	.1701	.9667
	range	8.9136 - 10.3194	1.2645 - 1.6195				
1944 - 1959	mean ± S.D	11.6926 ± 1.0909	2.3086 ± .2705	.4892	.1213	.2204	.9731
	range	10.6017 - 12.7835	2.0381 - 2.5161				
1960 - 1976	mean ± S.D	14.3471 ± 2.5867	3.1070 ± .6801	1.0558	.2776	.2492	.9542
	range	11.7604 - 16.9338	2.4269 - 3.7871				

Appendix 8: Con't

(b) Using all flows above 9000M.L.

Period		Intercept	Slope	S.E. of Intercept	S.E. of Slope	S.E. of Estimate	R^2
October - March							
1928 - 1943	mean ± S.D	4.2641 ± 1.4390	.8208 ± .3505	.6367	.1551	.2439	.7568
	range	2.8251 - 5.7031	.4703 - 1.1713				
1944 - 1959	mean ± S.D	9.7770 ± 1.2666	1.7359 ± .3026	.5828	.1401	.3908	.9219
	range	8.5085 -11.0456	1.4333 - 2.0385				
1960 - 1976	mean ± S.D	11.9415 ± .7741	2.3488 ± .1909	.3584	.0884	.2239	.9819
	range	11.1674 -12.7156	2.1579 - 2.5397				
April - September							
1928 - 1943	mean ± S.D	9.7758 ± .9307	1.7644 ± .2238	.4309	.1036	.2890	.9571
	range	8.8451 -10.7065	1.5406 - 1.9881				
1944 - 1959	mean ± S.D	9.2178 ± 1.2811	1.3838 ± .3080	.5931	.1426	.3977	.8787
	range	7.9367 -10.5592	1.0758 - 1.6918				
1960 - 1976	mean ± S.D	8.9983 ± 1.2327	1.4660 ± .2914	.5707	.1349	.3532	.9008
	range	7.7656 -10.2310	1.1746 - 1.7574				

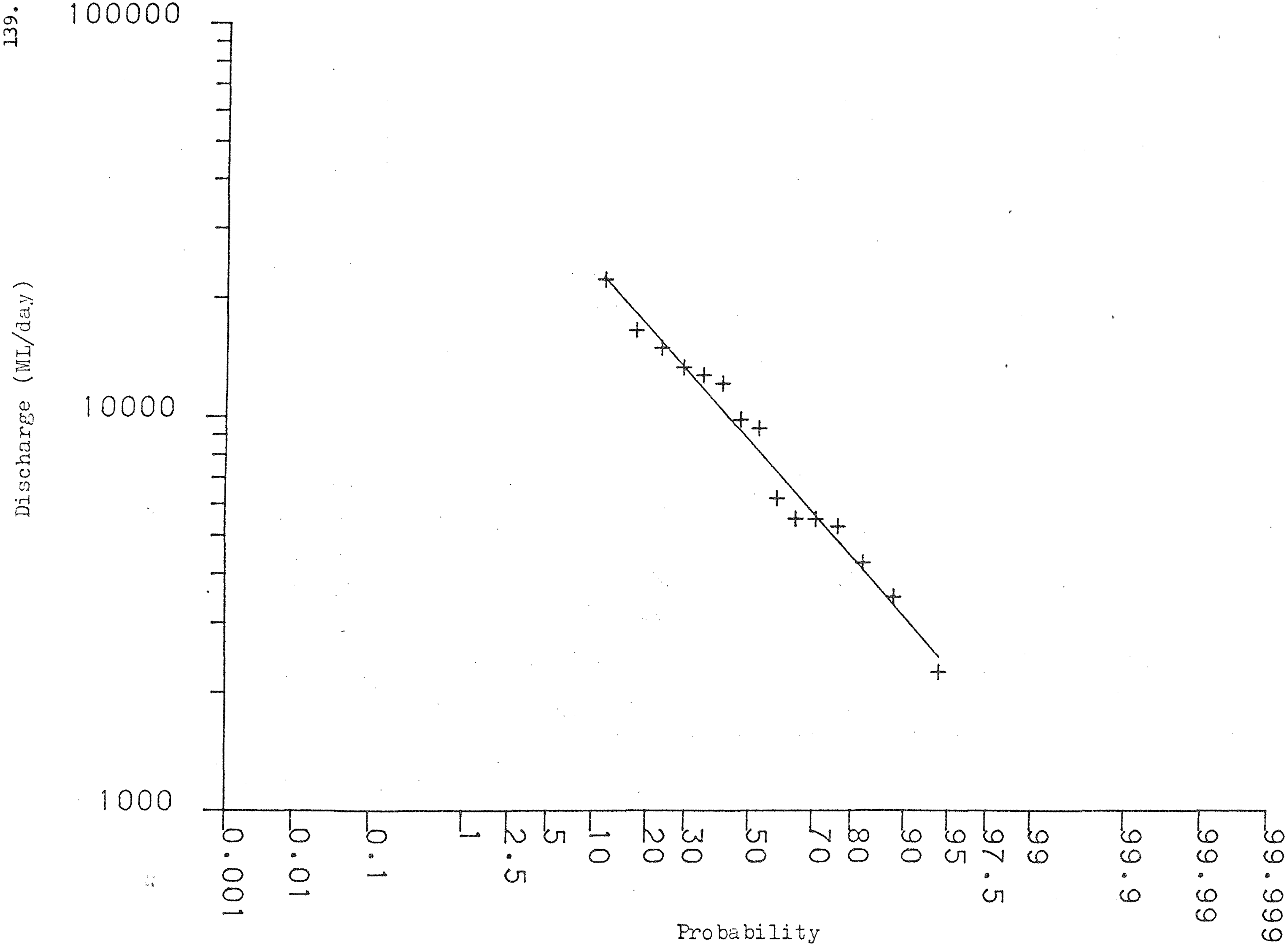
S.E. = Standard error

S.D = Standard deviation

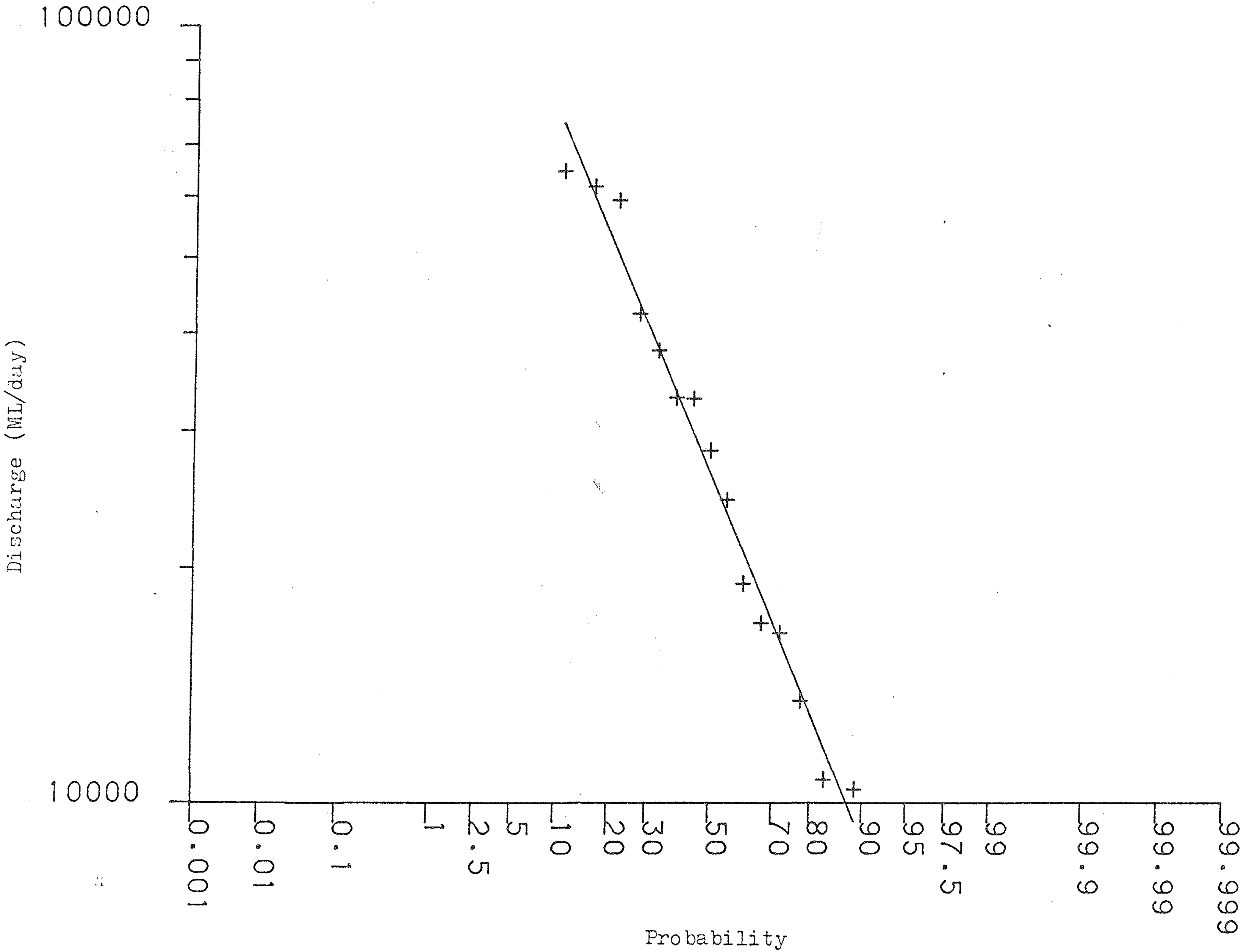
Appendix 9

Regression Lines Fitted to Flood Recurrence Probabilities for Cotter Crossing/Mt McDonald (Station No. 410035/410738) Using the Highest Flow in Each Season as a Data Base.

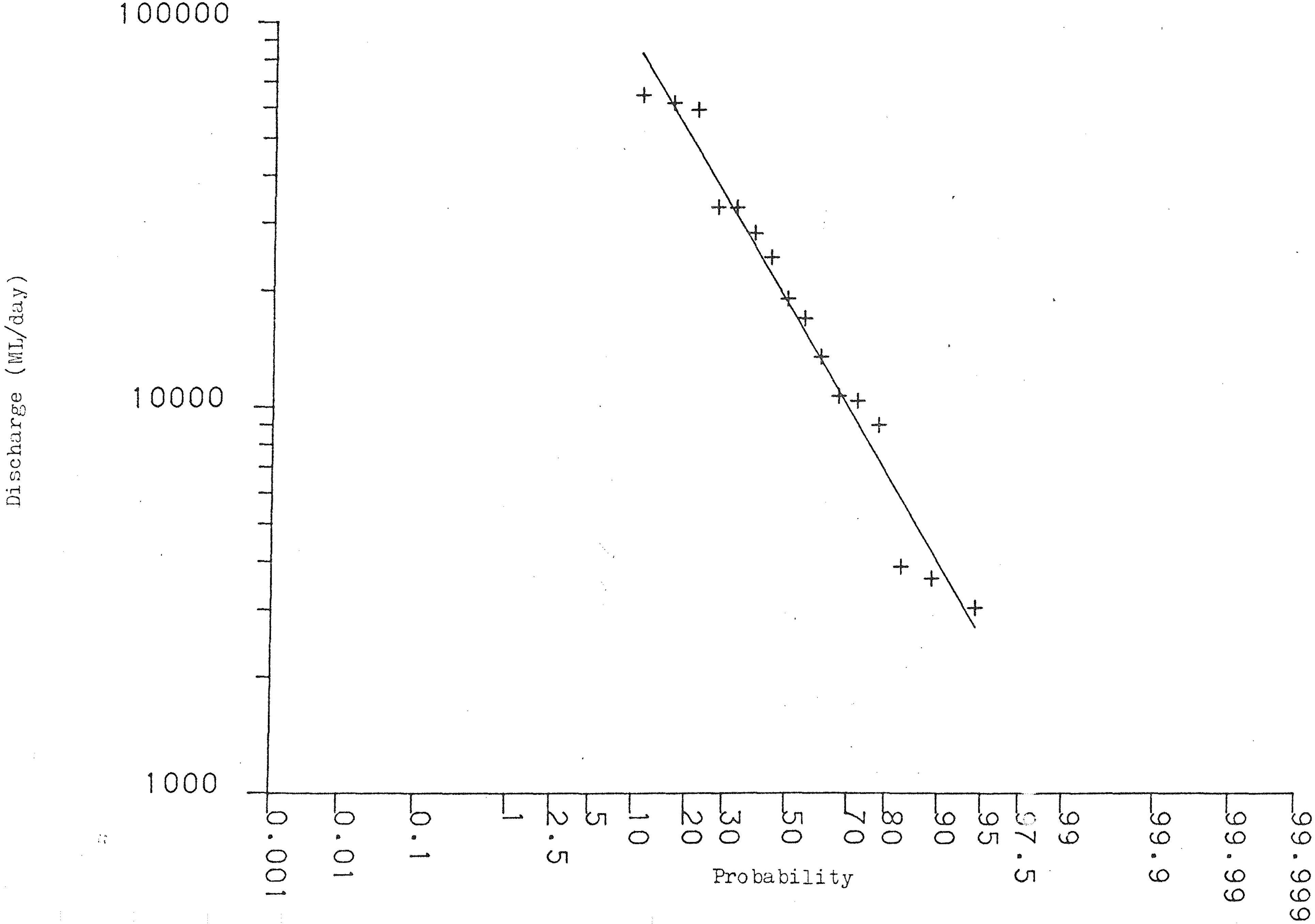
OCTOBER-MARCH 1928-1943 HIGHEST SEASONAL



OCTOBER-MARCH 1944-1959 HIGHEST SEASONAL

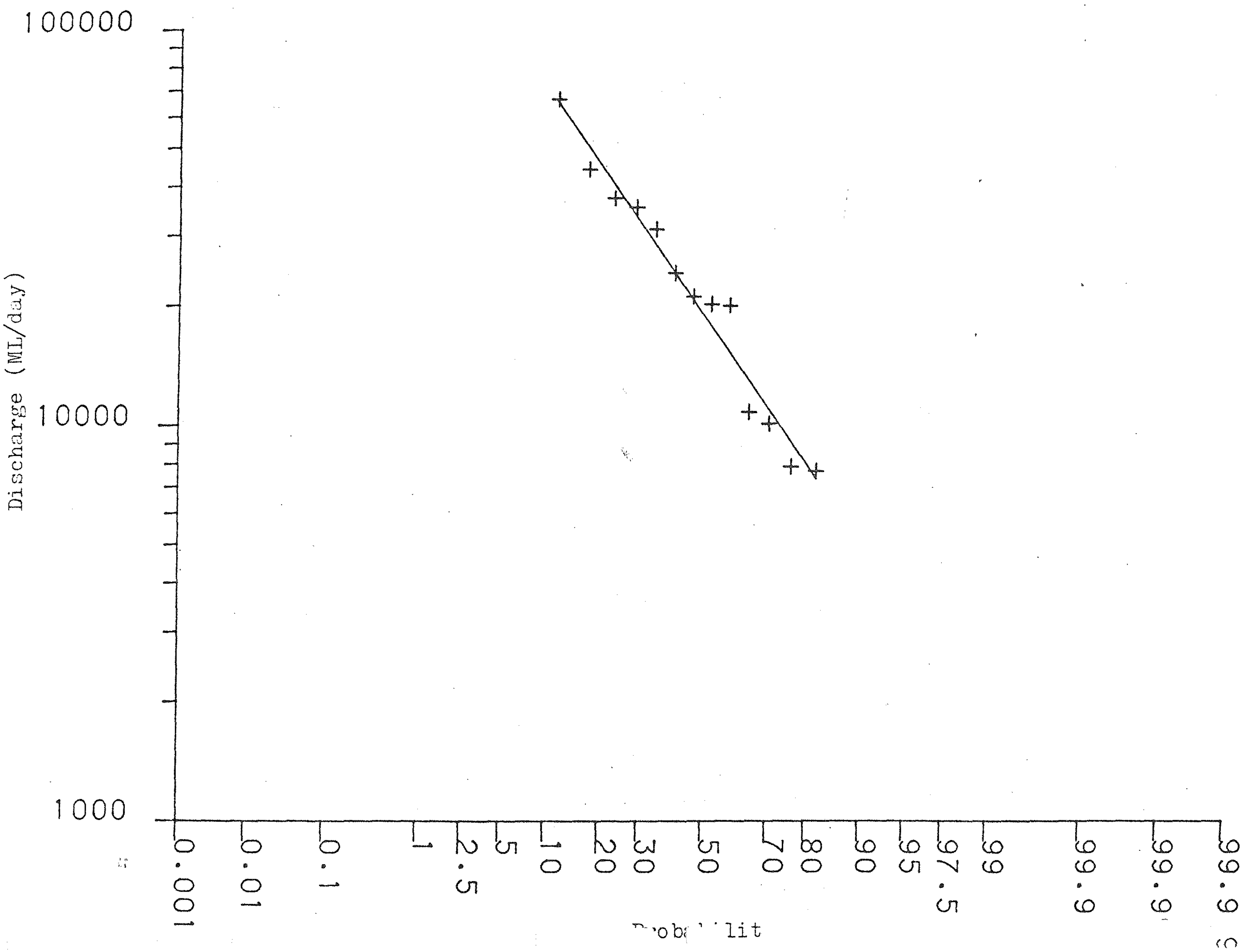


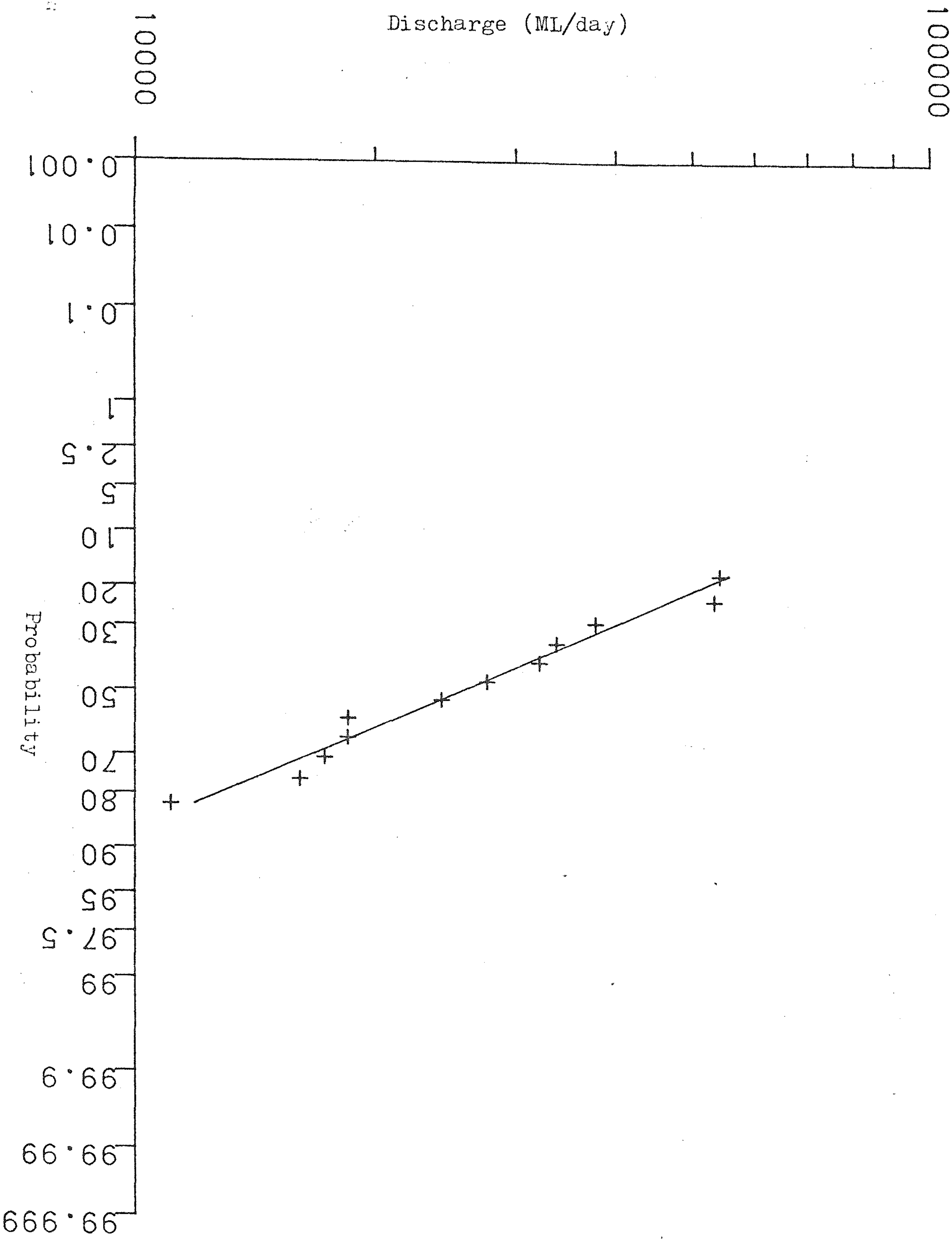
OCTOBER-MARCH 1960-1976 HIGHEST SEASONAL



142.

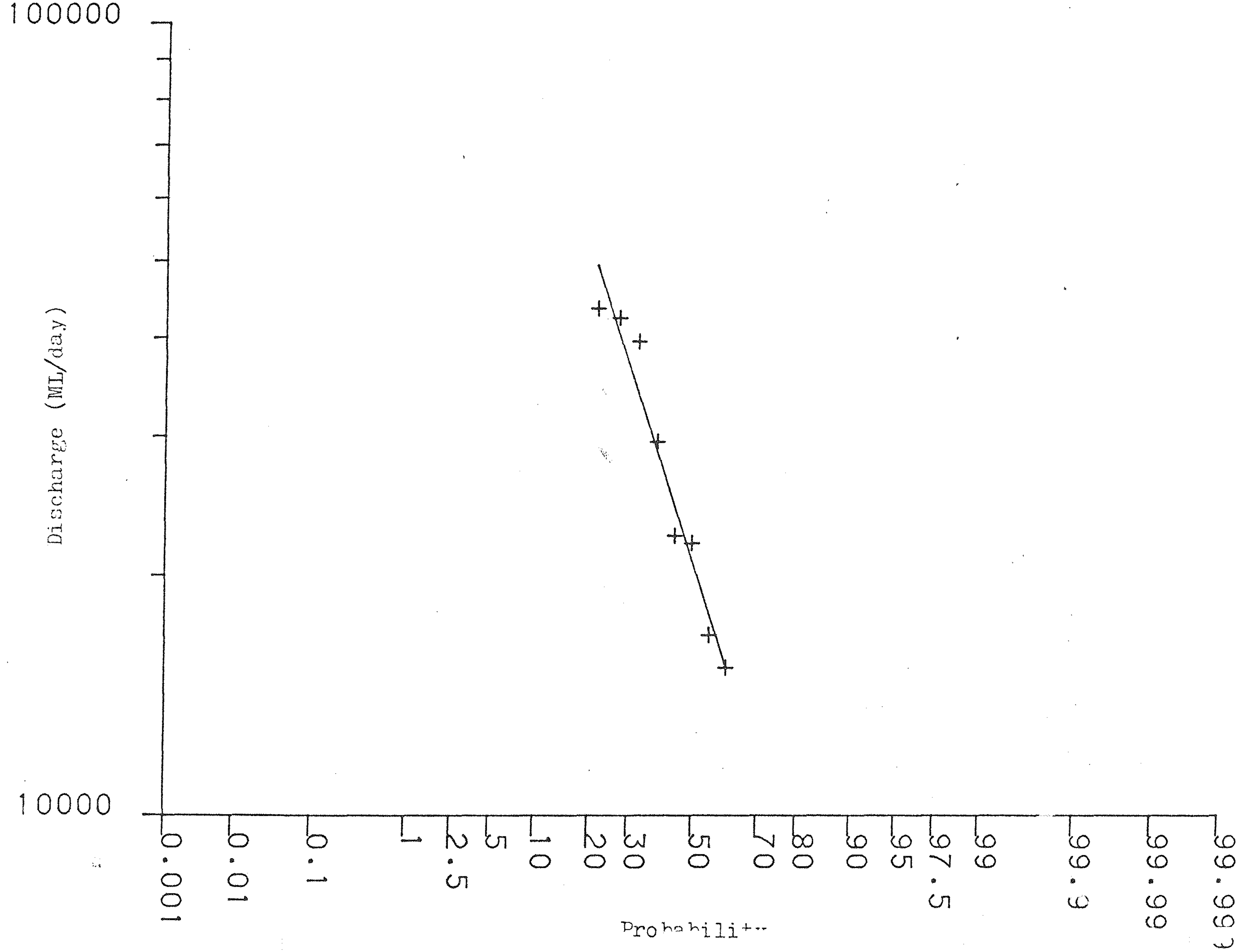
APRIL-SEPTEMBER 1928-1943 HIGH SEASONAL





APRIL-SEPTEMBER 1944-1959 HIGH SEASONAL

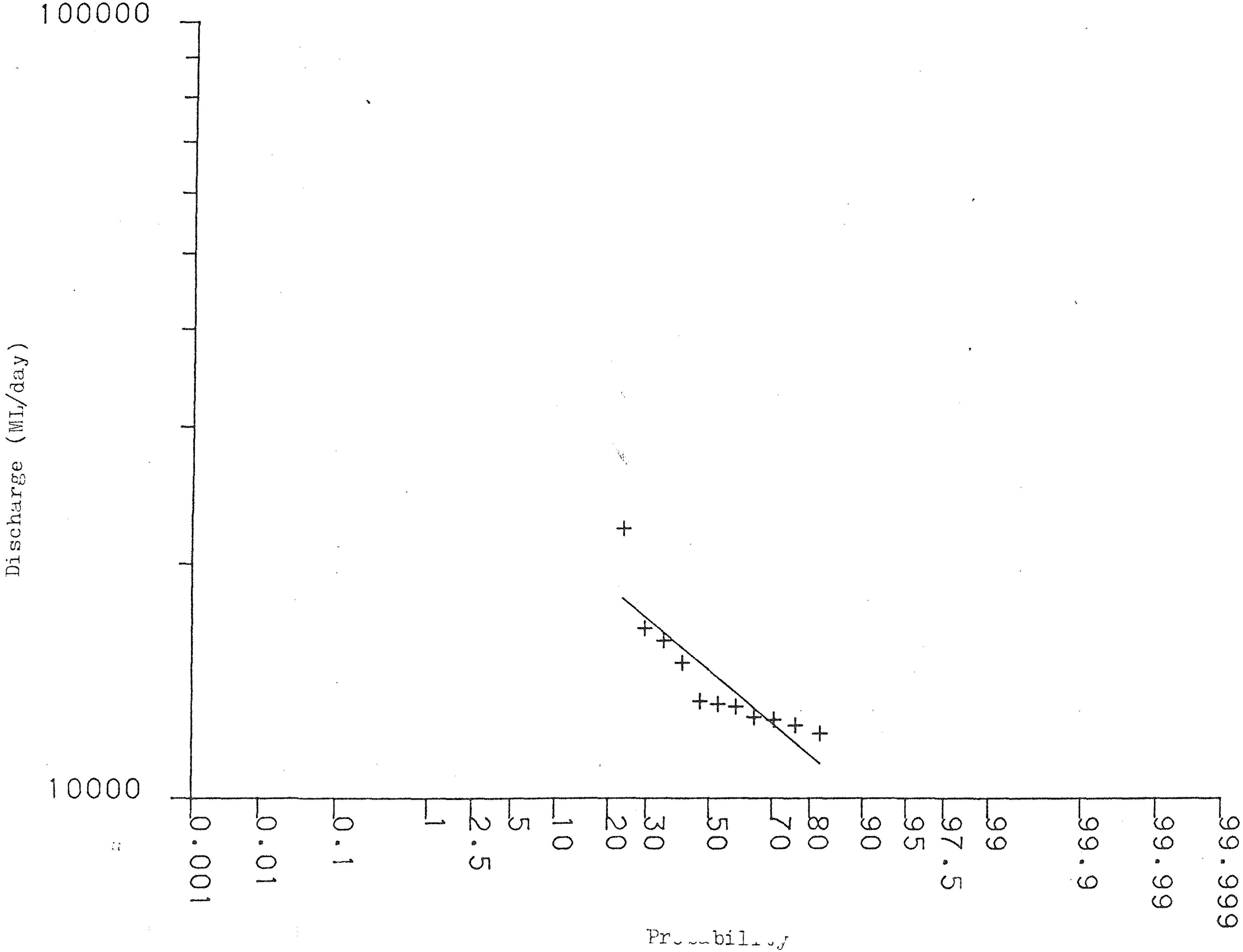
APRIL-SEPTEMBER 1960-1976 HIGH SEASONAL

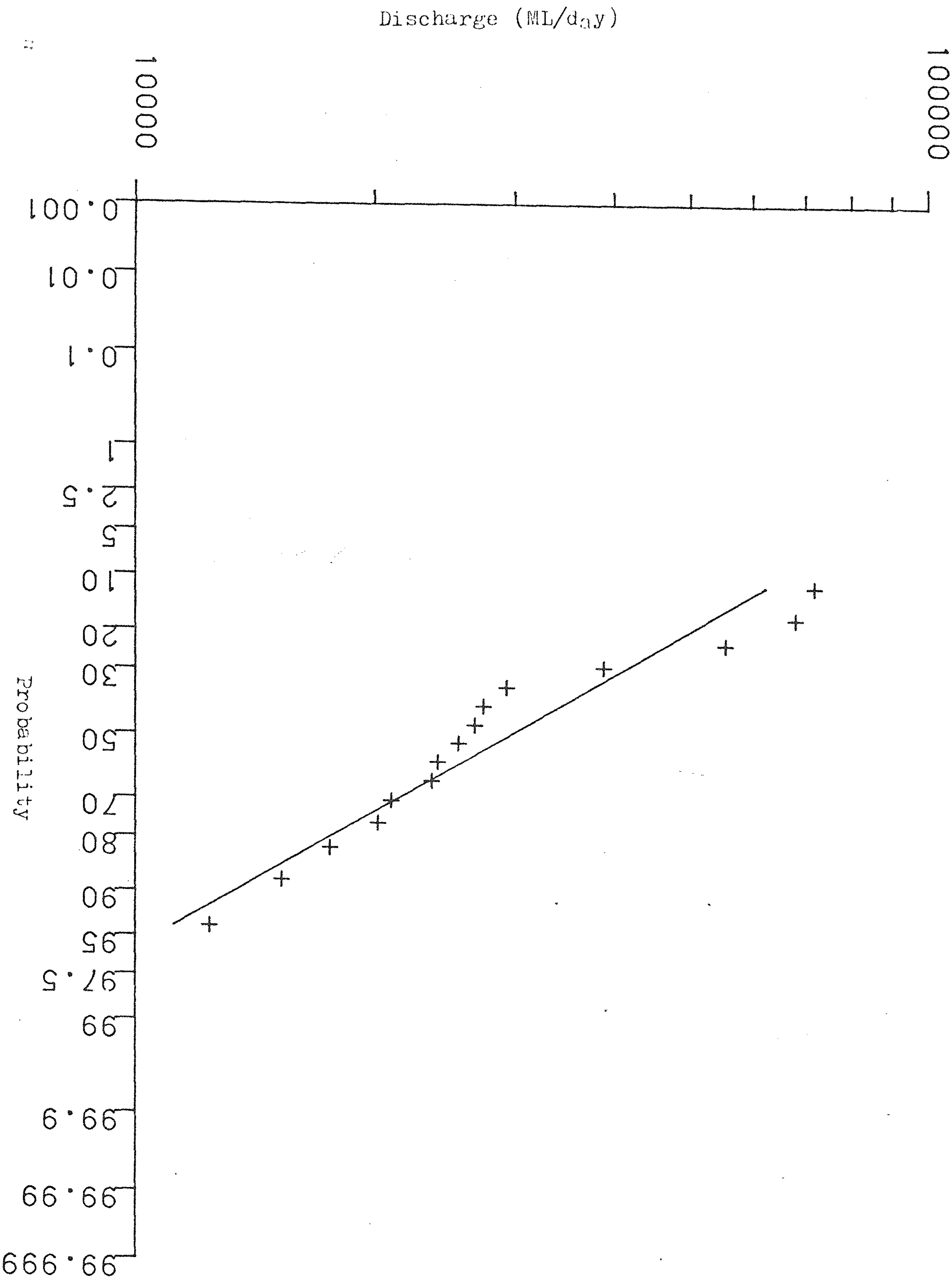


Appendix 10

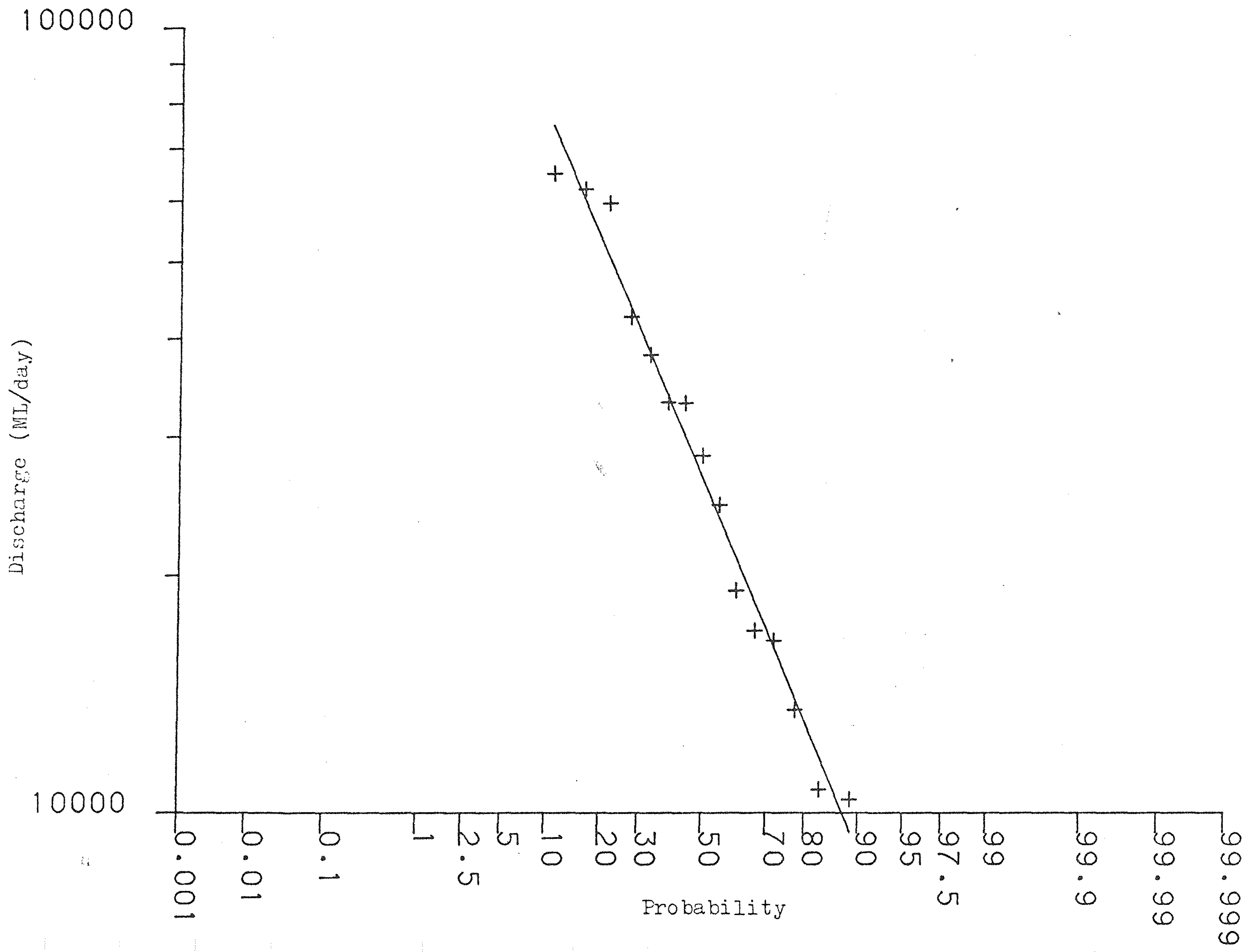
Regression Lines Fitted to Flood Recurrence Probabilities for Cotter Crossing/Mt McDonald (Station No. 410035/410738) Using all Flows in Excess of 9000ML as the Data Base.

OCTOBER-MARCH 1928-1943 ALL HIGH FLOWS

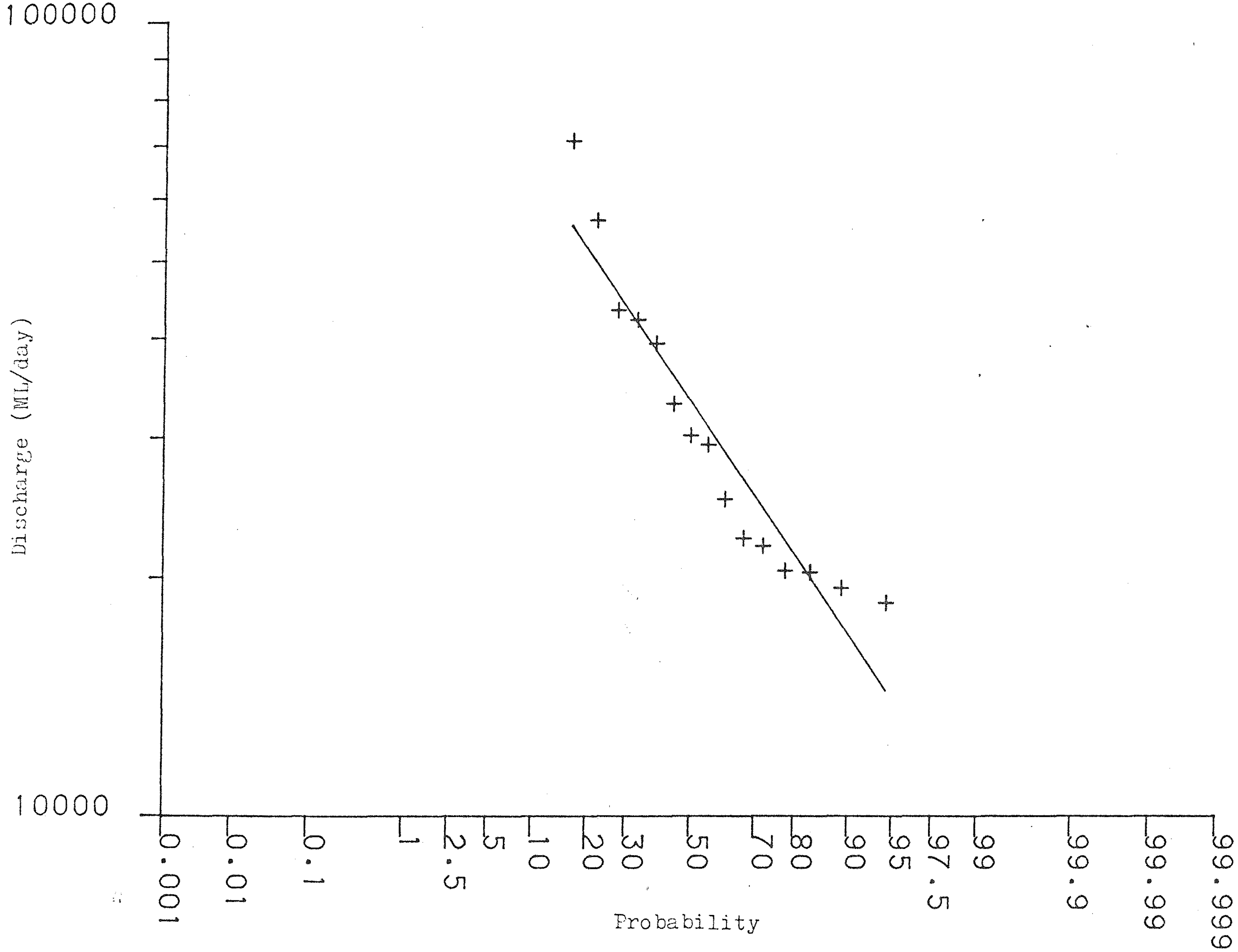


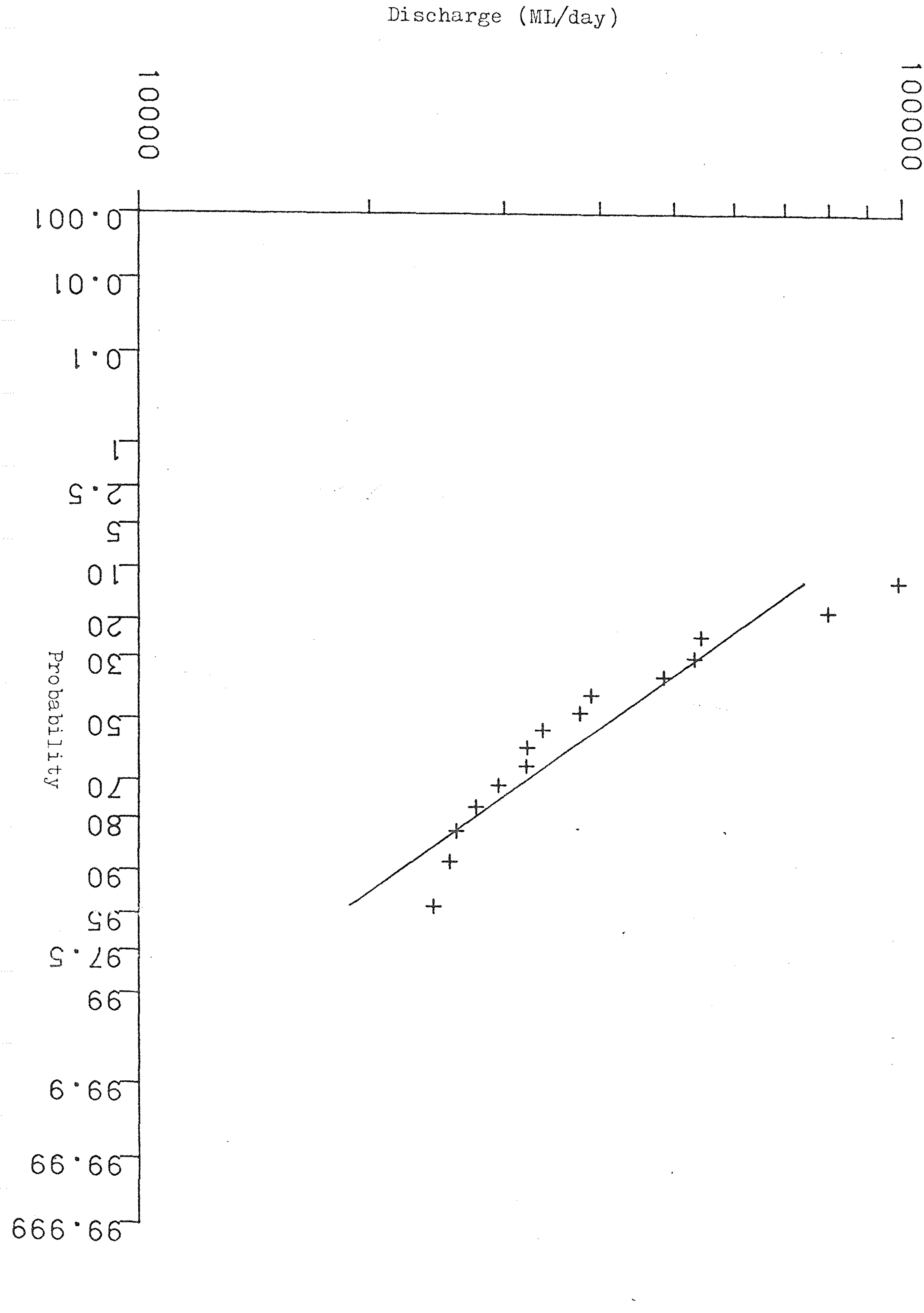

Discharge (ML/day)
10000
100000
Probability
0.001
0.01
0.1
1
2.5
5
10
20
30
50
70
80
90
95
97.5
99
99.9
99.99
99.999

OCTOBER-MARCH 1960-1976 ALL HIGH FLOWS



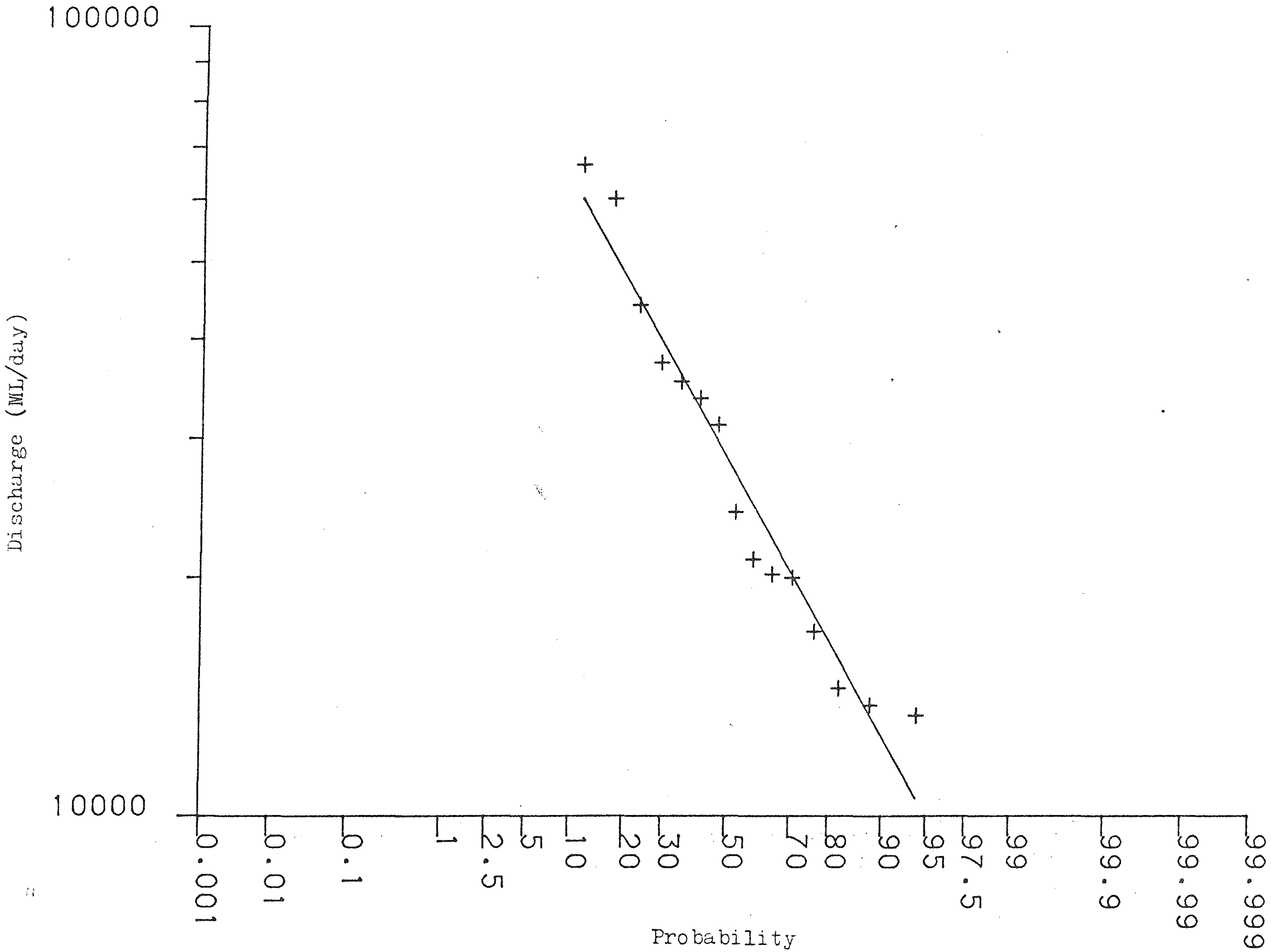
APRIL-SEPTEMBER 1960-1976 ALL HIGH FLOWS





APRIL-SEPTEMBER 1944-1959 ALL HIGH FLOWS

APRIL-SEPTEMBER 1928-1943 ALL HIGH FLOWS

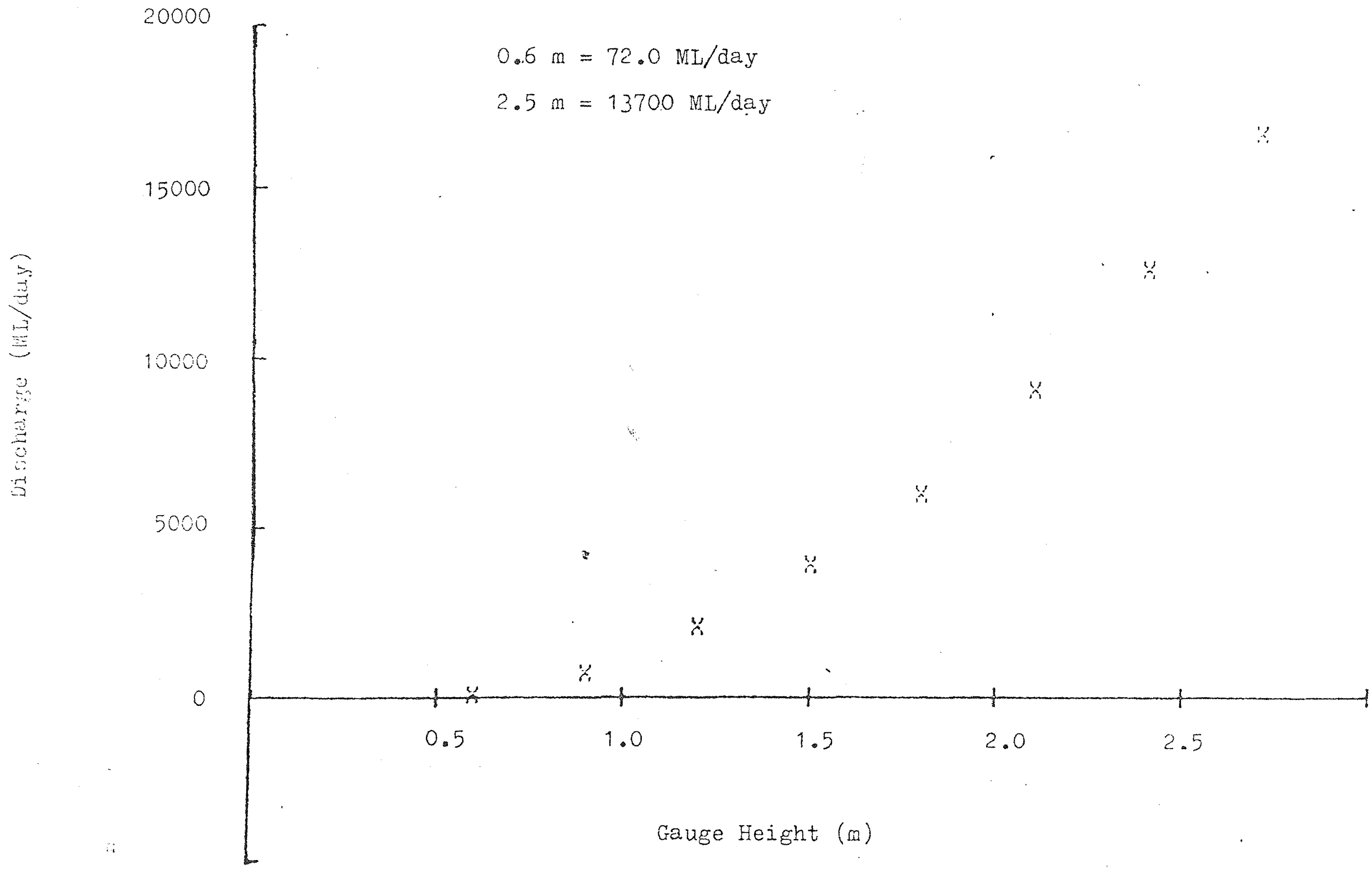


Appendix 11

Ratings Curves for the Gauging Station at Cotter Crossing/Mt McDonald (Station No. 410035/410738) for the Periods (a) 15.3.75 - 27.4.75 and (b) 1.9.30 - 16.4.34.

Appendix 11 (a)

15/3/75 - 27/4/75



Appendix 11 (b)