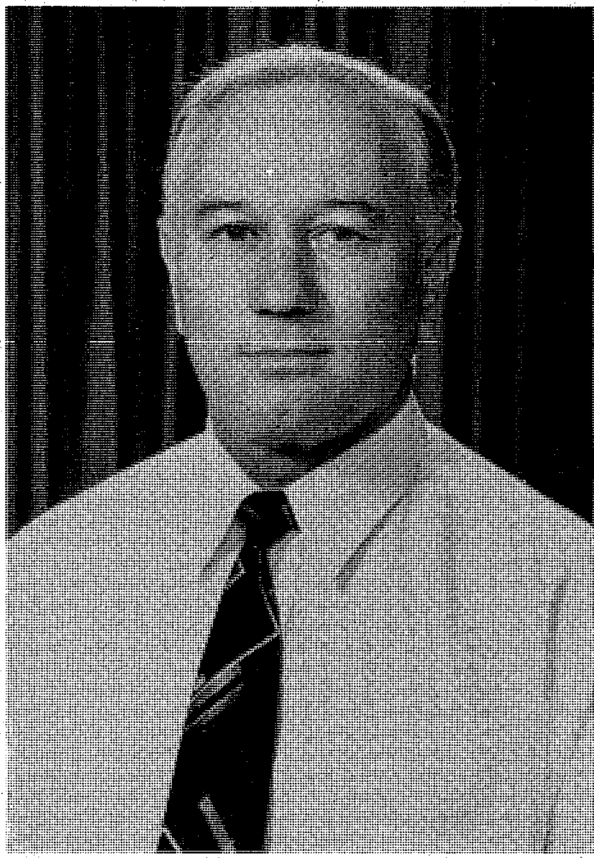
SWAN RIVER TRUST

Hydrocotyle ranunculoides: A control strategy for the Canning River Regional Park

Swan River Trust
Report No. 6
1993

MINISTER'S FOREWORD



The Canning River Regional Park has some of the best estuarine vegetation remaining along the Canning and Swan Rivers and supports over eighty species of birds and other wildlife. The Canning River is a scenic and recreational focus for the people of Perth and is highly valued by the community.

Since 1983 the Swan River Trust has been concerned about an introduced aquatic weed known as *Hydrocotyle ranunculoides* which was initially found in the drainage system but subsequently spread into the river.

By 1991 some sections of the Canning River were covered from bank to bank with floating mats of the weed. The infestation adversely affected the recreational and environmental values of the river and is a problem which could spread to other waterways.

In 1992 the Swan River Trust set up a working group comprising State government agencies, local government and community groups to develop a strategy for short-term control and long-term eradication of this weed.

The control and eradication strategy involves a combination of mechanical removal, ecological control and some use of herbicides. This integrated approach minimises the adverse impacts of removal on the ecology of the river system.

This is the first time that an integrated strategy has been developed for this unique problem. I entrust the implementation of this strategy to the Swan River Trust, knowing they will continue their excellent work in planning, protecting and managing the environment of the Swan-Canning River System.

Kevin Minson MLA
Minister for the Environment

WORKING GROUP

This report was collated with input from the *Hydrocotyle* Working Group, an informal technical group convened by the Swan River Trust to assist in the development of the control strategy. This report does not necessarily represent the views of individuals or departments involved.

The membership and participation in the group varied during the development of the strategy. The following is a list of all those that contributed:

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The following people and organisations are acknowledged for their contributions:

Members of the *Hydrocotyle* Working Group for their input, discussion, tolerance of the process and critical comment.

Critical comment by:

Robert Atkins, Greg Davis, Bruce Hamilton: Waterways Commission, Perth

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Summary

Hydrocotyle ranunculoides is a common aquarium plant which has been readily available from distributors of aquarium plants, nurseries etc. throughout metropolitan Perth and Western Australia. *Hydrocotyle* in the Canning River probably originated from the release of garden and aquaria wastes into drains or through dumping in the immediate vicinity of the river.

Hydrocotyle was first observed in Bannister Creek in 1983, and by 1987 had spread into the Canning River Regional Park. The weed remained fairly static in the river system until early 1991, when the distribution suddenly became more extensive. It is now a major problem which must be controlled in the short and eradicated in the long-term.

In November 1991 *Hydrocotyle* covered the Canning River in large mats, reaching from bank to bank in some places and the estimated volume was 17,500 m^3 (or 180 tonnes). In an attempt to contain the massive growth of *Hydrocotyle*, Department of Planning and Urban Development (DPUD), the Swan River Trust, Canning City Council and concerned residents conducted a two-week removal exercise involving mechanical (harvester, boats and backhoe) and hand removal of *Hydrocotyle* in November 1991. While relatively successful in the short-term, it appeared that the physical removal work undertaken resulted in the spread of *Hydrocotyle*. Each small segment that floated away from the large mats removed had the capacity to generate a new mat. This was the consequence of insufficient resources being available for a comprehensive follow-up program and highlights the need for commitment to long-term eradication.

By September 1992, the estimated volume within the Canning River Regional Park had increased to 40,000 m^3 (estimated 420 tonnes). The majority of this (30,000 m^3 or 310 tonnes), covering approximately 30% of the water area, was in the Kent St Weir to Nicholson Road Bridge section of the Canning River. Further downstream, between Kent St Weir and Shelley Bridge the volume was estimated at 5,000 to 10,000 m^3 (51 to 100 tonnes).

The current infestation of *Hydrocotyle* in the regional park has the potential to undermine the value of the park. The impacts of *Hydrocotyle* on the riverine system have not been quantified, however the following is a list of observed changes in the environment:

- provides a new habitat, resulting in increased populations of birds, invertebrates

- mats provide a safe haven for birds from predatory domestic animals

- mats may have increased erosion of sediments from the bed of the river and altered the passage of flow causing bank erosion in some places

- reduced water oxygen levels (as low as 3 mg/L) in the river

- nutrient removal - uncertain as to extent at this stage

- reduced recreation opportunities

Hydrocotyle has been located in nine main drainage systems leading into the Canning River. It has been suggested that the spread of *Hydrocotyle* throughout the drainage channels was the result of fragments being caught on

Water Authority machinery used for drain maintenance and that birds may be transporting fragments along flight routes.

There is concern that *Hydrocotyle* may be transported to irrigation channels and other naturally occurring fresh water bodies in the State, causing similar problems to those currently occurring in the Canning River. This could result not only in environmental degradation but also economic loss including reduced access to water for crop irrigation.

Currently, as far as can be determined, there is no other infestation of *H. ranunculoides* in Australia and there is no established protocol for the control and eradication of this weed. A closely related species, *H.bonariensis,* is a problem in southern USA and South America and parts of New South Wales.

The current growth of *Hydrocotyle* in the Canning River system indicates that this weed has the potential to develop into a serious environmental, economic and recreational threat to other lakes and waterways in WA and Australia.

On 26 October 1992 *Hydrocotyle* was gazetted as a Class P1 and Class P2 pest under the Agriculture and Related Resources Protection Act. Class P1 prevents importation, movement and trade of this plant and Class P2 requires that control and eradication of the plant be undertaken.

A two-part control and eradication strategy has been detailed in this document. The growth pattern of *Hydrocotyle* (dominantly vegetative reproduction) means that both stages of the strategy are based on the concept of integrated control using a combination of mechanical, chemical, biological and ecological control techniques where appropriate. This approach reduces the potential environmental impacts of any one control technique (e.g. herbicides).

Any combination control and eradication techniques undertaken in the Canning River will have an environmental impact. The main impact identified is the reduction in wildlife populations, including birds, crustacea and fish (Section 2.3). This impact will occur as a consequence of the habitat created by *Hydrocotyle* being removed from the river.

The aim of short-term management is to remove the majority of *Hydrocotyle* from the Canning River Regional Park and its associated drains during the summer 1992-1993. It must be recognised that eradication will take considerably longer than this.

Aquatic weed control programs need to be planned, thorough and diligently carried out until the weed is eradicated from the area. Regular surveys and follow-up control of subsequent weed outbreaks are required for a number of years. Eradication is possible with vigorous and diligent control measures at an early stage of the invasion in a relatively small, confined water body (Arthington and Mitchell 1986). *Hydrocotyle* eradication may be difficult considering it is well established within the river system.

Based on strategies used to control other aquatic weed species in Australia it will probably be necessary for active control and removal of *Hydrocotyle* to occur for between three and five

years, although this may be longer or shorter depending on success. It is assumed that the short-term management outlined in Section 5 will be successful in removing the bulk of the plant material and that regrowth is controllable.

Critical to eradication of *Hydrocotyle* will be the assessment of the success of the various techniques used in the short-term management program (Section

5.1), continued observation of *Hydrocotyle* biology and ecology and review of techniques available for eradication.

Although the ultimate aim is to eradicate *Hydrocotyle*, its current growth patterns and the extent of the invasion in the Canning River suggest that eradication may not be achievable. If this is the case control and management, rather than eradication, will be the most feasible option.

1. INTRODUCTION

1.1 Canning River Regional Park

The Canning River Regional Park includes the foreshore reserves and water between Riverton Bridge and Nicholson Road Bridge (Figure 1). This area was identified in the 1983 System Six report as having 'the best estuarine vegetation of the Canning and Swan Rivers', and supporting 85 species of birds (DCE 1983).

The funding and administration of the park is currently the responsibility of the Department of Planning and Urban Development on the advice of the Canning River Regional Park Interim Management Advisory Committee. In the long-term the park will be jointly managed by Conservation and Land Management and the Canning City Council. Management of this park has become increasingly difficult as a number of introduced aquatic weeds, including *Hydrocotyle* and *Hydrilla*, are posing a significant threat to the Canning River Regional Park.

The park contains a water control structure known as the Kent St Weir. The weir was constructed to maintain freshwater for farming purposes in a previously tidal section of the river.

1.2 Aquatic weeds

Native aquatic plants are important functional elements of waterways. They enhance water quality by absorbing nutrients that enter from the urban and rural catchments, provide food and shelter for small aquatic organisms, fish and birds and may also assist in reducing erosion and stabilising the banks and beds of rivers. Thus the presence of these plants is usually an asset, however, in some situations rapid plant growth may adversely affect the waterway. This often happens when alien aquatic plants are introduced into a water body.

Studies on alien aquatic plants with a capacity for invasion of their 'non-native' environments have shown several common features. These are:

- vegetative reproduction is common and often the only method of reproduction,
- humans are the main agents for dispersal of the plants, and
- the plants that are capable of very rapid rates of reproduction often become serious weeds (Arthington and Mitchell 1986).

There are three main stages in successful invasion of plants: invasion, establishment of the population through reproduction, and dispersal. The *Hydrocotyle* population in the Canning River is well established and the dispersion phase of the invasion process poses a significant environmental and economic risk to waterway systems.

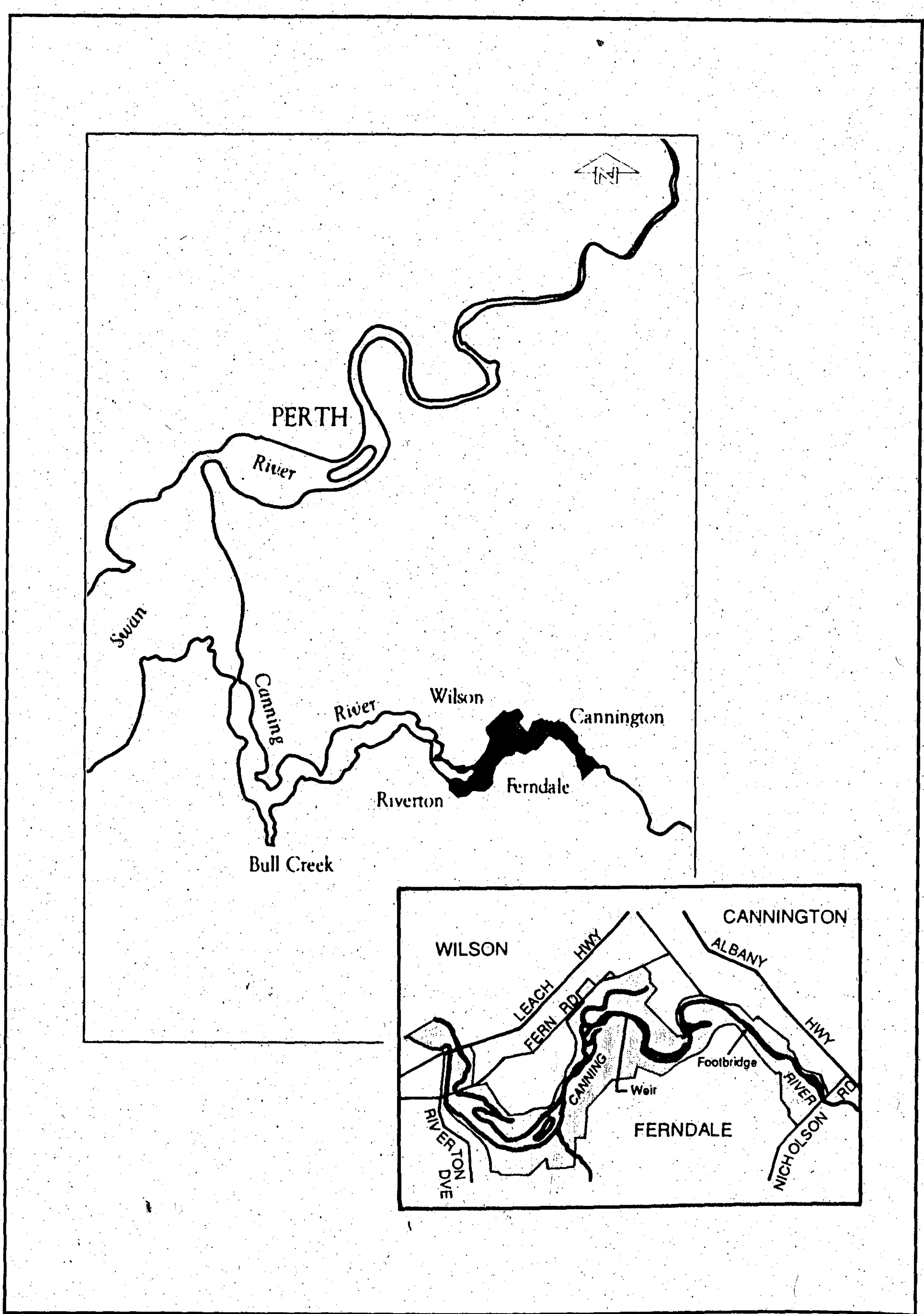

Figure 1 Location of the Canning River Regional Park.

Once a species has invaded an area it is possible to distinguish two types of factors which may be responsible for the invasion process:

- plant factors such as mode of reproduction (vegetative and sexual), reproductive capacity, stress tolerance (salinity and nutrient requirements), rate of vegetative growth and an effective dispersal mechanism, and

- environmental factors such as habitat disturbance, nutrient availability, and competition from native species (Arthington and Mitchell 1986).

Many invading aquatic plants are taxonomically close to species which do not exhibit such behaviour and/or morphologically very similar to other plants which often occupy the same habitat but may not grow aggressively, e.g. *Centella asiatica* (Arthington and Mitchell 1986).

Adverse effects include: disruption of the food web and ecosystems, interference with water flow and flood mitigation, reduction in water availability for human use through increased evapotranspiration, and interference in recreational activities, boat movement and water access. These deleterious effects of aquatic plant outbreaks complicate water resource management thus increasing the cost of effective management of water bodies. The costs of controlling such outbreaks can be enormous.

1.2.1 *Hydrocotyle* species in Australia

There are 100 species in tropical and temperate regions of the world. Fifty five species of this genus are native to Australia and 24 of these are found in Western Australia (Marchant et al. 1987). One species, *Hydrocotyle lemnoides*, is considered to be aquatic while the others are generally described as wetland plants (growing in areas of shallow semi-permanent or permanent water) (Aston 1973).

A literature search has revealed more specific information on only two *Hydrocotyle* species in Australia, *Hydrocotyle bonariensis* and *Hydrocotyle verticillata*. *Hydrocotyle bonariensis* is native to North and South America and has been located in Bunbury (WA), the east coast of New South Wales and South Australia (Marchant et al. 1987; Sainty and Jacobs 1981). Sainty and Jacobs (1981) described its habitat as sandy or soils near the coast and reported that it was also capable of growing submerged and floating (attached to a bank). Modest control of this species has been achieved using the herbicide amitrole (Sainty pers. comm. 1992).

Hydrocotyle verticillata was recorded in the Brisbane (1875) and Atherton (1901) districts, eastern NSW and Victoria. According to Aston (1973) *Hydrocotyle verticillata* had apparently died out within Queensland. In the 1800s in Victoria it was recorded in the lower Mitta Mitta River, Lake Moodemere and the north-east district. The only record in the 1900s is of a large and dense growth in a backwater of the Goulburn River near Nagambie in 1963. According to Aston (1973) this was still flourishing at the time of publishing.

Marchant et al. (1987) describe 11 species of *Hydrocotyle* recorded in the Perth Region. This information is contained in Appendix 1.

Hydrocotyle ranunculoides is an aquatic species native to Europe and possibly North and South America, and is a common aquarium plant throughout Western Australia and Australia.

Within the Canning River Regional Park, *Hydrocotyle* is of particular concern. It was first observed by APB officers in Bannister Creek, Riverton, in 1983. At this time, it was not considered a problem, however it has spread at such a rate that it now poses a serious threat to the integrity of the park.

Currently, as far as can be determined, there is no other infestation of *Hydrocotyle* in Australia and there is no established protocol for the control and eradication of this weed.

1.3 State and national implications

The current growth of *Hydrocotyle* in the Canning River system indicates that this weed has the potential to develop into a serious environmental, economic and recreational threat to other lakes and waterways. The mass of plant material in the river is a potential source for the spread of the weed within this State and also throughout Australia, potentially displacing native species of plants and animals.

In addition, if *Hydrocotyle* successfully invaded irrigation channels in the south-west or the Ord River Dam then the economic implications for irrigated agriculture would be significant. CSIRO, Murray Darling Basin Commission and other government agencies in the eastern States have expressed serious concern about the potential of this plant to invade waterways throughout Australia.

On 26 October 1992, *Hydrocotyle* was gazetted as a Class P1 and Class P2 pest within Western Australia by the Agriculture Protection Board. Class P1 prevents the importation, movement and trade of this plant and Class P2 aims at eradication.

1.4 Report structure

The Swan River Trust established a *Hydrocotyle* Working Group in 1992 to collate information on the biology and ecology of *Hydrocotyle*, the history of invasion and changes in distribution since it was first observed in 1983. In addition the group assessed previous control techniques and identified a preferred strategy for the short and long-term eradication of this plant from the Canning River and its tributaries.

The information contained in this document is intended to provide a basis for further investigation and should not be considered a definitive work on the biology and ecology of this plant.

For ease of reference the term *Hydrocotyle* has been used throughout the report as an abbreviation of *Hydrocotyle ranunculoides* unless otherwise stated.

2. BIOLOGY AND ECOLOGY OF *HYDROCOTYLE RANUNCULOIDES*

The genus *Hydrocotyle* is a member of the family Apiaceae. Members of this genus are rarely aquatic. *Hydrocotyle ranunculoides* is an aquatic species which originated in Europe and possibly North and South America, and is a common aquarium plant throughout Western Australia and Australia. There is relatively little published scientific and ecological information about this species of *Hydrocotyle* .

2.1 Morphology

Hydrocotyle ranunculoides is an aquatic stoloniferous and rhizomatous plant with a creeping stem with nodes at approximately 40 mm intervals. At the nodes there are profuse long filiform (hairlike) roots. The leaves are emergent with the leaf stalks coming from the nodes on the horizontal stolons (definition: horizontally growing stem that roots at nodes; Abercrombie et al. 1977). When the plant flowers the stalk also comes from the nodes (Figure 2).

The leaves range from being circular to reniform (kidney shaped), are non-sclerophyllous (soft), less than 1 mm thick and vary in size (20-45 x 25-55 mm) and have shallow-lobed outlines (Marchant et al. 1987). Observations in the Canning River have recorded leaf sizes up to 100 mm (Plate 1).

This species is capable of sexual reproduction, producing small creamy-yellow flowers, approximately 3 mm in diameter, on an umbel (floral head), averaging nine flowers per umbel (Figure 2 and Plate 2).

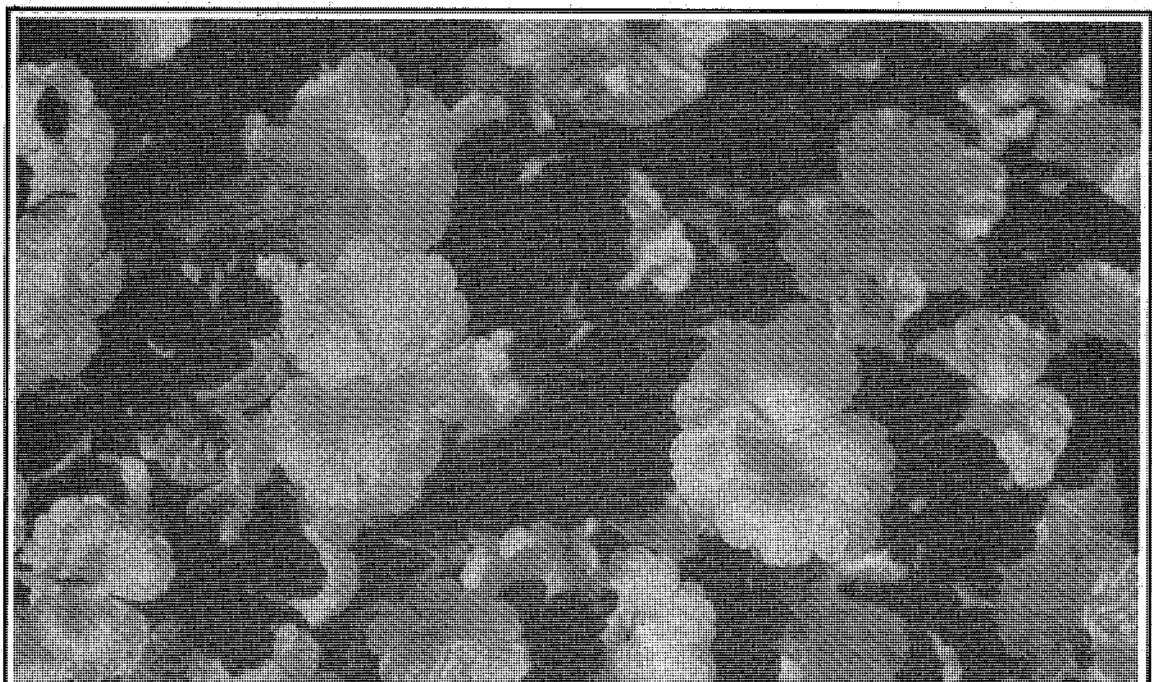

Plate 1 Leaf form of *Hydrocotyle ranunculoides* in the Canning River

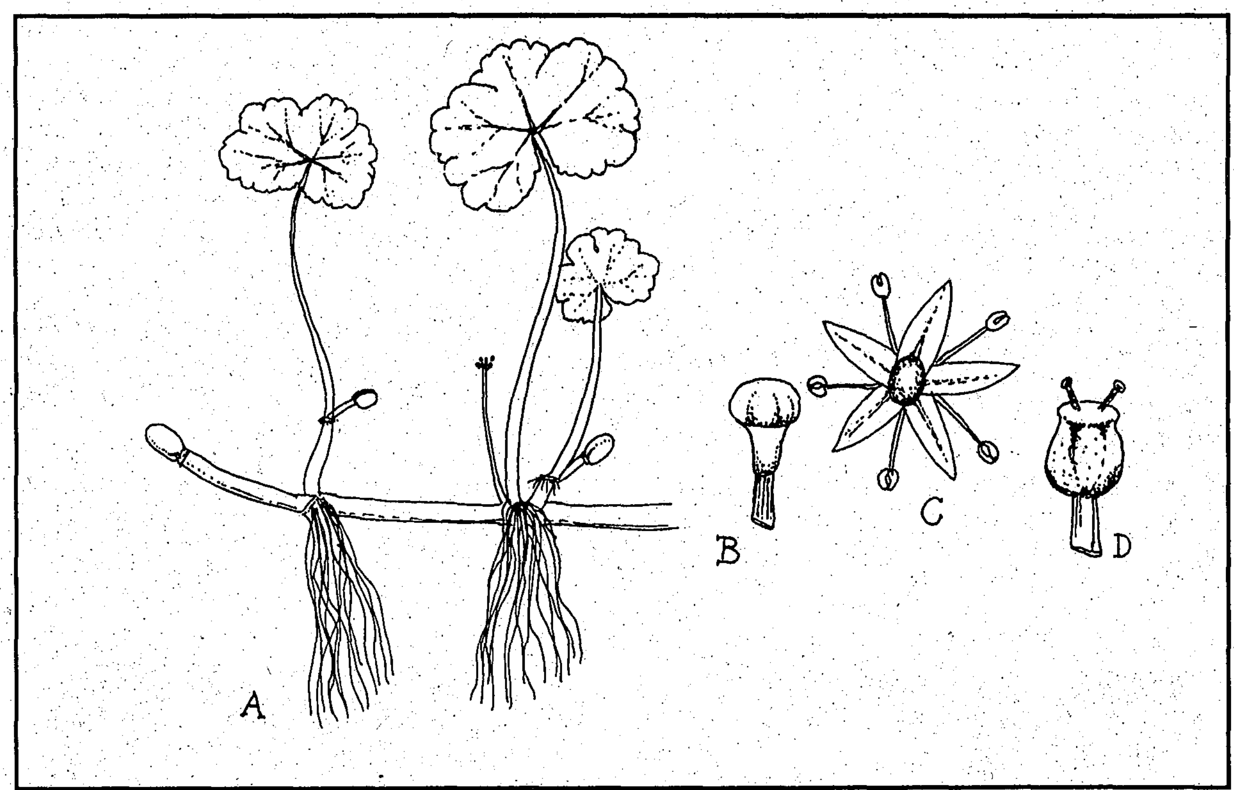

Figure 2 Growth form of *Hydrocotyle ranunculoides* **A** Habit (1/3 of actual size). **B**, Flower Bud (5 times actual size). **C**, Flower (10 times actual size). **D**, Mericarp (5 times actual size)

According to Marchant et al. (1987) this species usually flowers to a small extent in February; however in September 1992 it was observed flowering profusely, with an estimated 1,000 floral heads per square metre in some mats. Each floral head contains nine flowers and each flower can produce one seed.

Seeds have not been observed or collected, however if it is assumed that each flower produces a viable seed then production of seed could exceed 9,000 seeds/m^2.

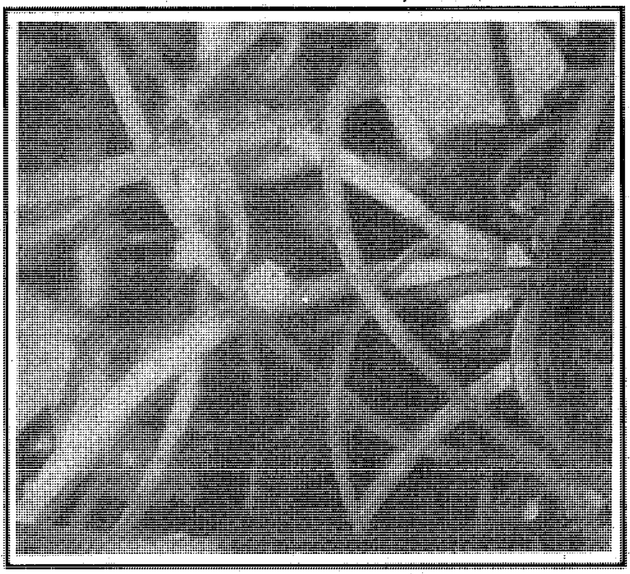

Plate 2 Floral head of *Hydrocotyle ranunculoides*

Based on the estimated area of *Hydrocotyle* in the river in September 1992, and assuming the same flowering rate throughout, potentially 360 million seeds have been generated. There is no information available on the viability of seeds produced by *Hydrocotyle*.

Reproduction in the nutrient-enriched conditions of the Canning River was thought to be principally asexual and vegetative reproduction. Fragments of stolons which include one leaf bud, possibly as small as 3 cm, can develop into large mats.

However, the potential seed generation occurring in the river in September 1992 indicates that *Hydrocotyle* may be reproducing successfully by both sexual and asexual means.

2.2 Ecology

In the Canning River *Hydrocotyle* develops into dense interwoven mats. The plant anchors to the bank at a depth of up to 15 cm, with the main bulk of the plant floating on the water. The extent of the rhizome growth onto the bank varies in accordance with waterlogging, height of the land, and the temporal extent of the flooding.

The average thickness of leaf matter above the water is between 40 cm and 50 cm, with the trailing root system up to 60 cm long (Plate 3). *Hydrocotyle* mats can be of different dimensions, ranging from small patches (1 m^2) to mats extending over hundreds of metres and up to 30 m wide, the width of the river channel (Plate 4). It has been observed that where *Hydrocotyle* is not rooted to a substrate and is attached to overhanging branches and snags, mats tend to remain small (less than 1.5 m^2).

No senescing (dying) leaves have been observed in any mats. Leaf stalks on the advancing edge of mats are deep red. These lighten to pale green as the mats thicken.

The vertical extent of the *Hydrocotyle* in the river generally corresponds with the high and low water marks, a range of approximately 60 cm. However,

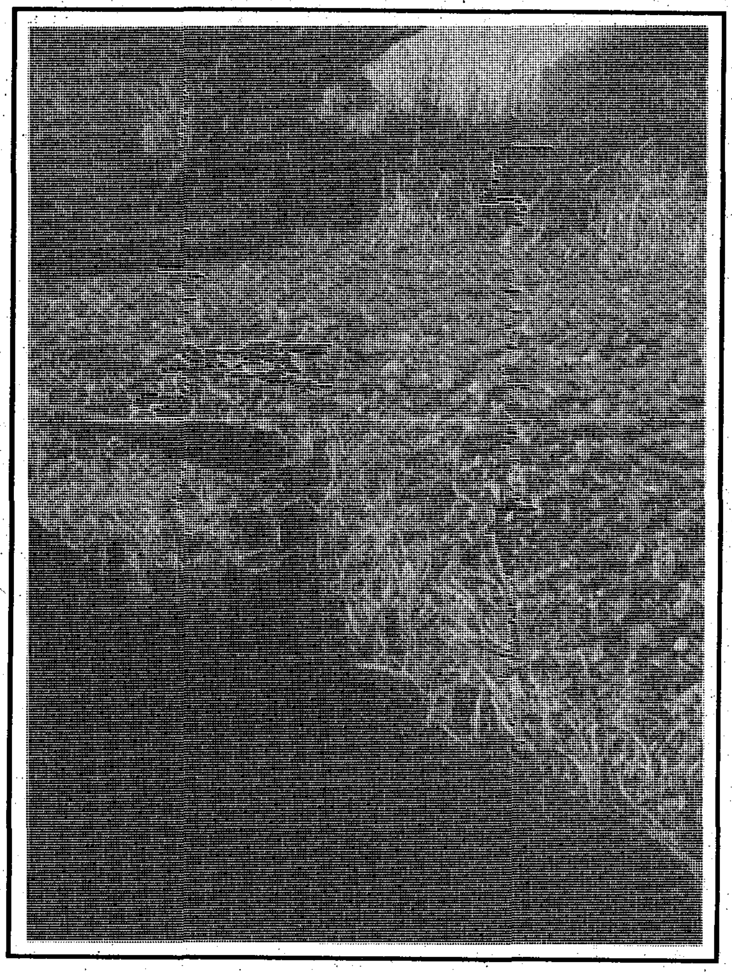

Plate 3 Mats in the Canning River grow up to 50 cm above the water

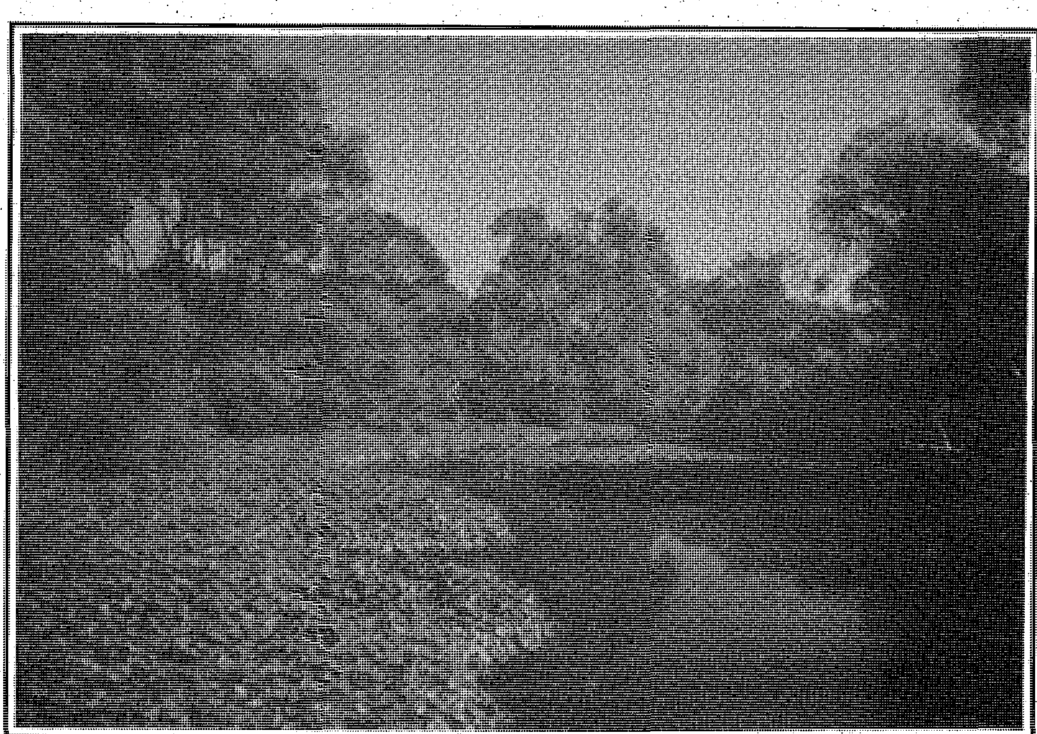

Plate 4 Extent of the mats in the Canning River vary from small patches up to hundreds of metres long, covering the river from bank to bank

2.3.4 Water and sediments

The dense mats of *Hydrocotyle* found in the Canning River would have significant impacts on the underlying water and sediments. The aquatic weed *Salvinia molesta* also forms dense layers of floating vegetation and below this layer many significant changes have been found to occur (McComb and Lake 1990). These changes include reduction in light penetration, inhibited exchange between air and water, reduction in wind mixing, depletion in oxygen levels, nutrient release from sediments, hydrogen sulphide accumulation, and an alteration in pH due to increases in dissolved carbon dioxide. These changes can have a profound impact on the ecosystem and cause a decline in water quality.

Although *Salvinia molesta* is generally thought to grow in more stagnant water, an infestation of this species in the Canning River in 1974-1975 resulted in similar impacts to those described by McComb and Lake (1990). Therefore, the assumption has been made that similar impacts on water quality may be occurring in the Canning River as a result of the *Hydrocotyle* growth.

Preliminary results of investigations on invertebrate diversity in the river have recorded dissolved oxygen levels as low as 3 mg/L in the water column. Oxygen levels below 4.5 mg/L are generally considered unsuitable for the maintenance of aquatic life (Department of Conservation and Environment 1981). There is insufficient dissolved oxygen data at this stage to determine whether these low levels are seasonal or as a direct consequence of *Hydrocotyle* growth.

Despite these possible negative impacts *Hydrocotyle* is probably removing nutrients from the water column thus reducing the concentrations. However, as the plant mass is not being removed from the system the nutrients are being cycled rather than removed.

2.4 Impact on river recreation

Floating mats of *Hydrocotyle* have the potential to interfere with recreational activities within the regional park. Activities likely to be affected include canoeing and aesthetic views of the river. Recreational activity is restricted by mats of *Hydrocotyle* which extend from bank to bank often excluding access to upstream or downstream areas.

The dense mats of *Hydrocotyle* create a safety issue for river users. A person attempting to walk across a mat, becoming entangled in a mat or falling into the river (and being unable to reach the bank because of the mats) may drown.

2.5 Factors influencing *Hydrocotyle* growth

2.5.1 Kent St Weir

The Kent St Weir has been in place in a variety of forms since 1911 and the current structure dates from 1962. The weir was constructed to maintain freshwater for farming purposes in a previously tidal section of the river. Licences for landholders to extract water from the river (riparian rights) were granted and some of these remain current (Richards 1991).

The weir height is altered each season with boards. The aim is to facilitate water flow and reduce flooding risk in winter (i.e. no boards) and maintain sufficient water within the river in summer for recreational and some minor agricultural use (i.e. boards). Around mid-October to mid-November each year the boards are replaced in the weir. This results in an increased water level within the river. Water levels have been observed to rise one metre after the boards have been installed.

This creates significant difficulties in controlling *Hydrocotyle*. Lower water levels mean that greater areas of bank are exposed and are therefore less suitable as *Hydrocotyle* habitat. However, the rhizomes may be able to survive within the moist bank sediments and regerminate on the next 'flooding' cycle. This 'flooding' of the river in mid-spring can result in large areas that were previously dry becoming waterlogged. This in effect increases the potential habitat for *Hydrocotyle* and enables the plant to grow amongst other species such as *Typha*. This significantly reduces the efficiency of control techniques and without eradication in these areas provides a continued in-river source of *Hydrocotyle*.

2.5.2 Current nutrient status of the river

The Swan River Trust monitors nutrient (nitrogen and phosphorus) loads in two of the eight Water Authority of WA main drains that discharge into the Canning River Regional Park. In addition another three of six main tributaries upstream of Nicholson Road Bridge are monitored for nutrient loads. Load calculations are based on a minimum of weekly nutrient analysis and stage height recorders which integrate the probe every five minutes. Monitoring is continued throughout the year or when the drainage systems cease to flow. No monitoring of the volume or quality of water flowing over Kent St Weir has been conducted to date.

Between 1987 and 1990 an annual average total of 10.6 tonnes of phosphorus and 95.5 tonnes of nitrogen were discharged into the Canning River from the five drains monitored. The actual load to the river would be greater than this when other drainage discharges are included. However, there is no estimate at this stage of the contribution from these other drains. There is no data available on water flows of the Canning River.

Natural background levels of phosphorus in the river are low (0.01 mg/L). The average annual levels of phosphorus in the Canning River, upstream of Kent St Weir between 1979 and 1985 was 0.22 mg/L (Thurlow et al. 1986). The Vollenweider and Kerekes (1980) classification system for eutrophic lakes places the Canning River in the mesotrophic range or moderately nutrient enriched. Annual blooms of the microscopic green algae, *Euglena*, have been reported in this section of the river since 1976. This is an indication of nutrient enrichment.

Although no information is known about the nutrient requirements of *Hydrocotyle* the levels in the river are probably not limiting to its growth. It is not possible to easily assess nutrient removal by this plant. There are 14 major drainage systems discharging into the Canning River and therefore even a basic upstream and downstream assessment of nutrient levels would not provide information on nutrient uptake by *Hydrocotyle*.

2.6 Advantages and disadvantages of *Hydrocotyle* in the Canning River

Table 1 summarises the advantages and disadvantages of the growth of *Hydrocotyle* in the Canning River. These are related to short-term observations of the impact of this plant on the river ecology and are based on a subjective view of the likely or observed impacts. Long-term impacts depend on whether management is undertaken or not. The basis for control of *Hydrocotyle* has been outlined in Sections 2.3 and 2.4.

Advantages	**Disadvantages**
may improve water quality (nutrient removal)	may spread to other waterways
provides habitat resulting in increased faunal populations	decreased water quality (decreased dissolved oxygen levels)
	reduces recreational opportunities
	may displace native plants
	may cause erosion
	rapid growth rate
	aesthetics (decreased views of open water)
	safety hazard (entanglement in mats may result in drowning)

Table 1. Summary of the advantages and disadvantages of *Hydrocotyle*.

3. INVASION OF THE CANNING RIVER BY *HYDROCOTYLE RANUNCULOIDES*

3.1 Possible sources

Hydrocotyle has been a common aquarium plant, readily available from distributors of aquarium plants, nurseries etc. throughout the metropolitan area and the rest of the State. The *Hydrocotyle* in the Canning River probably originated from the release of garden and aquaria wastes into drains or through dumping in the immediate vicinity of the river.

3.2 Changes in distribution in the Canning River from 1983 to 1992

Hydrocotyle was first observed in Bannister Creek in 1983 when Agriculture Protection Board officers were undertaking an eradication program for water hyacinth and *Salvinia*. By 1987 *Hydrocotyle* had spread into the Canning River Regional Park. The weed remained fairly static in the river system until early 1991, when the distribution suddenly became more extensive. Figures 3, 4 and 5 illustrate the change in distribution in the section of river between Kent St Weir and Nicholson Rd Bridge from 1989 to 1992 and Table 2 shows the estimated volumes and tonnages.

	Volume (m^3)	Estimated Tonnage	% River Covered
February 1989	167	2	0.14
December 1989	4 451	46	4
January 1991	10 678	110	9
January 1992	5 147	53	4
September 1992	30 760	320	27

Table 2. Change in the volume of *Hydrocotyle* in the Canning River, between Kent St Weir and Nicholson Rd Bridge, 1989 to 1992.

In November 1991, the *Hydrocotyle* was in large mats covering the river bank to bank in some sections and was distributed from Kent St Weir to Nicholson Rd Bridge, with an estimated volume of 17,000 m^3 (175 tonnes). In an attempt to contain this massive bloom of *Hydrocotyle*, Department of Planning and Urban Development (DPUD), the Swan River Trust, Canning City Council and concerned residents, conducted a two-week removal exercise (Section 5) involving mechanical and manual removal of *Hydrocotyle*. The mechanical removal included the use of one of the algal harvesters used in the Peel-Harvey Estuary as well as backhoes and boats. These control measures were followed up by maintenance control by DPUD until mid-January 1992, when growth rates exceeded the rate of removal.

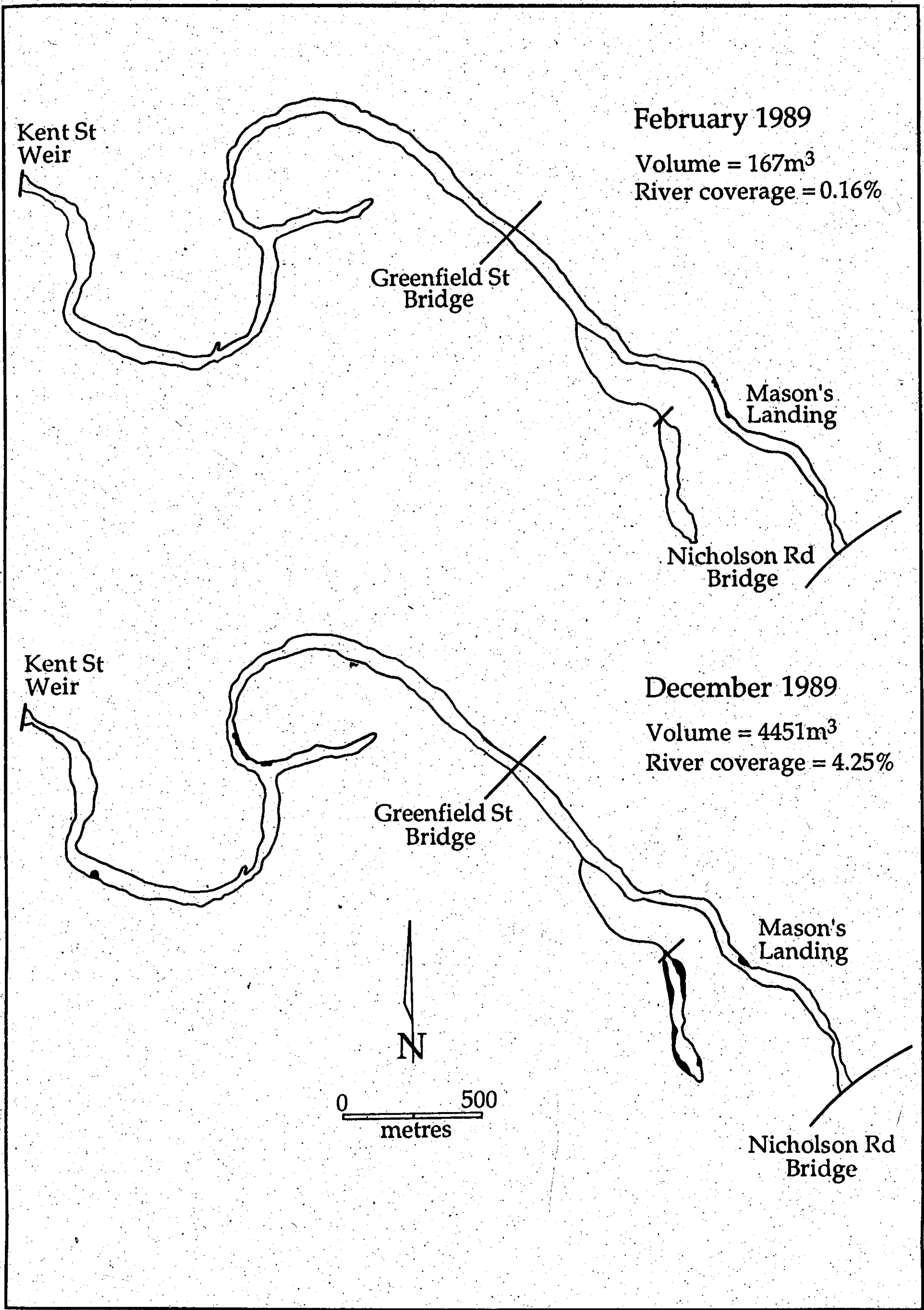

Figure 3 *Hydrocotyle* distribution between Kent St Weir and Nicholson Rd Bridge, February and December 1989

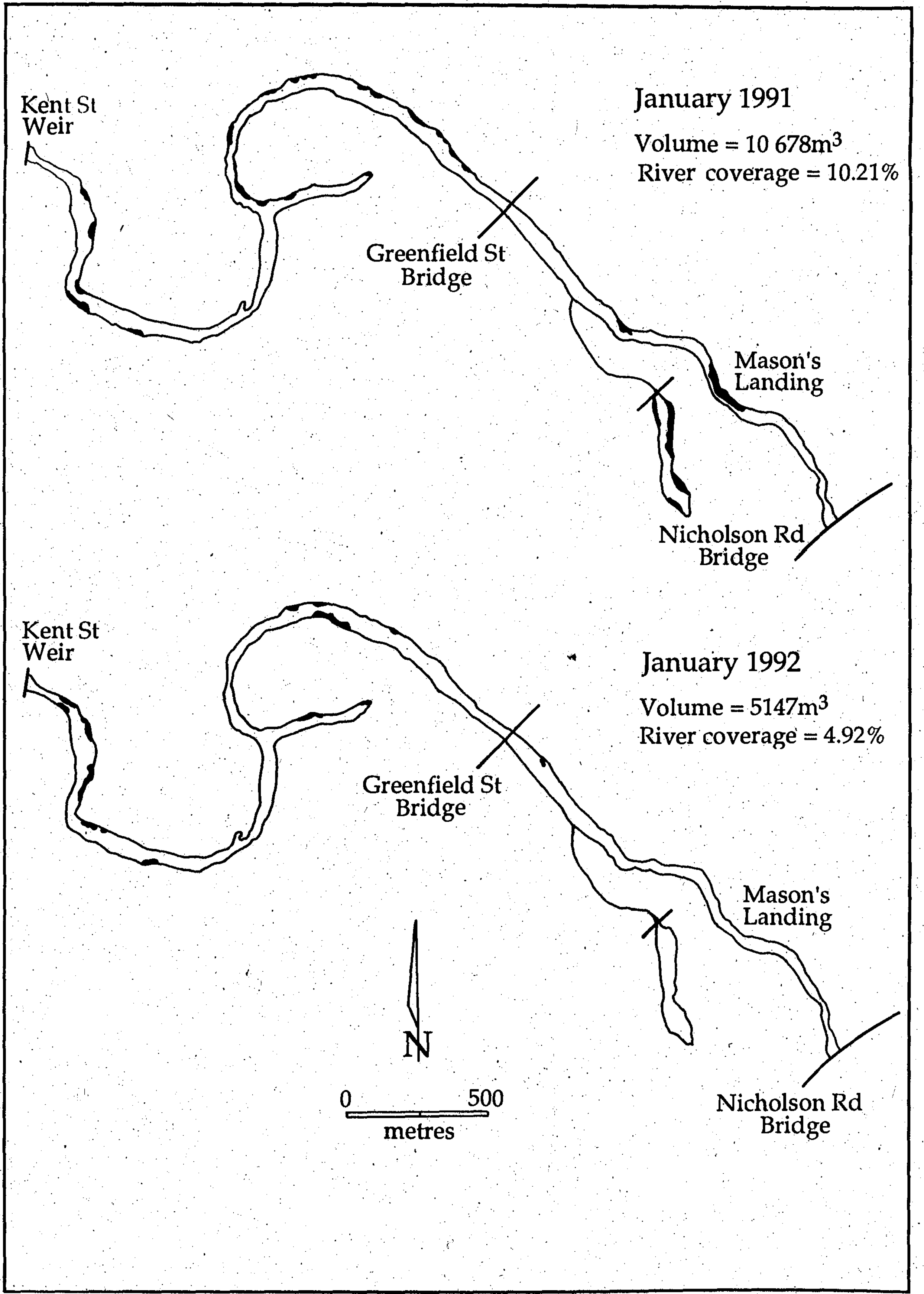

Figure 4 *Hydrocotyle* distribution between Kent St Weir and Nicholson Rd Bridge, January 1991 and January 1992

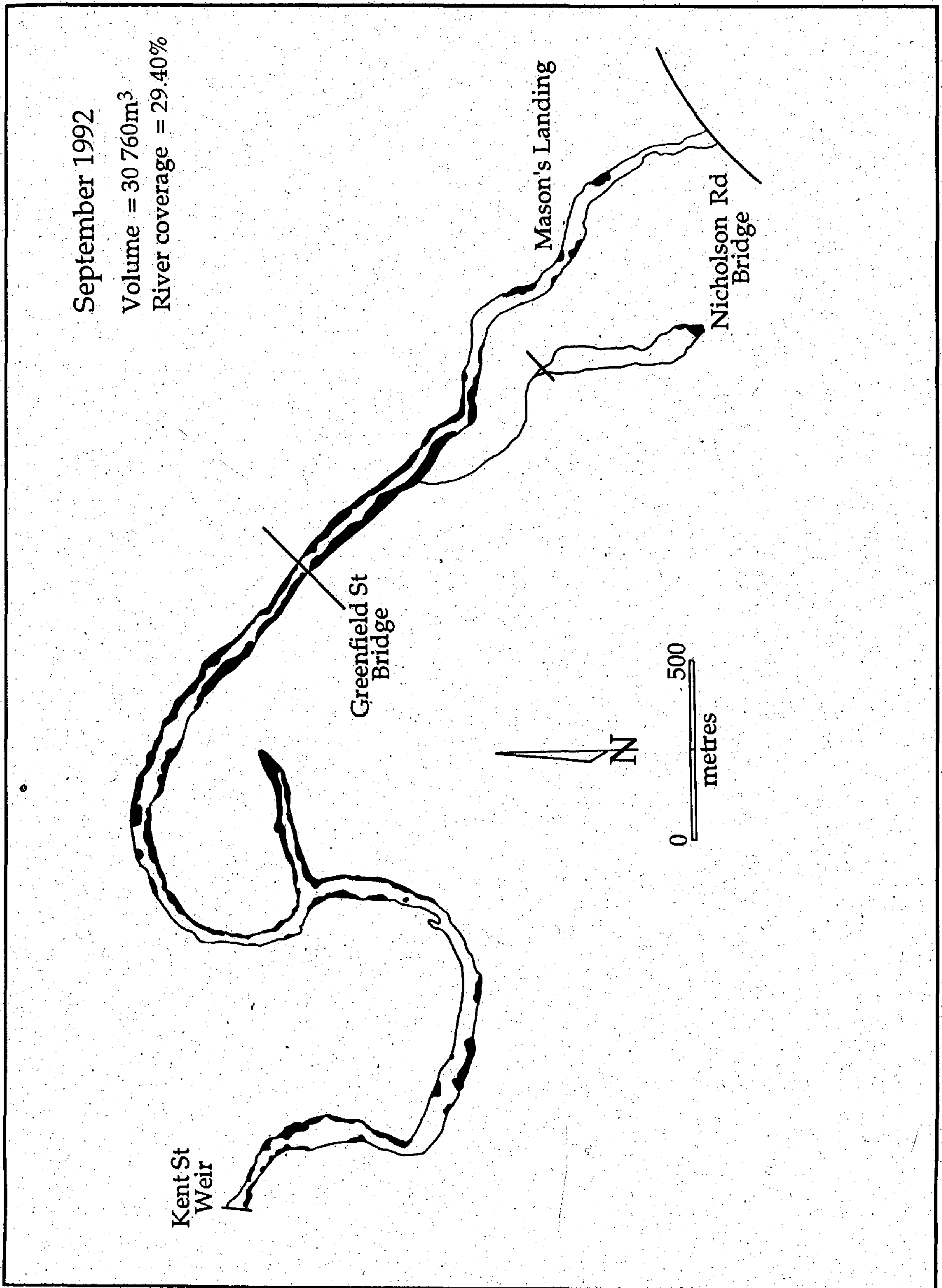

Figure 5 *Hydrocotyle* distribution between Kent St Weir and Nicholson Rd Bridge, September 1992

In September 1992, the estimated volume within the Canning River Regional Park was 40,000 m^3 (420 tonnes). The majority of this (30,000 m^3 or 310 tonnes) was between the Kent St Weir and Nicholson Rd Bridge section of the Canning River, covering approximately 30% of the water area. At this time there were numerous small mats and some large mats, although no sections of the river were blocked by *Hydrocotyle* mats from bank to bank.

Further downstream, between Kent St Weir and Shelley Bridge the volume was estimated at 10,000 m^3 (or 103 tonnes). At the beginning of the summer 1991-1992, salinity levels downstream of the weir increased to levels sufficient to kill *Hydrocotyle* mats. During the 1991-1992 summer, rainfall occurred in the Perth Metropolitan Area, maintaining a low enough salinity for *Hydrocotyle* to continue growing throughout the summer in this tidal section. Consequently the volume of *Hydrocotyle* in this section of the river was significantly greater than at the same time in 1990-1991.

It was estimated that the total weight of *Hydrocotyle* within the river in September 1992 was approximately 420 tonnes. This estimate is probably low because material that was not removed from the river over the summer 1991-1992 would be heavier than new growth.

While relatively successful in the short-term, it appears that physical removal work undertaken in November 1991 has resulted in the spread of *Hydrocotyle*. Each small section that floated away from the large mats removed had the capacity to generate a new mat.

The 1992 explosion of this plant appears to have been due to a number of factors; mainly an above average rainfall summer increasing nutrient loads and the lack of a coordinated follow-up program following the removal exercise of November 1991 (Section 4). Although DPUD did undertake follow-up work in conjunction with Community Service Order people, the program was aimed at maintenance not eradication.

3.3 Spread through drainage systems

Hydrocotyle has been located in nine Water Authority of WA main drainage systems and one local authority drain leading into the Canning River. It has been suggested that the spread of *Hydrocotyle* throughout the drainage channels was the result of fragments being caught on Water Authority machinery used for drain maintenance. There is widespread concern that *Hydrocotyle* may be transported to irrigation channels and other naturally occurring fresh water bodies in the metropolitan area, potentially causing similar problems to those currently occurring in the Canning River system.

Hydrocotyle has been located in the following drains (Figure 6):

North of the river

- Wilson Main Drain
- A local authority drain near the Railway Park
- Mills Main Drain - in both the Kalgan Rd B.D. and the Ewing St B.D. *Hydrocotyle* was traced to immediately west of the compensating basin adjacent to Abernethy Road
- Lacey St Main Drain near Hogarth St
- Yule Brook Main Drain

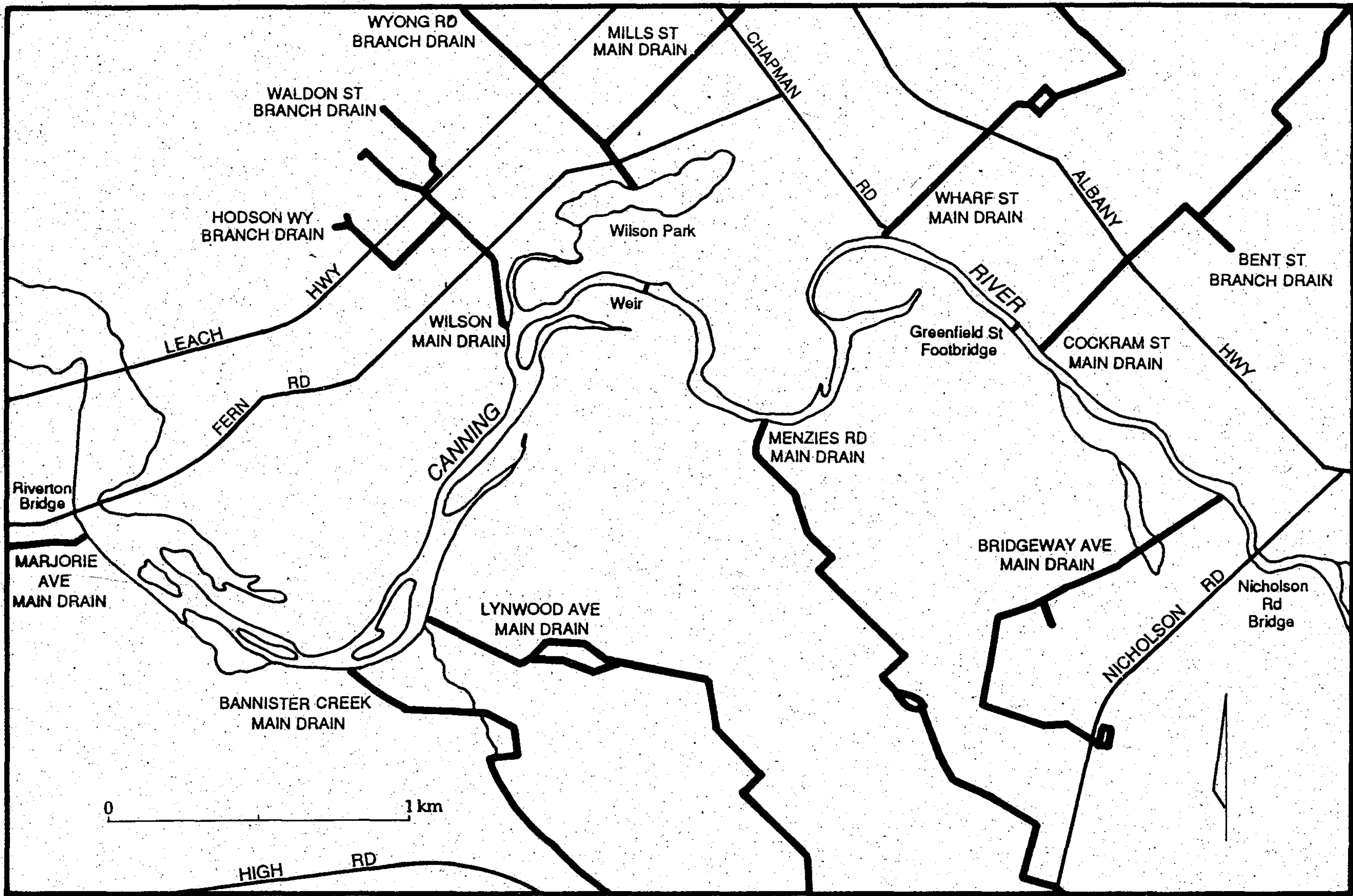

Figure 6 Drainage system in the Canning River Regional Park

South of the river

- Marjorie St Main Drain - small patches
- Lynwood Ave Main Drain - back to Alyxia Crescent
- Bannister Creek Main Drain- possibly in Whaleback golf course
- Menzies Main Drain immediately adjacent to river
- Bridgeway Ave Main Drain - in lake adjacent to river and up to Eastfield Court

The majority of these drains discharge directly into the Canning River Regional Park. Yule Brook discharges upstream of Nicholson Rd Bridge (outside the Regional Park). The identification of *Hydrocotyle* in this drain is of concern because it may result in infestation of areas of the river relatively free of the weed (upstream of the bridge there was one small mat, 10 m^2 in September 1992).

3.4 Overview of removal in November 1991

In November 1991 an intensive two-week control program was implemented with the aim of removing *Hydrocotyle* from the river system and increasing community awareness of the problem. A range of techniques were used including harvesting, other mechanical methods (backhoe and boat), manual removal and herbicides.

Table 3 shows the groups that participated in this control program. A total of 404 people days were deployed over the two-week period with an average of 28 people per day removing *Hydrocotyle*. Removal using backhoe, boat and manual labour amounted to approximately 7,000 m^3 (72 tonnes). The harvester removed approximately 7,000 m^3 (72 tonnes) in three days. The total volume removed during the control program was approximately 17,000 m^3 (or 175 tonnes), which represented approximately 75% of the biomass in the river.

Group	Number of people/day	Number of days
Canning Senior High School	110	2
Canning City Council	20	2
Community	15	4
Department of Planning and Urban Development	12	2
Swan River Trust	30	2

Table 3. Groups participating in the two-week intensive control program.

Follow-up after this exercise involved an average of two Community Service Order people per day for four months. The main removal technique involved cutting mats and floating them by boat to the shore where the mats were dragged from the water. There is no estimate of how much material was removed by this group of people.

Physical and chemical control methods were trialed in 1991, and the limited long-term success of these has been attributed to the lack of monitoring and follow-up treatment. Ecological (e.g. alteration of salinity) and biological methods can not be applied for the control of *Hydrocotyle* because of the life cycle and growth of this plant (Section 2).

4. CONTROL AND ERADICATION OF AQUATIC WEEDS

Once an introduced plant has successfully invaded and established itself and is found to have adverse ecological and environmental effects it is important that its further spread be prevented. The following quote from Arthington and Mitchell (1986) describes the process required to achieve eradication of aquatic weeds.

> Eradication is possible if the infestation is vigorously and persistently controlled at an early stage of the invasion of a relatively small, confined water body. Often however, the water body is too large with parts that may be inaccessible, or the infestation is too well established. In either case it is critically important that control attempts are well planned and thorough and that they are persistently carried out. Regular surveys and follow-up control of outbreaks from surviving plants are required for a number of years.

A strategy based on the concept of integrated control using mechanical, chemical, biological and ecological control techniques where appropriate, aims to use techniques with minimal and/or manageable environmental impacts. This type of strategy does not rely on one approach and therefore reduces the environmental impacts of any one method. An ideal weed eradication strategy would involve a combination of short-term management while aiming for long-term eradication.

In addition, removal of the plant should not be considered in isolation as this action creates an empty space in the ecosystem that may be filled again. It must always be recognised that controlling one weed problem may create a worse one (Murfitt and Haslam 1981).

Any combination of control and eradication techniques undertaken in the Canning River will have an environmental impact. The main impact identified is the reduction in wildlife populations, including birds, crustacea and fish (Section 2.3). This impact will occur as a consequence of the habitat created by *Hydrocotyle* being removed from the river. It is possible that herbicides will be blamed for the loss of wildlife unless they are used judiciously.

The rate of success in controlling *Hydrocotyle* with herbicides or harvesting is probably similar, around 90 - 98%. It is the last 2-10% that is not effectively treated or removed that has the potential to regenerate into a large biomass. A thorough and persistent follow-up program aimed at destroying that last percentage of *Hydrocotyle* is essential for eradication of this weed from the waterway.

The next section will outline the strategy for removing the bulk of the biomass in the short-term and also identify a suitable procedure for the long-term (three-five year) eradication of *Hydrocotyle*.

5. SHORT-TERM CONTROL OF *HYDROCOTYLE RANUNCULOIDES*

AIM: To remove the majority of *Hydrocotyle* from the Canning River Regional Park and associated drains.

Aquatic weed control programs need to be planned, thorough and diligently carried out until the weed is eradicated from the area. Regular surveys and follow-up control of subsequent weed outbreaks are required for a number of years. Eradication is possible with vigorous and diligent control measures at an early stage of the invasion in a relatively small, confined water body (Arthington and Mitchell 1986). *Hydrocotyle* eradication may be difficult considering it is well established within the river system.

The growth pattern of *Hydrocotyle* (dominantly vegetative reproduction) means that it is necessary to develop an integrated control strategy that does not rely on one approach but combines a variety of techniques. This reduces the potential environmental impacts of any one method (e.g. herbicides).

The aim of short-term management is to remove the majority of *Hydrocotyle* from the Canning River Regional Park and its associated drains during the summer 1992/1993. It must be recognised that eradication will take considerably longer than this. Details on the long-term eradication program are outlined in Section 6.

There are four main methods for weed control: physical, chemical, ecological and biological. The next sections review and assess each of these methods and Table 4 provides a summary of the advantages and disadvantages of each control option. In addition, the techniques used in November 1991 are reviewed and suggested improvements made, and the potential environmental impacts of the eradication of *Hydrocotyle* from the Canning River system and its associated drains are identified.

Control Technique	Advantage	Disadvantage
Physical removal	- removes large volume quickly - disposal easy - public acceptance - minimises impact on ecology	- sediment resuspension causes nutrient release - cutting of mats creates fragments (could be controlled using booms) - manoeuvring machinery on land - bank disturbance and removal - cost
Physical removal then selective herbicides	- bulk removed quickly - herbicides used selectively on banks - minimises impact on ecology of river and banks - uses combination rather than one technique - public acceptance - disposal easy	- cost - same as using physical removal - longer term than broadscale herbicide use - complicated and requires coordination
Herbicides - broadscale use	- kills plant and prevents regeneration of fragments (depending on herbicide) - relatively cheap	- large mass of plant material sinking and decomposing in the water column leading to oxygen reduction and fish deaths - impact of herbicide on aquatic environment not quantified - public perception of herbicides - none registered for use against *Hydrocotyle* - impact on riparian and recreational users - morphology of plant and mat density means that herbicide may not kill entire mat

Table 4. Summary of the advantages and disadvantages of various options for the control of *Hydrocotyle*.

Control Technique	Advantage	Disadvantage
Herbicides - broadscale then physical removal	- reduces mass of plant material requiring removal	- mats still require cutting - fragments may remain viable - occupational health issues introduced - impact on riparian and recreational users - disposal difficult
Biological	- specific to species	- not available - 24 native WA species - same family as celery and carrots - would take approximately three years to develop
Ecological - hydrological modification	- kills off without chemicals - minimal impact - low cost	- freshwater lens maintained because of freshwater inputs -unpredictable summer rainfall - upstream of Kent St Weir has been freshwater since 1922 - difficult to predict impact - impact on riparian users
Ecological - nutrient reduction (water and sediment)	- reduces food source - improves health of river system	- long-term scenario, not achievable in required time - limiting nutrient levels unknown

Table 4 (continued) Summary of the advantages and disadvantages of various options for the control of *Hydrocotyle*.

5.1 Physical removal

5.1.1 Mechanical techniques

5.1.1.1 Harvester

A conveyor harvester comprises a box type pontoon hull (8 m x 3.6 m), which is self propelled by two large paddle wheels (one each side of the hull), mounted centrally, carrying three, in-line steel mesh, 2 m wide, conveyor beds. Weed is collected by an inclined conveyor bed mounted on the bow of the pontoon. The maximum collection depth is 1.5 m. Weed is stored on a centrally mounted horizontal conveyor (4.7 m long) and is discharged to shore by the third conveyor inclined over the stern.

One harvester from the Peel-Harvey Estuary was transported to the area to remove the bulk of the volume of *Hydrocotyle* at the end of 1991, and resulted in approximately 7,000 m^3 (or 72 tonnes) being removed from the river (Plate 6).

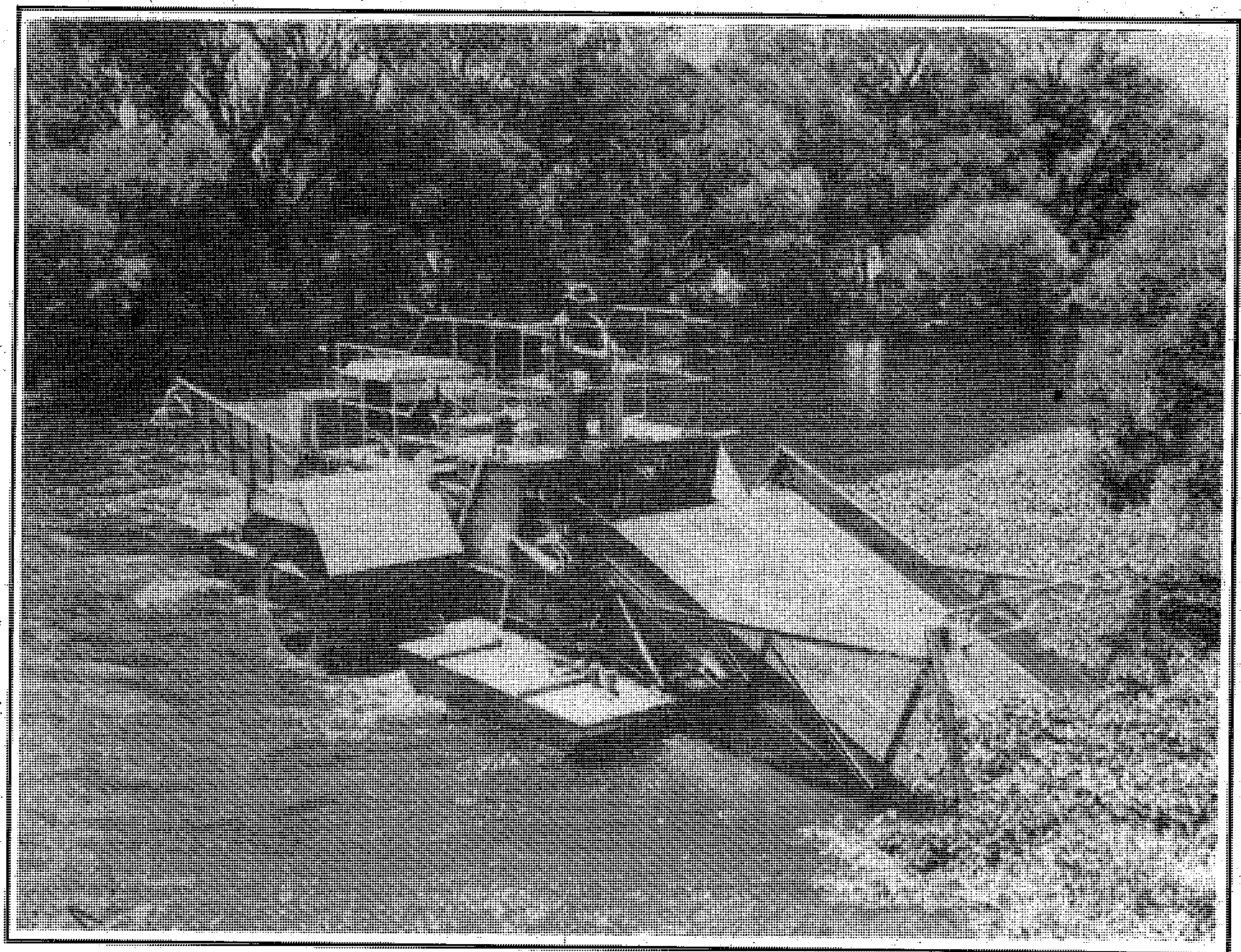

Plate 6 The conveyor harvester used in the removal program of 1991

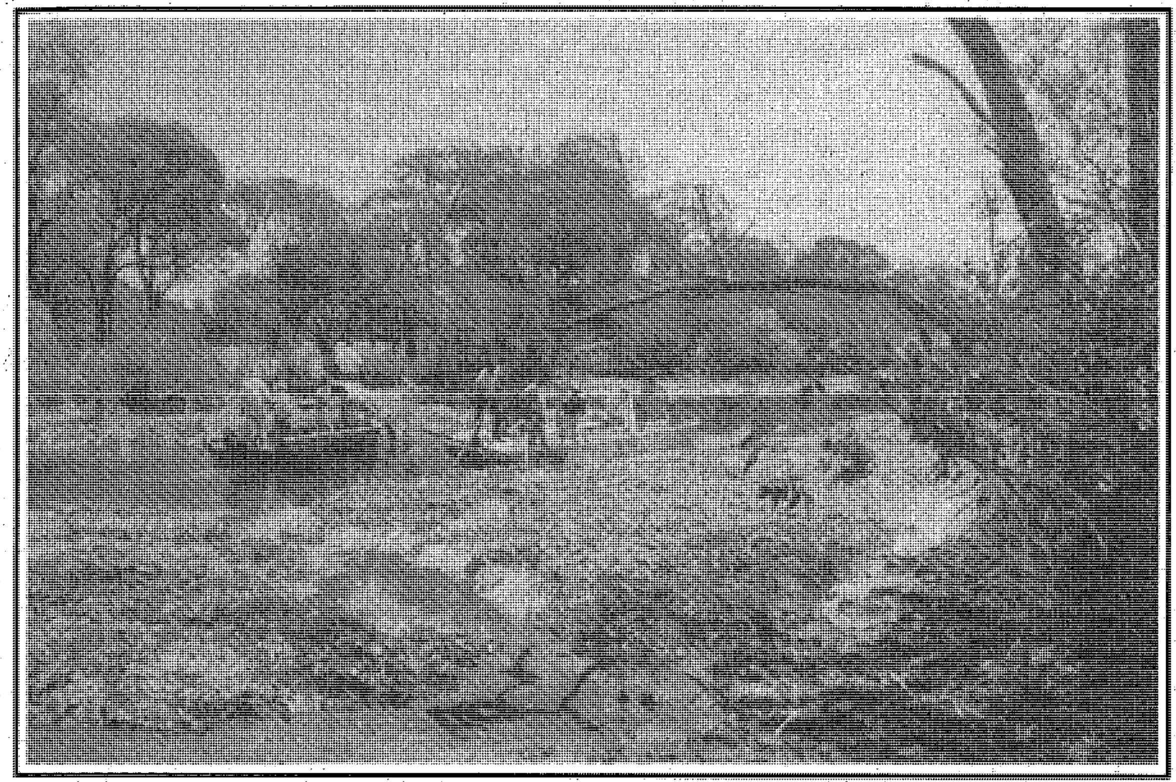

Plate 7 Using sickles and scythes to cut mats away from the bank and floating them downstream during the removal program of 1991

Plate 8 Removal of mats from the river and stockpiling using a backhoe and bobcat

The advantage of the harvesting method is that it is an effective method of removing a large volume of weed in a short period of time. However, it caused sediment resuspension due to the action of the paddle wheels. This may have resulted in the release of nutrients, supplying an addition food source for the *Hydrocotyle*. Conversely, the agitation caused by the harvester may have resulted in sediments becoming more oxygenated and therefore more strongly binding nutrients.

The harvester is dedicated to removal of macroalgae in the Peel-Harvey estuarine system, and has been made available to assist in *Hydrocotyle* control. However, this relocation is time limited due to the annual intensification of macroalgal growth expected in the Peel-Harvey system in March.

In 1991, large mats had to be cut into sections that the harvester could load. The plant material was then transported to shore and the conveyer deposited the material on the bank of the river. The cutting of mats and the subsequent loading onto the harvester resulted in the fragmentation of plant material. No systematic collection of these fragments was undertaken and each had the potential to regenerate into another mat. The use of a boom system to trap small fragments and an intensive follow-up herbicide program would reduce the chances of these fragments growing into a large mat.

Other considerations included the development of a means of effectively cutting the *Hydrocotyle* to minimise fragmentation. Techniques will be trialed during the summer of 1992-1993. One technique to be trialed will be the use of knife cutters on the forward conveyor of the harvester. However, the harvester is unable to access all areas of the river and alternative removal methods must be considered.

5.1.1.2 Boats and backhoe

The major technique used in 1991 to mechanically remove the *Hydrocotyle* involved people in boats cutting the mats into sections using sickles and scythes, then floating the mats to shore. The mats were then lifted out by a combination of bobcat and backhoe, stockpiled on the bank and later transported from the site (Plates 7 and 8).

This method was relatively effective in achieving bulk removal, however there were problems with fragmentation and sediment stirring similar to those outlined in Section 5.1.1 (Plate 9).

Problems were also noted in manoeuvring the machinery amongst the trees to locations on the bank where retrieval was possible. The backhoe could be positioned in more locations than the bobcat, which required the construction of a ramp area. Assessment of the bank areas where these machines were used has suggested that erosion rates did not differ significantly from other areas of the river where machinery had not been used.

5.1.1.3 Pontoon with rake

A pontoon with a rake attachment would be able to access shallow areas and transport large volumes of the weed.

5.1.1.4 Booms

The booms will not significantly impede the movement of aquatic animals as they will only be suspended in the first 20 cm of the water column and will be constantly monitored to ensure entanglement does not occur.

Plate 9 Manual removal causing fragmentation of *Hydrocotyle* and stirring of sediments

5.1.2 Manual removal

This method is used widely, in a variety of forms, around the world by volunteer groups to reduce or contain infestations of both terrestrial and aquatic weed species. Techniques used include digging and cutting and are generally aimed at causing minimal environmental disturbance.

No specific procedure was used in the November 1991 exercise; techniques used were based largely on trial and error and therefore varied with each individual (Plate 10). The basic technique used to remove *Hydrocotyle* involved cutting the weed into manageable portions with a scythe or sickle, and dragging the mat section onto the bank. Rooted sections of the mats were dug out.

Disturbance caused through accessing banks may have resulted in the burial of fragments that later regenerated. Regeneration in some areas that appeared 'free' of *Hydrocotyle* immediately after the control program was observed within two weeks (Plate 11). Other areas showed no regeneration. It was difficult to determine the causes of these differences. This method also resulted in the generation of large numbers of fragments which were not contained.

The involvement of volunteers in the November 1991 removal program was not considered to be consistent and their use as a major removal technique may not be appropriate. The labour cost was high in terms of material removed from the river. To include volunteers in a program of eradication requires coordination and supervision, the setting of achievable tasks and ongoing commitment from volunteers. This would be difficult, if not impossible, to sustain over any length of time.

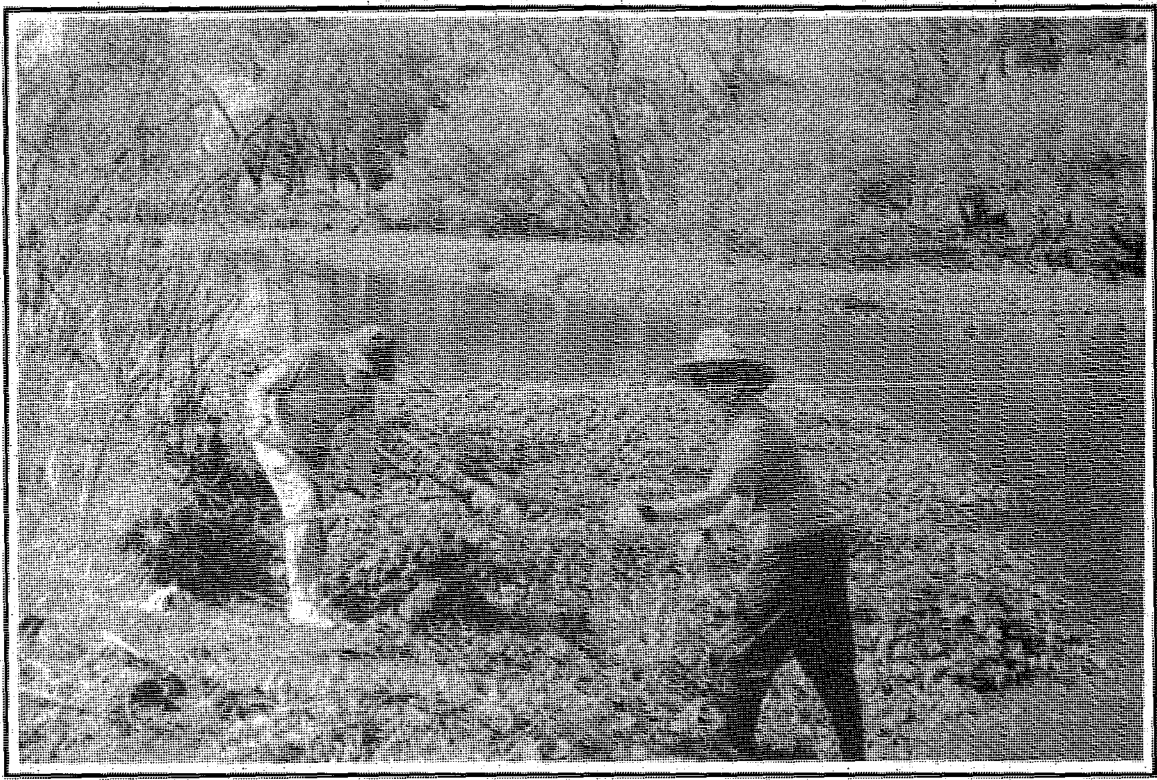

Plate 10 Various manual techniques were used during the removal program of 1991 including cutting the mats into manageable portions and digging the rhizomes out of the banks

Plate 11 Regeneration of *Hydrocotyle* mats several weeks after the removal program

Like all of the other techniques, manual removal is itself a disturbance, and must be followed by continued monitoring, as any the removal of the, weed may itself create a niche suitable for reinvasion. Continued surveillance is vital if this form of control is to be effective.

Despite the disadvantages and organisational difficulties, it is essential to involve the community in the control and removal of *Hydrocotyle* . Assistance in retrieving fragments, accessing areas inaccessible to machinery and increasing awareness through involvement will help to ensure that the short-term program of control is successful.

5.1.3 Conclusion on physical removal

Physical control techniques must be very selective to avoid damage to native plant communities, wherever possible. In addition, these techniques may only achieve partial removal because of physical barriers such as snags in the river.

The potential impacts and benefits of this approach include:

- it is relatively environmentally 'friendly'
- disposal options remain open
- nutrients are removed from the system by removing the plant material
- rapid removal of the bulk of the plant material means the river is opened for water-based recreation
- the cutting of mats results in fragmentation, each potentially capable of regenerating
- boom systems and intensive follow-up would be required to catch fragments
- there is potential for increased bank erosion caused by machinery access
- may increase sediment nutrient release into the water column
- direct contact recreation would be interrupted by the activity of machinery, but would not be excluded

It is necessary to use physical removal methods in conjunction with other techniques for the control of *Hydrocotyle*, because each segment produced by vegetative reproduction is capable of developing into a whole mat (as found in 1991). This section deals only with the procedure for physical removal.

The short-term program will include both mechanical and manual techniques. Mechanical techniques will include a combination of the use of harvester, backhoe, boats and pontoon as appropriate. Plant material will be transported to the banks and removed from the river. To reduce the volume of material requiring disposal, drying piles will be trialed. These will require surveillance to ensure that material is not returned to the river. It is anticipated that after drying for two weeks (depending on weather conditions) the mass of plant material will have reduced by up to 80%. Once dried the plant material will be disposed of in an approved manner (composting or landfill).

The river has been divided into discrete operational cells. Work will commence in the most upstream cell and work downstream. This approach has been adopted for two reasons: firstly, this generally coincides with the areas of greatest infestation and, secondly, any missed fragments are likely to flow downstream enabling further removal. Further detail of the operational cells is contained in Section 5.5.1.

Manual removal areas will be defined as part of the operations phase, however it is anticipated that the biggest contribution that this technique will be able to provide is follow-up removal of fragments as machinery moves from one operational cell to the next. A number of 'community days' will be incorporated into the short-term program.

Disposal of material generated by manual removal will depend on the volume removed. It may be possible to dry the material on the banks and leave it there to decompose. However, concern over the potential viability of the seeds means that this method may not be acceptable and removal from the regional park will be necessary.

To limit dispersion of fragments created by physical removal the use of booms (floating fences made of fine wire or fine fishing net) around areas where the *Hydrocotyle* is being removed appears to be essential. This will assist in trapping fragments and will reduce the potential for reinfestation and spread of this weed. A variety of 'booms' will be trialed and particular attention will be paid to the impact on aquatic animals.

Floating signs will be placed in the river upstream and downstream of operational areas to inform recreational users of the use of machinery in the area.

5.2 Herbicide application

Herbicides kill plants through either the inhibition or disruption of vital biochemical processes such as photosynthesis, respiration and protein synthesis. The effect is caused by either direct contact (cell desiccation) or systemic (translocative) action. Contact herbicides (e.g. diquat, paraquat) kill only the plant part to which the chemical is applied whereas systemic herbicides (e.g. glyphosate, atrazine) are absorbed by the plant parts and are then translocated throughout the plant system (Task Force on Water Quality Guidelines 1991).

The advantage of translocated herbicides is that they are taken to the site of metabolic action of the plant, and thus prevent regeneration. Contact herbicides only kill the parts of the plant contacted. As *Hydrocotyle* forms dense mats, the destruction of the foliage may only be short-term as buds can regenerate into mats if not removed. One of the problems associated with contact herbicides is the variation in selectivity and resultant damage to non-target plant species.

When herbicides are used on or adjacent to waterways many issues must be carefully considered. In particular, there is a need to understand the biological and ecological significance of chemical measures on water quality and of the interactions between weed control and other aspects of water quality (Bowmer 1990). Water quality criteria for herbicides are threshold concentrations beyond which adverse effects for aquatic organisms can be expected. These criteria would be used to determine the application rates of any herbicides in the Canning River.

As well as concentration criteria, the persistence of a compound should be considered to determine if the herbicide would have a downstream effect. Due to the small amounts of herbicides being used and the diluting effect of the downstream water body it may be difficult to monitor any downstream effects. Bowmer (1990) stresses the importance of considering the interaction of herbicides with other toxicants and whether there may be synergistic or antagonistic effects.

Because aquatic ecosystems are complex using the toxicity for a single herbicide may not be useful. For example if diquat is applied to a heavily weed infested lake a number of subsequent problems can occur. As the weeds die and are decomposed by bacteria the amount of available dissolved oxygen for other animals decreases. The immediate consequences of reduced oxygen levels include fish kills and an increase in nutrients released by microbial decomposition and sediment release. Subsequently the increased nutrient levels may result in development of algal blooms, beginning a cycle of 'boom' and 'crash' within the system (Moore and Fletcher n.d.).

The use of herbicides may represent the cheapest and potentially most efficient form of removing *Hydrocotyle* from the Canning River. However, their use must be evaluated carefully in terms of environmental impacts and benefits. The foremost consideration in dealing with herbicides in the river is the impact of their use on non-target native vegetation and animal life, and on the environment generally.

5.2.1 Suitable herbicides for *Hydrocotyle* control

Non-selective herbicides can be applied directly to the foliage of the target species - a process known as spot application. Two methods are appropriate for use in the river:

- foliage spraying using low pressure with or without a spray hood, and

- wick wiper or brush application (which eliminates the risk of drift). Spray drift is a function of prevailing conditions, system pressure, size and height of nozzle.

An important consideration for the use of chemicals in the control of *Hydrocotyle* is to minimise environmental contamination and application to non-target species.

In 1991 the Department of Agriculture conducted laboratory trials on a variety of herbicides that were considered to be potentially suitable for *Hydrocotyle* control. The aim was to identify effective herbicides that would give maximum control while being safe in terms of operator usage, and impact on flora and fauna (Peirce and Rayner 1992). Five herbicides were trialed under greenhouse conditions: chlorsulfuron, metsulfuron, glyphosate, simazine and imazethapyr. Table 5 presents the results obtained from this experiment. The report concluded that both glyphosate and metsulfuron produced acceptable control in laboratory conditions when used in conjunction with the organosilicone surfactant 'pulse'.

Herbicide Treatment	Application Rate	% Visual Control
Chlorsulfuron + wetting agent	1 g/10L	65
Chlorsulfuron + pulse	1 g/10L	76
Metsulfuron + wetting agent	1 g/10L	64
Metsulfuron + pulse	1 g/10L	94
Glyphosate + pulse	10 ml/L	91
Simazine + wetting agent	10 ml/L	82
Simazine + pulse	10 ml/L	71
Imazethapyr + wetting agent	1 ml/L	64
Imazethapyr + pulse	1 ml/L	72
Control	0	0
Diquat 1992	1.25 L/ha - 5.0 L/ha	80 - 98 (respectively)

Table 5. Results of the Department of Agriculture's laboratory trials (Peirce and Rayner 1992) on herbicides considered suitable for *Hydrocotyle* control.

The diquat trials in 1992 concluded that spraying the leaf surface was the most effective treatment method (reducing cover by 80 - 90%). The effect of treatments decreased over time and considerable recovery was observed on all treatments after 30 days. The report concluded that because a large proportion of the *Hydrocotyle* mat was below the surface of the water it did not come in contact with the herbicide. A translocative herbicide may be more effective in control (Peirce and Rayner 1992).

Table 6 summarises available information on the toxicity of each of the chemicals trialed on various animal groups found within the river system. The information is very general and is based on the likelihood of the species being adversely affected by the application of maximum recommended rates of the herbicide to pest plants.

Herbicide	Fish	Crustaceans	Birds	Microbes
Chlorsulfuron	low		low	low
Diquat	low-moderate	moderate	low-high	low
Glyphosate	low	low-moderate	low-moderate	low
Metsulfuron-methyl	moderate	low	low	low
Simazine	low		low -moderate	

Table 6. Acute toxicity of various herbicides to aquatic organisms (Brain and O'Connor 1988; Moore and Fletcher n.d.)

After application of herbicides to large weed infestations there is a deoxygenation hazard. Decomposing and dying plants reduce oxygen levels in the water and these may be low enough to kill fish. The effect is more likely during warm weather, in stagnant or slow moving water or when weed infestations are heavy (Moore and Fletcher n.d.).

Table 7 details the possible environmental effects of each of the trialed herbicides.

Herbicide	Activity	Mobility			Half-Life (weeks)		Break-
		Soil	Water	Air	Soil	Water	down
Chlorsulfuron	F,R	M	M	L	4-20	1-2	Ch,Mi
Diquat	F	L	L	L	0	1	Ch,Ph
Glyphosate	F	L	L	L	0-3	12+	Mi
Metsulfuron-methyl	F,R	L	M	L	1-4	0-1	Ch,Mi
Simazine							

Table 7. Environmental effects of herbicides trialed for *Hydrocotyle* control (Moore and Fletcher n.d.)

Table Code

Activity - F = Herbicide absorbed via foliage
R = Herbicide absorbed via roots

Mobility - L = Low mobility
M = Medium mobility
H = High mobility

Half-Life - The time it takes the herbicide to halve its concentration in soil or water

Breakdown -The methods by which most of the herbicide is removed from the environment
Ch = Chemical
Mi = Microbial
Ph = Photodecomposition

In addition to the laboratory trials the Department of Agriculture conducted trial spraying on six 1 m strips of *Hydrocotyle*, adjacent to Queen's Park Road. After 21 days all of the *Hydrocotyle* sprayed was dead. Glyphosate with oil was apparently the best, although glyphosate alone achieved a high success rate (J Peirce pers. comm.).

Based on the laboratory and field trial success rates, toxicological information and information on environmental effects, glyphosate and diquat are probably most suitable herbicides for control of *Hydrocotyle* in the Canning River. However, neither herbicide is registered in Western Australia for use in aquatic systems and special permission would be required to use them.

5.2.1.1 Glyphosate

Glyphosate is a non-selective, water soluble herbicide which is strongly adsorbed to soil and sediment particles (Worthing and Hance 1991). Once bound to particles glyphosate appears to be nearly immobile under normal conditions. Microbial degradation appears to be the primary mechanism of breakdown of glyphosate in both terrestrial and aquatic environments. Rates of degradation range from a few days to several months or years depending on conditions. Glyphosate is considered to dissipate rapidly from the water column, particularly if there is a high sediment load (Task Force on Water Quality Guidelines 1991).

The relatively high solubility of glyphosate indicates that a major pathway of exposure to aquatic organisms is via the water. However, published data indicate a low potential for accumulation in aquatic organisms (Task Force on Water Quality Guidelines 1991).

Glyphosate has a low toxicity to mammals, fish and microbes and low to medium toxicity to birds and other aquatic life (Table 6; Brain and O'Connor 1988; Moore and Fletcher n.d.).

Polyoxyethyleneamine, the surfactant component of most glyphosate formulations, is generally considered to be more toxic than the active ingredient (Task Force on Water Quality Guidelines 1991). One formulation of glyphosate known as Rodeo lacks the surfactant and is stated to be preferable to Round-up in wetland areas.

5.2.1.2 Diquat

Diquat is a post-emergent contact herbicide used for weed and grass control and is also registered for the control of aquatic weeds. It strongly adsorbs to inorganic and organic material, thus concentrations in water rapidly decrease. It is considered that, due to soil adsorption, diquat is relatively immobile in terrestrial and aquatic systems (Task Force on Water Quality Guidelines 1991).

Diquat usually rapidly dissipates from natural water systems via sorption by sediments and suspended material and by sorption and uptake by plants. The herbicide may be released as plant tissue decays and be readsorbed by sediments. This means that except immediately after application, levels in the water column are low (Task Force on Water Quality Guidelines 1991).

Task Force on Water Quality Guidelines (1991) reports that numerous studies have been carried out on the toxicity of diquat to fish and other fauna and concludes that it does not appear to bioaccumulate to any significant degree in aquatic biota. It has a low to high acute toxicity to birds and low to medium acute toxicity to fish and other aquatic life (Brain and O'Connor 1988; Moore and Fletcher n.d.). In natural waters it is considered to break down within 8 to 27 days (Howard 1990; Task Force on Water Quality Guidelines 1991).

5.2.1.3 Other herbicides

Other herbicides suitable for *Hydrocotyle* control will be reviewed and considered during the control program. Prior to any herbicide being used laboratory and field trials will be undertaken to assess suitability as a control agent.

5.2.1.4 Registered uses

Currently both herbicides, diquat and glyphosate, are registered for aquatic use, however, not against *Hydrocotyle*. Glyphosate is restricted for use on waterway and drain banks (Health Department WA pers. comm.). Therefore, specific approval for any use of these herbicides in the control of *Hydrocotyle* would be required under the Health Act (Pesticides) Regulations (1956).

5.2.2 Application scenarios

Two scenarios are possible for the use of herbicides: total spraying and selective spraying of *Hydrocotyle* mats. Total spraying may involve either leaving the plant material in the river to decompose or removing the treated mat from the river using physical techniques outlined in Section 5.1. The estimated tonnage of *Hydrocotyle* in the Canning River in September 1992 was 420 tonnes. Assuming that the plant material sinks after treatment, the biomass to be broken down is significant and likely to cause serious degradation of water quality (deoxygenation, fish kills and algae blooms).

The implications of leaving the plant material in the river to decompose are highlighted below:

- the spraying of large mats and/or areas of the infestation with herbicides may result in a need to control recreational access to the river to reduce the likelihood of the public coming into direct contact with herbicide residues on the mats;

- spraying would need to be carefully timed to ensure that harvesting equipment was able to retrieve the material before it sinks;

- sprayed mats would still require cutting prior to removal, introducing potential occupational safety issues for those involved;

- the use of a translocative herbicide may not ensure that fragments are not capable of regeneration if the buds are not affected;

- the use of a direct contact herbicide would not prevent fragments from regrowing;

- there is potential for increased bank erosion caused by machinery access;

- there is considerable concern in the community about the use of herbicides and riparian users may be affected;

- disposal options may be limited by the fact that the plant material has been treated with herbicides, despite the relatively fast breakdown of the two herbicides considered suitable.

Treating and then physically removing the mat may reduce the volume of weed requiring removal. However, mats would still require cutting to be removed, introducing potential occupational safety issues for those involved and jeopardising disposal as compost or at approved landfill sites.

Selective applications of herbicides in areas where machinery access is restricted and as a tool for follow-up eradication are considered to be the most appropriate. Techniques that could be used here include established spraying methods and 'wand' and spray bottle. These techniques will be trialed during the short-term management program.

Only glyphosate will be used in the 'wand' and spray bottle systems. This is because diquat is considered an eye and skin irritant and protective clothing is required by those using the chemical on a regular basis. Areas where herbicides have been used will be marked, either by using dyes in the herbicide mixture or by using surveyors tape to mark the area. This will ensure that areas are not re-treated (given that glyphosate takes 21 days to create a visual impact the possibility of areas being resprayed is high) and that the public is aware of the use of herbicides in these areas.

5.2.3 Impacts of herbicides

Potential impacts of using herbicides include toxic effects on fish and aquatic invertebrates and an indirect effect to birds through a reduction of food source. In addition, herbicide residues may impact on riparian users and affect crops irrigated with river water. Although it is possible to minimise the potential for herbicides to get into water, this concern will remain and any ill health of crop plants in the area will be rightly or wrongly blamed on the herbicides.

5.2.4 Monitoring

The use of herbicides in the river system will require monitoring. According to Bowmer (1990) designing a monitoring program using the concentration of a particular herbicide in water as a criterion is not always useful for flowing water since pulses of contamination may be missed by routine sampling over a time period. Also information on both the pattern of concentration and time required to affect non-target plants with herbicides is very limited (Bowmer 1990). Monitoring of herbicide levels in the water after treatment for *Hydrocotyle* control will need to address these issues or acknowledge the limitations of the methods.

Two monitoring programs will be implemented. The herbicide monitoring program will assess the impact of the use of herbicides on the aquatic animals (primarily fish and marron), water and sediments. Samples will be collected prior to the use of any herbicides to establish background levels and periodically throughout the short-term program. The sampling frequency will depend on the frequency and volumes of herbicides used.

5.2.5 Conclusion on herbicide use

Because of the potential impacts of broad-scale herbicide use it is preferable to use herbicides as a follow-up to physical removal of the bulk of the plant material. This would minimise the impact of herbicides on the ecosystem, avoid community concerns and increase the options available for disposal. Glyphosate is the most appropriate herbicide for *Hydrocotyle* control in the Canning River.

If the entire sections of the river covered with *Hydrocotyle* mats were sprayed problems with high levels of herbicides and decomposition of the plant material would result. Physical removal of the bulk of the plant material followed by hand removal from the bank could result in significant levels of damage to the banks in order to successfully remove all of the rhizomes. In many areas access to the river is restricted by fringing native vegetation and removal by hand is not appropriate.

5.3 Biological control

Biological control involves the study and use of parasites, predators and pathogens for the regulation of host population densities. The object of this method of control is not to eradicate the weed but to reduce the level of infestation to a point where the plant is no longer perceived to be a problem.

Hydrocotyle belongs to the Apiaceae family which includes carrot and celery. A potential biological control agent must be specific enough to not result in damage to these commercial crops. There are 24 species of *Hydrocotyle* native to WA (55 Australia wide), therefore any potential biological control agent must be specific to only one species of this genus.

Although this technique may have the lowest long-term environmental impact, the chances of discovering a suitable biological control agent that meets the above criteria in time for use as a control method, or even as a long-term option, is remote. The release of the weevil, *Cyrtogabus singularis*, for the control of *Salvinia molesta* took approximately three years from first identifying a suitable insect through testing its impact on native species to its release (Creagh 1991). There is insufficient time to develop such a control technique and the chances of identifying a suitable, specific agent appear to be almost non-existent.

5.4 Ecological control

Ecological control is modifying the environment to affect the growth of an introduced weed. Modifications may include flooding, nutrient reduction, salt-wedge intrusion and light reduction.

Neither of the ecological control options outlined below are considered suitable for use in the short-term program.

5.4.1 Hydrological modification

Hydrocotyle is considered to be a freshwater species, therefore, increased salinity could kill plant material. The section of the river downstream of the Kent St Weir is tidal. In previous years when the salt wedge has extended to the weir *Hydrocotyle* has died as a consequence of the increased salinity.

The option of removing Kent St Weir and allowing the salt wedge to move into the freshwater area is considered to be one ecological control option available. Salt water is denser than freshwater and therefore will move along the bottom of the river. Continued freshwater discharge to the river will enable the maintenance of a freshwater layer above the salt water. A number of drains discharge throughout the year, potentially enabling this situation to occur.

The possibility of summer rainfall appears to have increased in recent years. Therefore it is impossible to predict whether high salinities could be maintained for long enough to kill *Hydrocotyle*. In addition the section of the river between Kent St weir and Nicholson Rd Bridge has been maintained as a freshwater environment since 1922. It is difficult to predict the impact of allowing salt water into this area for one summer. Also the extent of salt wedge penetration up the river is unknown.

Riparian users would be unable to extract water from the river for the period that the Weir was removed.

In 1974 attempts to eradicate a *Salvinia molesta* infestation from the Canning River used this technique. There are differing opinions of the success of this method and whether salt water penetration or herbicide use was the major cause of the demise of this plant.

The potential for a lens of freshwater sufficient to support *Hydrocotyle* growth suggests that this option would not be a viable control technique.

5.4.2 Nutrient reduction

The reduction of nutrient loads to the Canning River would reduce the opportunities for species such as *Hydrocotyle* to invade. However, once established in the river system it may still out-compete other plant species. Nutrient reduction can not be considered as the ultimate control strategy for this reason. It is not achievable in the short-term and must be considered as part of a long-term strategy, not only for *Hydrocotyle* eradication but also for the health of the river system generally.

It will be necessary to identify sources of nutrients and develop integrated catchment management plans to reduce nutrient loads to the Canning River. Since 1987 the Swan River Trust has been monitoring the five largest of the 14 Water Authority drains that discharge into the Canning River. The results will be used to identify major contributing catchments and set priorities for nutrient reduction

Loading to the river is one important source of nutrient, the other is the nutrient contained in the sediments of the river. It has been estimated that a 10 cm layer of nutrient-enriched sediment is on the bed of the river. This is potentially a significant source of nutrients for aquatic plant growth.

Generally these nutrients would be tightly bound to the sediments and therefore unavailable for plant growth. Deoxygenation of the water column can lead to nutrient release from the sediments. Therefore, even if all nutrient discharges to the river ceased, there potentially remains enough nutrient in the sediments to maintain high levels in the water column.

Removal of nutrient-enriched sediments is a long-term option, not only for *Hydrocotyle* eradication but to maintain a healthy river ecosystem.

5.5 Priority areas

Priority areas for the short-term management program have been defined on the basis of areas of greatest infestation and the opportunity for seasonal variations to naturally control the distribution of *Hydrocotyle*. Table 8 details the estimated volume and biomass of *Hydrocotyle* in sections of the river in September 1992. The majority of the *Hydrocotyle* biomass (75%) was located between Kent St Weir and Nicholson Rd Bridge.

Section	Estimated volume (m^3)	Estimated biomass (tonnes)	% of total in River
Nicholson Rd Bridge to Mason's Landing	510	5.1	1
Mason's Landing to Greenfield St Bridge	9,800	102.9	24
Greenfield St Bridge to Chapman Rd	8,300	87.3	20
Chapman Rd to Kent St Weir	12,148	127	30
Kent St Weir to Shelley Bridge	10,000	105	24

Table 8. Estimated volume and biomass of *Hydrocotyle* in sections of the Canning River in September 1992.

The area downstream of the weir is tidal and it is anticipated, assuming a dry summer, that salinity levels will increase above 6.9 ppt, therefore killing the *Hydrocotyle* in that area. However, mats growing on the banks in this section may not be affected by the salt wedge. However, techniques are outlined in this section if a wet summer similar to 1991-1992 occurs. During this period record summer rainfall occurred in the Perth Metropolitan Area, maintaining a low enough salinity for *Hydrocotyle* to continue growing throughout the summer in this tidal section.

5.5.1 Control options for sections of the Canning River

The control options for sections of the river outlined below are provided as a guide only and will be subject to review on commencement of the operations.

5.5.1.1 Nicholson Rd Bridge to Mason's Landing

This section includes a small mat (September 1992) located approximately 200 m upstream of the bridge. In September 1992 mats downstream of the bridge were generally less than 1 m^2. The proposed removal techniques are the use of boats to float mats to the harvester (working downstream, Section 5.1.1.2) or to remove mats by dragging them onto the banks using a backhoe.

5.5.1.2 Mason's Landing to Greenfield Bridge

In September 1992 this section contained approximately 10,000 m^3 of *Hydrocotyle*. In November 1991 the use of the harvester in this area was considered very successful. Therefore it is proposed that the harvester be the major control technique in this section. Boats/backhoe and manual removal will also be required. The section from Leige St to Cockram St was particularly suited to manual removal techniques in September 1992.

The proposal for the Bridgeway Lagoon is for it to be sprayed with glyphosate. Residual herbicide monitoring of this area will be necessary.

5.5.1.3 Greenfield Bridge to Chapman St

In September 1992 this section contained approximately 8,300 m^3 of *Hydrocotyle*. The harvester will be used in this area after relocation over the Greenfield Bridge.

The harvester will be used as the major control technique in conjunction with boat/backhoe and manual removal. Many of the mats in this area are attached to overhanging branches and it will be necessary for these to be freed from the branches.

If the harvester can not be relocated to this section due to either time constraints or cost the boat/backhoe technique will be used.

5.5.1.4 Chapman St to Kent St Weir

In September 1992 this section contained approximately 12,100 m^3 of *Hydrocotyle*. The majority of the mats in this section are entangled with overhanging vegetation, creating difficulties for removal. If the harvester is relocated and time permits, *Hydrocotyle* removal using this technique is favoured. Alternatively the boat/backhoe technique will be used.

Two main backwaters in this area will be difficult to access using machinery due to their shallow water. There are two alternatives: the first is to rely on manual removal and the second is to judiciously spray the mats in the backwaters. The technique chosen will depend on a number of factors, the main one being the amount of people power available.

5.5.1.5 Kent St Weir to Shelley Bridge

In September 1992 this section contained approximately 10,000 m^3 of *Hydrocotyle*. A dry summer during 1992-1993 will negate the need for an intensive removal program in this section. During a dry summer salinity levels in this section will increase beyond the tolerance of *Hydrocotyle* (6.9 ppt) and only minimal control will be necessary. The community will be encouraged to become involved in removal from banks and amongst vegetation.

However, a contingency plan will be necessary in the event of a wet summer as occurred in 1991-1992. This will involve the use of the backhoe/boat technique and manual removal where appropriate.

5.5.1.6 Drains

There is no estimate of the volume of *Hydrocotyle* in the drainage systems discharging into the Canning River. Currently the Water Authority of WA undertake a weed removal program in all the drains in the area every three months. This program involves both spraying with glyphosate and mechanical removal.

An intensive removal program is required to ensure that all *Hydrocotyle* is removed from the drainage systems. An inspection procedure will be necessary to prevent the transport of small fragments by machinery. Failure to achieve eradication would result in a source of *Hydrocotyle* being maintained and the potential for the current problem in the river to occur again.

5.6 Techniques and procedures

5.5.1 Action areas

Wherever possible booms will be used around active removal areas to trap the fragments created. These will be designed to be lightweight and moveable. In areas where machinery is working it will not be possible to surround the area and booms will be placed upstream and downstream of the action area and follow-up undertaken to collect fragments.

5.6.2 Manual removal

Sickles and scythes will be available for cutting mats prior to dragging to shore. In areas where manual removal is used it will be possible to use a boom to trap fragments. A variety of boom types will be trialed.

5.6.3 Locations of backhoe/bobcat

Specific locations for backhoe/ bobcat and other machinery will be defined in the action stage of the removal strategy. Consideration will be given to bird breeding areas, bank stability, vegetation and access for machinery in the choice of sites.

5.6.4 Disposal

Options for disposal include landfill, sale as a compost material and donation to the Perth Zoological Gardens for use in 'Zoo Poo'. If possible the sale of the *Hydrocotyle* would be preferable as it would off-set some of the costs of removal.

5.7 Community involvement

5.7.1 LEAP and volunteers

Westrek has applied for Federal funding under the Landcare and Environmental Projects (LEAP) for 15 people to work on the removal of *Hydrocotyle*. This grant application has been successful and up to 15 people will be involved in removing the weed, two to three days a weeks for six months.

The Conservation Council of WA has prepared a list of volunteers willing to be involved in manual removal. In addition it is anticipated that other residents in the area may become involved.

Areas may be allocated to these groups as required and assessment of the effectiveness of manual removal will be made.

5.7.2 Supervision and coordination

The program involves the use of a large range of machinery, and large numbers of people. To ensure the most cost-effective control program a full-time coordinator has been appointed.

5.8 Follow-up

Systematic follow-up is important. This will form the basis of the long-term eradication program outlined in Section 6. Spraying of banks and small residual mats as well as manual removal will be included in this program.

An assessment of the short-term control program will be undertaken to determine the most suitable long-term eradication program for *Hydrocotyle*.

5.9 Estimated cost

The estimated cost for removal of *Hydrocotyle* from the Canning River as outlined in this document is $187,000 for six months. The detail of this is shown below.

Item	**Cost**
Harvester relocation[1]	6,000
Harvester operating costs (requires skilled operator)[2]	20,000
Booms (10)	5,000
Boat operating costs[3]	11,000
Backhoe operation (requires skilled operator)[2] - if SRT purchase[2]	20,000
Transportation (requires skilled operator)[2]	17,000
Pontoon (modifications)[5]	6,000
Flat bottom punts (purchase and operate)	5,000
Herbicides (chemicals and operator)	14,000
Other equipment	1,000
Supervisor[6]	15,000
Monitoring	40,000
Research proposal[7]	35,000
Total	**187,000**

Notes

1. Peel Inlet Management Authority harvester available from November to January inclusive.

2. Skilled operators are required for the harvester, backhoe and truck.

3. Assuming a minimum of two people per boat. Cutting into 4 m wide strips and transporting to harvester.

4. The Swan River Trust decide whether a replacement backhoe will be purchased.

5. Pontoon owned by SRT with modifications would enable access to areas inaccessible to harvester.

6. The program involves the use of a large range of machinery, and large numbers of people. Therefore to ensure the most cost-effective control program it would be necessary to have one person responsible for full-time coordination. The staff resources do not currently exist within

the Swan River Trust or the Department of Planning and Urban Development for the coordination necessary to ensure the success of this program.

7. Program being designed with Murdoch University to provide assessment of removal techniques and feedback on improvements for long-term follow-up.

In addition the eradication of *Hydrocotyle* from Water Authority drainage systems in the area will be achieved using a combination of manual removal and chemical control.

6. LONG-TERM ERADICATION

AIM: To eradicate *Hydrocotyle* from the Canning River Regional Park and its associated drains and thereby prevent its spread through Western Australia.

As stated in Section 5, it will be necessary to undertake a thorough and intensive program to eradicate *Hydrocotyle*. The knowledge gathered on the biology and ecology of *Hydrocotyle* and the ecosystem this species occupies, will facilitate the development of an effective eradication program.

Based on strategies used to control other aquatic weed species in Australia it is likely that active control and removal of *Hydrocotyle* will be necessary for between three and five years, although this may be longer or shorter depending on success. It is assumed that the short-term management outlined in Section 5 will be successful in removing the bulk of the plant material and that regrowth is controllable.

Critical to eradication of *Hydrocotyle* will be the assessment of the success of the various techniques used in the short-term management program (Section 5.1), continued observation of *Hydrocotyle* biology and ecology, and review of techniques available for eradication.

Although the aim is to eradicate *Hydrocotyle*, its current growth patterns and the extent of the invasion in the Canning River suggest that this may not be achievable. Comment received from Drs Jacobs, Sainty and Brock all suggest that eradication is an optimistic goal and that in three to five years plant numbers will probably only be reduced to levels that allow regular but low levels of control activity. If this is the case control and management, rather than eradication, will be the most feasible option.

6.1 Control options

The long-term eradication program will include chemical, mechanical, and ecological control techniques as appropriate.

6.1.1 Chemical control

The chemical most suitable for follow-up would be glyphosate as this translocates into the rhizomes preventing regeneration. In addition, only the banks would be treated, therefore reducing possible impacts on aquatic organisms. Small floating mats could also be sprayed and allowed to decompose in the waterway. It is anticipated that this approach would not create a significant impact on water quality. Approval would be required under the Health Act (Pesticides) Regulations (1956) to use glyphosate in this way. It is anticipated that approval from the Health Department will be obtained on a six-monthly basis.

Established spraying techniques will be used to apply the herbicide. In addition, 'wands' and spray bottles may be used in localised areas. These techniques will be continually monitored and modified as necessary.

Areas treated with glyphosate would be marked to ensure that people involved in physical removal are not inadvertently exposed to herbicides. It may be possible to include a dye in the formulation so that treated areas are obvious.

There have been no documented cases of plants developing resistance to Round-up. Resistance to glyphosate is not seen to be a problem for *Hydrocotyle* in the Canning River. Because reproduction is mainly vegetative and the morphology is stoloniferous, each mat is essentially one plant. Plant resistance is a genetic mechanism which occurs at sexual reproduction with the exchange of genetic material. It is not known if sexual reproduction is occurring in the Canning River, but resistance to glyphosate by *Hydrocotyle* appears unlikely since the plant has reacted to glyphosate during trials (Terry Piper pers. comm.). Even if some of the seeds produced by the plant are viable and form new plants, resistance is not considered to be an issue.

During the program other herbicides may be evaluated for use in conjunction with glyphosate to minimise the possibility of resistance. Diquat may be used where large mats have grown (e.g. in wetlands) to rapidly kill the bulk of the plant material. Follow-up control will be by the application of glyphosate, which can be translocated throughout the plant and reach the point of attachment in the banks.

The chemical control program will operate along the entire length of the river, on a six weekly basis. The timing will depend on the success of spraying as shown by the rate and extent of regrowth.

6.1.2 Mechanical control

The need for mechanical control will depend on the location and extent of regrowth. If the chemical control program is not sufficient and the mats of *Hydrocotyle* regenerate a mechanical control program may be necessary. The proposed surveillance program will be at sufficient intervals to identify any fast growing mats and a bulk removal plan could be initiated at an early stage. In 1992 rapid growth of the mats became apparent as early as August but by January 1993 the volume of plant material had increased five times and covered entire sections of the river.

The mechanical control techniques would be based on those outlined in Section 5.1 and on the success of techniques used in the short-term control program.

As part of the eradication program some manual removal will be required for any small mats growing out of the bank. A small manually operated crane will be constructed for use from a small boat for removing mats from the water and to unload the plant material from the boat.

6.1.3 Biological control

As discussed in Section 5.3 it is unlikely that a suitable biological control agent will developed and approved for release in the near future. However, should a suitable agent be developed its option for use will remain open.

6.1.4 Ecological control

Options for ecological control in the long-term include hydrological modification and nutrient reduction and these are discussed in Section 5.4.

The average nutrient discharge to the Canning River from the five drains monitored by the Swan River Trust between 1987 and 1990 was 10.6 tonnes of phosphorus and 95.5 tonnes of nitrogen. The actual load to the river would be greater than this however, since no extrapolation for the ungauged catchments has been made at this stage.

Reduction of nutrient loads to the Canning River would reduce the opportunities for aquatic weed species such as *Hydrocotyle* to invade. However, nutrient reduction must be considered as part of a long-term strategy, not only for *Hydrocotyle* eradication but also for the health of the river system generally. Section 5.4.2 discusses options available for nutrient reduction in the Canning River.

The reduction of nutrient loads and sinks within the river is the long-term aim of the Swan River Trust. This will require the definition of what the 'ideal' state of the river system should be. The results of nutrient load monitoring will be used to identify major contributing catchments and to set priorities for nutrient reduction within these. Investigations on sediment removal and/or management to reduce nutrient release will continue as part of this overall aim.

Another technique which may be trialed during the long-term program is the early removal of the boards from the Kent St Weir. Currently the boards are placed across the weir during summer to maintain the upstream section of the river as a freshwater system by preventing the salt wedge moving up the river. This technique may not be feasible for the Canning River because of the problems associated with riparian users explained in Section 5.4.

6.2 Working sections of the Canning River

Programs for control of *Hydrocotyle* in the Canning River and associated drains, wetlands and backwaters will occur simultaneously. As weed is removed from the river, the control in drains and wetlands will also be treated to prevent reinfestation in the river.

The chemical control program will be undertaken by the Agriculture Protection Board under contract to the Swan River Trust using glyphosate and other herbicides as necessary. The aim of the program is to prevent regrowth of *Hydrocotyle* from the banks, thus preventing the formation of large mats extending across the river. Spraying will take place on a regular basis, the interval being determined by inspections by the Agriculture Protection Board and the Swan River Trust.

Currently the bulk of the infestation of *Hydrocotyle* is between Kent St Weir and Nicholson Rd Bridge. The focus of the chemical control program will be in this area. However, the weed has been found in a number of wetlands associated with the river, as well as in some areas downstream of the weir. The spraying program may be extended into these areas, subject to growth patterns and ongoing discussions with the Trust.

6.2.1 Drains

Hydrocotyle has been located in Water Authority drains leading into the Canning River Regional Park as well as a local authority drain. The Water Authority have implemented a strategy to control *Hydrocotyle* in their drains using a combination of physical removal and chemical control.

An intensive removal program is required to ensure that all *Hydrocotyle* is removed from the drainage systems. Inspection will be necessary to prevent the transport of small fragments by machinery. Failure to achieve eradication would result in a source of *Hydrocotyle* being maintained and the potential for the current problem in the river to occur again.

The Water Authority undertook initial inspection and treatment of drains and compensating basins in February 1993. Follow-up control by the Water Authority will be carried out weekly to fortnightly thereafter until the problem subsides. Inspection will be carried out periodically with the Swan River Trust to ensure that any outbreak can be brought under control.

6.2.2 Wetlands and backwaters

Wilson Park wetland contains extensive mats of *Hydrocotyle*, growing out from the *Typha* around the edges of the wetland (Plate 12). The wetland is connected to the river downstream of the Kent St Weir via a local authority drain and is normally tidal. At this point the river is tidal and during the summer months the salt wedge penetrates up the river to the weir.

Currently the drain connecting the wetland to the river has been filled with building rubble and it appears to be preventing the flow of brackish or saline river water into the wetland during an incoming tide. The only water movement appears to be freshwater flowing from the wetland during flow periods. If the drain was cleared and water flow was no longer restricted, there may be a sufficient inflow of brackish or saline water into the wetland to control the weed.

There are a number of options available for the Wilson Park wetland. The large mats mean that there is some potential for mechanical removal. Other options to be considered include chemical control using Velpar, manual removal with community involvement, and spraying the mats with a saline solution or salt granules.

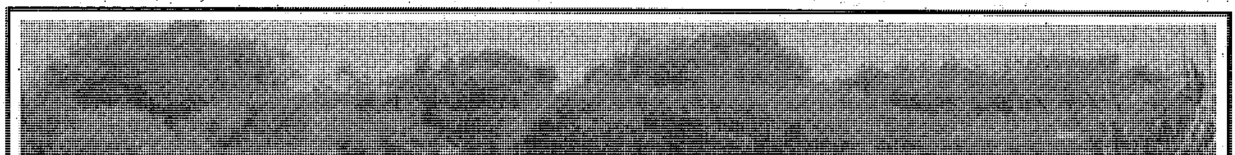

Plate 12 Mats of *Hydrocotyle* growing out from the *Typha* around the edges of the Wilson Park wetland

There are a number of other smaller wetlands upstream of the Kent St Weir where these techniques will be used. Currently the backwater known as Bridgeway Lagoon near Nicholson Rd Bridge contains the largest amount of plant material. The eradication of the weed from these wetlands will be done on an ongoing basis in association with Department of Planning and Urban Development , the Agriculture Protection Board and Canning City Council.

6.3 Monitoring

The aim of the monitoring program is to assess the impacts of the control and eradication strategies on the Canning River. This will consist of two parts, a pesticide monitoring program and an invertebrate monitoring program.

The pesticide monitoring program will assess the impact of the use of herbicides on the water and sediments in the River. The sampling frequency will depend on the frequency, volumes and type of herbicides used and will be carried out by the Swan River Trust in consultation with the Chemistry Centre of WA. Health Department approval for the use of glyphosate for *Hydrocotyle* control requires a report on the results to be provided to the Pesticides Advisory Committee.

Aquatic invertebrate monitoring will investigate the density and species diversity of the invertebrates in the sediments and in the *Hydrocotyle* mats. After the physical removal program further sampling will be done to assess the impacts of other control techniques such as herbicide spraying.

6.4 Surveillance

As the quote in Section 5 states

> ... it is critically important that control attempts are well planned and thorough and that they are persistently carried out. Regular surveys and follow-up control of outbreaks from surviving plants are required for a number of years. (Arthington and Mitchell 1986).

A monthly surveillance program has been initiated and this will increase to fortnightly in September, the beginning of the plant's growth season. This will ensure early detection and control of any outbreaks. A surveillance officer is required to undertake this program and also to carry out any ongoing manual removal.

It is estimated that assessment time and follow-up treatment will take 5 days in the river and an additional two days in the drainage systems for at least the first 12 months. Follow-up treatment will involve chemical and manual removal.

As part of the Water Authority's control program they will undertake inspections of the main drains, in association with the Swan River Trust.

6.5 Estimated cost

The estimated annual cost for this ongoing eradication program is $40,000/yr and the detail is outlined below. This costing is preliminary and will be refined as the long-term program is defined.

	1993-94	Following Years	FTE
Item	Cost	Cost	
Surveillance officer	$25,000	$25,000	0.5
Chemical control program	$20,000	$15,000	
Contingencies	$10,000	$5,000	
Monitoring	$7,000	$7,000	
Equipment	$5,000	$1,000	
Total	**$67,000**	**$53,000**	

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APPENDIX 1

HYDROCOTYLE SPECIES FOUND IN THE PERTH REGION

HYDROCOTYLE L.

Small annual herbs, sometimes creeping and rooting at the nodes, rarely aquatic. Stipules translucent, entire or laciniate. Umbels simple, rarely compound, usually pedunculate; flowers usually bisexual, usually shortly pedicellate; bracts present or absent. Calyx lobes minute, inconspicuous. Petals white to purple, ovate, acute, valvate in bud. Stamens usually small; filaments very short; anthers circular in outline. Styles short, divergent, the bases enlarged to form a flat, disc-like stylopodium with a raised margin; stigmas capitate. Fruit of 2 usually laterally compressed mericarps; vittae absent; carpophore undivided, deciduous or persistent. Mericarps each usually 5-ribbed, the dorsal rib prominent and the intermediate ribs often prominent and curved. Seeds straight, laterally compressed. 100 species in tropical and temperate regions of the world, of which 24 occur in W.A.

1. Umbels compound. Leaves peltately attached .... ***H. bonariensis**
1. Umbels simple. Leaves not peltately attached.
  2. Fruit as long as or longer than broad, circular, broadly elliptic or tetragonal.
    3. Stems narrowly winged. Terrestrial herb.
      4. Fruits broadly elliptic, laterally compressed. Leaves usually triangular-hastate, 1.5-3.5 x 2.5-5 mm .... **H. alata**
      4. Fruit tetragonal, not laterally compressed. Leaves reniform to circular and cordate, 5-11 x 7-16 mm .... **H. tetragonocarpa**
    3. Stems not winged. Aquatic herb.
      5. Leaves floating, circular, 2-4 mm across .... **H. lemnoides**
      5. Leaves emergent, reniform to circular and cordate with a deep sinus, 20-45 x 25-55 mm .... ***H. ranunculoides**
  2. Fruit broader than long, transversely elliptic.
    6. Aquatic stoloniferous herb, growing in water, leaves emergent .... ***H. ranunculoides**
    6. Terrestrial herb, growing on sand or damp soil.
      7. Lateral rib of mericarps indistinct, unthickened. Mostly hairy annuals.
        8. Mericarps smooth between dorsal and very prominent intermediate rib. Lobes of leaves softly mucronate .... **H. callicarpa**
        8. Mericarps tuberculate or with transverse reticulations between dorsal and intermediate ribs. Lobes of leaves not mucronate.
          9. Mericarps tuberculate. Stipules entire .... **H. pilifera**
          9. Mericarps with transverse reticulations between intermediate and dorsal rib. Stipules laciniate .... **H. hispidula**
      7. Lateral rib slightly or distinctly thickened. Glabrous annuals.
        10. Flowers 2-6 per umbel. Area between indistinct intermediate rib and dorsal rib glabrous .... **H. diantha**
        10. Flowers 8-20 per umbel. Area between dorsal rib and prominent intermediate ribs hairy .... **H. blepharocarpa**

H. alata A. Rich.

Small glabrous herb 10-50 mm high; branchlets slender, spreading, narrowly winged. Stipules broad, sometimes lobed. Leaves palmately 3-5-lobed, often triangular-hastate in outline, broader than long, 1.5-3.5(5) x 2.5-5(8) mm. Umbels simple; flowers 6-12 per umbel, sessile but becoming very shortly pedicellate in fruit; bracts linear, ca 0.5 mm long. Fruit broadly elliptic in outline, 1.5 x 1-1.5 mm, laterally compressed; carpophore deciduous. Mericarps usually minutely rugose or papillose; ribs 2 or 3 on each side, almost equal, rounded.

Recorded for the Coastal Plain and the Darling Scarp near Perth. Occurs in winter-wet depressions associated with either granitic outcrops, swamps or salt lakes in the extreme south west of the state and extends along the south coast from Busselton and Collie to east of Esperance.

Flowers September-December.

H. blepharocarpa F. Muell.

Small, almost glabrous herb; branchlets spreading, slender, flattened to narrowly winged, 10-50 mm long. Stipules laciniate. Leaves circular to very broadly ovate in outline, 2-7 x 3-8 mm, deeply 3-5-lobed, cordate at the base, lobes crenate. Umbels simple; flowers 8-20 per umbel, becoming shortly pedicellate when in fruit; bracts filiform, to 0.5 mm long. Fruit transversely broadly elliptic in outline, ca 1 x 1-1.5 mm, laterally compressed; carpophore undivided, deciduous. Mericarps with a pale, rounded, dorsal rib; intermediate rib prominent, rather acute, area between intermediate and dorsal ribs densely hairy with coarse, white hairs, the area between intermediate rib and lateral rib smooth to very minutely papillose; lateral rib slightly thickened.

Occurs on near-coastal sands and limestones of the Perth Region, collected from Yanchep and Rottnest Island. Extends south to Cape Leeuwin and along the south coast to the Porongurup Range.

Flowers August-October.

H. lemnoides Benth.

An aquatic plant with long, matted, filiform, submerged stems and roots. Stipules broad, entire. Leaves few, floating on the surface; blades more or less circular, 2-4 mm across, margins entire or minutely crenulate. Umbels simple, apparently unisexual, sessile or shortly pedunculate; flowers purple, 3-6 per umbel, sessile or shortly pedicellate, male umbels more or less sessile, female umbels shortly pedunculate; bracts minute, linear. Fruit circular in outline, 1-1.5 x 1-1.5 mm, laterally compressed; carpophore deciduous. Mericarps convex, almost smooth, ribs indistinct.

Apparently endemic in the Perth Region, recorded only from swamps near Perth, rarely collected.

Flowers October.

H. pilifera Turcz.

Robust erect herb 60-160 mm high; stems usually hairy with long, coarse, spreading hairs which are 1-2 mm long. Stipules white, not translucent, adnate to the petiole, entire. Leaves reniform in outline, 4-11 x 7-23 mm, deeply divided into 5 obtriangular segments each of which is lobed or toothed, glabrous or sparsely hairy. Umbels simple, on hairy peduncles; flowers 6-25 per umbel; pedicels 1-2 mm long; bracts absent. Staminal filaments slender, longer than petals. Styles slender, ca 1 mm long. Fruit transversely elliptic in outline, 1-1.5 x 2-2.5 mm, laterally compressed; carpophore persistent. Mericarps smooth to very minutely papillose; dorsal and intermediate ribs prominent, rounded and with prominent transverse reticulations between the dorsal and intermediate ribs; enclosed pit between the intermediate and undeveloped lateral ribs, usually smooth.

Occurs on moist soils, usually on the Darling Scarp and Range near Perth and southwards to near Waroona. Also recorded for Hamelin Bay.

Flowers September-November.

A small glabrous variant, with tubercles in the pit between the intermediate and undeveloped lateral ribs, occurs north and east of the region from Badgingarra and Koorda to Coolgardie and south from Coolgardie to the south coast and into the Stirling Range. This variant has also been recorded for Claremont and Yalgorup.

***H. ranunculoides L.f.**

Glabrous stoloniferous herb, rooting profusely at the nodes. Stipules short, broad, entire. Leaves emergent; petioles long, thickened towards the base; leaf blades circular to reniform in outline, 20-45 x 25-55 mm, cordate with a deep basal sinus, crenate to shallowly (3-)7-11-lobed. Umbels simple, small, 3-4 mm across; flowers 5-10 per umbel; peduncles slender, ca 20 mm long, much shorter than the petioles; pedicels short, ca 1 mm long; bracts broad, ca 0.5 mm long, entire. Ovary more or less circular, ca 1 x 1 mm, glabrous, the ribs thickened and the area between the ribs smooth. Fruit more or less circular in outline, 2-3 mm across, laterally compressed. Mericarps with thickened, but not prominent ribs.

Naturalized in permanent, fresh water streams of the Coastal Plain. Recorded for Perth. Native to Europe.

Flowers recorded for February.

H. tetragonocarpa Bunge

A slender glabrous herb; stems flattened, narrowly winged, to 150 mm long. Stipules slightly laciniate. Leaves reniform to circular in outline, 5-11 x 7-16 mm, cordate at the base, shortly 5-7-lobed, each lobe crenate. Umbels simple; flowers 6-12 per umbel, almost sessile; bracts small, narrowly ovate. Fruits longer than broad, acutely tetragonal, 1.5-2 x 1-1.5 mm; not compressed laterallly, of 2 trigonous mericarps, connate at the broad commissure; carpophore deciduous. Mericarps with prominent, acute or rounded dorsal and lateral ribs; intermediate rib indistinct.

Occurs on sands of the Coastal Plain near Perth and south to Yalgorup National Park. Extends south along the coast to Albany.

Flowers August-December.

***H. bonariensis Lam.**

Robust, creeping, glabrous herb, rooting at the nodes. Stipules entire. Petioles long, stout; leaf blades broadly elliptic to circular, 30-50 x 35-60 mm, crenately lobed, peltate. Umbels irregularly compound on stout peduncles; rays with umbellules of shortly pedicellate flowers, some of the rays with single flowers rather than umbellules; bracts narrowly ovate, scarious. Stamens minute. Fruit transversely elliptic in outline, 1.5-2 x 2-3 mm, laterally compressed; carpophore deciduous. Mericarps with prominent ribs; the dorsal rib acute; the intermediate and lateral ribs more obtuse, minutely reticulate between dorsal and intermediate ribs and with an almost smooth pit between the intermediate and lateral ribs.

Naturalized in disturbed sandy soil at Bunbury. Native to North and South America.

Flowers much of the year.

H. callicarpa Bunge — Small Pennywort

Small annual herb 15-80 mm high; stems either glabrous or hairy with long, soft, spreading hairs. Stipules laciniate. Leaves 3-6 x 5-10 mm, deeply divided into 3-5 usually acutely lobed segments, each lobe ending in a soft, flexible mucro. Umbels simple; flowers 6-16 per umbel, distinctly pedicellate; pedicels 1-1.5 mm long when in fruit. Fruit transversely elliptic in outline, 0.75-1 x 1-1.5 mm, laterally compressed; carpophore persistent. Mericarps smooth to minutely papillose; dorsal rib prominent, rounded; intermediate rib very prominent, rounded, extending the whole length of the mericarp, semi-circular and enclosing a flat central pit; lateral rib absent or indistinct.

Occurs on moist soil of the Coastal Plain and Darling Scarp and Range near Perth. Extends northwards to Mt. Lesueur and Wongan Hills, eastwards to near Southern Cross and southwards to the extreme south west and along the south coast to Cape Le Grand. Also occurs in S.A., Vic., Tas. and N.S.W.

Flowers August-November.

H. diantha DC.

Small glabrous herb; slender, slightly winged, stems 30-100 mm long. Stipules broad, usually entire. Leaves circular or reniform in outline, 2-5(8) x 3-9(15) mm, obtusely and palmately 5-7-lobed. Umbels simple, sessile or shortly pedunculate; flowers 2-6 per umbel, shortly pedicellate; fruiting pedicels 0.5-2 mm long; bracts linear, 0.5 mm long. Fruit transversely elliptic in outline, 1.5-2 x 2-2.5 mm, laterally compressed; carpophore persistent. Mericarps smooth to minutely papillose; dorsal rib prominent, rounded and extended as a minutely reticulate, thickened wing; intermediate rib less distinct; lateral rib prominent, rounded.

Occurs on sandy soils of the Coastal Plain from Yanchep to Pinjarra. Extends south to the extreme south west and along the south coast to Esperance and to Norseman, where it often occurs on granitic soils.

Flowers August-November.

H. hispidula Bunge

An erect or procumbent herb, usually 0.1-0.2 m high, sparsely hairy with long, curled hairs. Stipules laciniate. Leaves circular in outline, 6-10 x 10-17 mm, deeply divided into 5 segments, each acutely lobed, sparsely hairy on both sides. Umbels simple; flowers 5-12 per umbel; fruiting pedicels 0.5-2 mm long; bracts long, filiform, laciniate. Fruit small, transversely elliptic in outline, ca 1 x 1.5 mm, laterally compressed; carpophore persistent. Mericarps with numerous tubercles between the ribs; dorsal and intermediate ribs obtuse and prominent.

Occurs on the sandy soils of the Coastal Plain from Perth to Pinjarra. Also occurs along the south coast.

Flowers September-November.