THE APPLICATION OF TRIPLOID GRASS CARP AS BIOLOGICAL CONTROL AGENT FOR THE OVER-ABUNDANT GROWTH OF AQUATIC WEEDS IN IRRIGATION CANAL SYSTEMS

BJ du Plessis • GJ Steyn

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Water Research Commission

THE APPLICATION OF TRIPLOID GRASS CARP AS BIOLOGICAL CONTROL AGENT FOR THE OVER-ABUNDANT GROWTH OF AQUATIC WEEDS IN IRRIGATION CANAL SYSTEMS

Report to the Water Research Commission

On the project K5/816
'Use of triploid grass carp as a biological
control measure for excessive water weed growth
in irrigation systems'

By

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I. EXECUTIVE SUMMARY

The overabundant proliferation of aquatic weeds in South African water conveyance systems cause a series of operational problems. Filamentous algae, such as *Cladophora glomerata* and pondweeds impede flow and reduce the capacity of irrigation canals to a significant extent. In worst case scenarios, irrigation scheme managers are faced with situations where they are unable to deliver water at the downstream ends of canal systems. This situation also contributes to water losses, crop losses and structural damage to concrete-lined canals.

This report is the product of a research project funded by the Water Research Commission to investigate the possible application of sterile (triploid) grass carp (*Ctenopharyngodon idella*) as biological control agent on aquatic weeds in concrete-lined irrigation canals. The aims of the project were *firstly* to investigate the suitability of a concrete-lined irrigation canal as grass carp habitat; *secondly* to test the efficacy of sterile grass carp as bio-control agent on filamentous algae; *thirdly* to evaluate the economic feasibility of this biological approach against the current chemical, physical and mechanical control methods; and *fourthly* to propose a management plan for the operational application of triploid grass carp as bio-control agent in irrigation canals.

To achieve the goals set for the project, the Ramah-3 Canal near the town of Orania, was selected to serve as experimental canal. This canal can be regarded as a typical South African concrete-lined canal, and is located in the Orange-Riet River Canal System, downstream of the Vanderkloof Dam.

As the majority of local irrigation canals are concrete-lined, skepticism existed amongst local scientists if the fish will be able survive in canals with a presumed high constant flow and low diversity of hydraulic biotopes. It was therefore a priority to establish the suitability of concrete-lined canals as habitat for this herbivorous fish specie.

The study found that flow velocities in the Ramah Canal System never exceeded 1 m/s, even under high flow conditions (full capacity and 110% plus conditions) of more than 5 m^3/s. It was found that grass carp thrived at flow rates ranging from 0.48 to 0.80 meter/second, moving with ease upstream and downstream in a 16 km long experimental section of the Ramah-3 Canal.

The sterile grass carp controlled the algal biomass in the Ramah Canal to significant levels. *Cladophora* was efficiently controlled at stocking rates of 3 to 7 fish per km canal. Triploid grass carp retrieved from the canal system after a six-month experimental period were found to be in an excellent physiological condition and displayed a mean weight increase of more than 300%. An ideal stocking protocol will probably be 10 individuals of 20 – 30 cm in length per kilometer canal, with a 10-15% annual supplementation figure.

Civil structures, such as culverts, super-elevated canals and bridges will provide the fish with sufficient protection against possible predators. A few possible adaptations to the existing canal operation regimes should ensure that triploid grass carp could be managed as an effective biological control agent. This should be determined on a site-specific basis and could include additional civil structures such as sanctuary dams and small in-line fishways to ensure free migration throughout the target system.

An attempt was made to conduct a brief economic analysis, based on information on expenditures of local irrigation schemes on aquatic weed control in their canals. The outcome of this brief investigation was in line with overseas findings in that biological control with sterile grass carp will be more economical than the currently applied control methods of herbicidal and mechanical or physical control.

It can be concluded that the fish adapted to the artificial conditions experienced in a concrete-lined canal and perform their task as bio-control agent with ease. The authors are of the opinion that this bio-control technique will contribute to the current *Integrated Aquatic Weed Management Programmes* (IAWMPs) of the Department of Water Affairs and Forestry. Site-specific conditions for each irrigation scheme will however, dictate a different approach to the aquatic weed problem. It is therefore strongly recommended that suitable qualified specialists should develop all aquatic weed management programmes on a site-specific basis.

II. OPSOMMING *(Executive summary in Afrikaans)*

Die oormatige groei van wateronkruide in Suid Afrikaanse watervoorsieningstelsels veroorsaak 'n reeks van bedryfsprobleme. Draadagtige alge, soos *Cladophora glomerata* en ook watergrasse lei tot die belemmering van vloei, en het 'n beduidende vermindering in die kapasiteit van kanale tot gevolg. In sekere gevalle word die bestuurders van besproeiingskemas gekonfronteer met situasies waar daar nie aan die water aanvraag op die stelsel voldoen kan word nie. Hierdie situasie dra by tot water verliese, gewas verliese en strukturele skade aan beton belynde kanale.

Hierdie verslag is die produk van 'n navorsingsprojek wat deur die Waternavorsingskommissie befonds is, en het dit ten doel om die moontlike toepassing van steriele (triploïde) graskarp (*Ctenopharyngodon idella*) as biologiese beheeragent op wateronkruide in beton belynde kanale te ondersoek. Die vooropgestelde doelwitte van die projek was om *eerstens* die geskiktheid van 'n beton belynde kanaal as graskarp habitat vas te stel; *tweedens* om die effektiwiteit van steriele graskarp as bio-agent op draadalge te evalueer; *derdens* om die ekonomiese lewensvatbaarheid van hierdie biologiese benadering tot wateronkruidbeheer vas te stel; en *vierdens* om 'n bestuursplan vir die aanwending van triploïde graskarp as bio-agent in besproeiingskanale op te stel.

Ten einde die vooropgestelde doelwitte van die projek te bereik, is die Ramah-3 Kanaal naby die dorp Orania geselekteer as eksperimentele kanaal. Hierdie kanaal kan as 'n tipiese Suid Afrikaanse beton belynde kanaal beskou word, en is in die Oranje–Rietrivier Kanaalstelsel, stroomaf van die Vanderkloofdam, geleë.

Aangesien die meerderheid van plaaslike kanale met beton belyn is, het daar skeptisisme onder sommige plaaslike wetenskaplikes bestaan omtrent die oorlewingsvermoë van die vis, in veronderstelde kondisies van hoë vloeitoestande en 'n gebrek aan hidrouliese biotope. Gevolglik is dit as 'n prioriteit beskou om die geskiktheid van beton belynde kanale as habitat vir hierdie herbivore visspesie vas te stel.

Van die belangrike bevindings van die studie was dat die vloeisnelhede in die Ramah kanaalsisteem nooit 1 m/s oorskry het nie. Selfs onder vol kapasiteit vloei toestande (5 m^3/s) van 110% plus, waartydens die kanaal oorgeloop het, is vloeimetings van laer as 1 m/s aangeteken. Dit is waargeneem dat graskarp gefloreer het onder vloeitoestande van 0.48 – 0.80 m/s, en met gemak stroomop en –af beweeg het in 'n 16 km lange eksperimentele seksie van die Ramah-3 Kanaal.

Die steriele graskarp het die alg biomassa in die Ramah Kanaal tot beduidende vlakke beheer. *Cladophora* was effektief onder beheer gebring teen besettingsdigthede van 3 tot 7 vis per kilometer kanaallengte. Daar is verder gevind dat triploïde graskarp, wat na 'n eksperimentele periode van 6 maande uit die kanaal herwin is, 'n uitstekende fisiologiese kondisie en 'n massa toename van sowat 300% gepresenteer het. Na raming sal die ideale protokol vir besettingsdigtheid waarskynlik in die orde van 10 individue, met 'n lengte van 20 tot 30 cm en 'n aanvullingsyfer van 10 – 15% per jaar wees.

Verder is daar gevind dat siviele strukture soos duikpype, oorvloei kanale en brue, voldoende beskerming teen predatore van die vis sal bied. 'n Moontlike paar veranderinge aan bestaande bedryfsprosedures sal verseker dat triploïde graskarp effektief as biologiese beheeragent in kanale bestuur kan word.

'n Oorsigtelike ekonomiese analise is gemaak deur huidige uitgawes van besproeiingskemas aan wateronkruidbeheer, met geprojekteerde koste vir biologiese beheer met graskarp te vergelyk. Die uitslag van hierdie oorsigtelike ondersoek was in lyn met oorsese bevindings dat biologiese beheer meer ekonomies as die huidige chemiese en meganies-fisiese beheer metodes sal wees.

Die gevolgtrekking kan dus gemaak word dat die vis aangepas het by die kunsmatige kondisies van 'n beton belynde kanaal, en hul funksie as biologiese beheeragent met gemak kon uitvoer. Die outeurs is van mening dat hierdie biologiese beheertegniek sal bydra tot die huidige Geintegreerde Wateronkruidbestuursprogramme (IAWMPs) van die Departement van Waterwese en Bosbou. Liggingspesifieke kondisies van elke besproeiingskema sal egter 'n unieke benadering tot die wateronkruid probleem op elke afsonderlike stelsel dikteer. Gevolglik word dit sterk aanbeveel dat toepaslik opgeleide spesialiste alle wateronkruidbestuursprogramme op 'n liggingspesifieke basis sal ontwikel.

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The Steering Committee comprises the following persons:

Dr Steve Mitchell	Water Research Commission (Chairperson)
Mr. FP Marais	Water Research Commission (Secretary)
Mr. Hennie Bosman	Department of Water Affairs and Forestry - Pretoria
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Director: IWQS (DWAF)	Institute for Water Quality Studies for analysis and maintenance of the water quality data bank.
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CHAPTER 1

INTRODUCTION

The excessive growth of aquatic weeds (algae and aquatic macrophytes) in South African water supply systems causes extensive operational problems in irrigation canals (Bruwer *et al.*, 1980; Du Plessis, 1992a, 1992b), and also play a role in increased water loss. The undesirable growth of aquatic weeds in canal systems are however, not the only problem for they manifest in other water conveyance structures such as pipeline networks and irrigation systems (Du Plessis and Van der Merwe, 1991).

Directly after the winter months, the increasing day length and a consequent rise in ambient temperatures result in increased water temperature and light penetration in irrigation canals. Optimum environmental conditions, in the presence of sufficient plant nutrients, leads to an increase in the biomass in affected irrigation canals. Filamentous algae and aquatic macrophytes, for example pondweeds, proliferates in a relatively short period of time to a dense mass that results in enormous operational problems with significant economic implications on water supply systems.

The peak water demand for irrigation of crops/vegetation and the optimum growth rate of aquatic weeds usually occurs (with the exception of the winter rainfall regions) at the same time of the season. Scheme managers cannot comply with the water demand of certain irrigation schemes for long periods of time. Large volumes of the canals' available capacity are displaced by plant biomass - this causes a series of operational problems, which includes the flooding of the canals (Du Plessis, 1992a, 1992b). The water loss as a result of flooding causes a shortage in the water supply to irrigators, which inevitably materialises in crop losses.

The magnitude of the problem of overabundant growth of aquatic weeds in water supply systems of a national scale and problems are experienced from the Cape Province (winter rainfall region), right through to the summer rainfall regions in the far Northern Province. It has however, been observed that the problem species may differ according to site-specific conditions (Joska and Bolton, 1994), but that *Cladophora* spp., a filamentous algae, is responsible for up to 80% of the biological related problems in irrigation water supply systems (Du Plessis and Davidson, 1996). Reports by Bruwer (1980, 1991), Bruwer *et al.* (1980), Du Plessis (1992a, 1992b) and Du Plessis *et al.* (1991) indicates that *Cladophora glomerata* is the primary problem aquatic weed in irrigation canals of the Hartbeespoort-, Pienaars River (Roodeplaat), Njelele- and Orange-Riet River Government Water Schemes.

The overabundant growth of aquatic weeds in South African water supply systems has already given rise to problems with extensive proportions. Du Plessis and Davidson (1996) list the following associated impacts:

- A negative influence on the hydraulic capacity and flow speed in the canals – to such a degree that in some cases the supplied water cannot reach the terminal point of the canal system. This decrease in canal capacity occurs particularly when the water demand is at its highest;
- Overestimation of the amount of water supplied because of the artificially increased water levels that is measured at calibrated weirs;
- Water loss because of the flooding of the canals;
- Impediment of floodgate (sluice) working at dividing structures;
- Drowning/water logging of the long-weirs occurs;
- Structure (slab) failure of concrete-lined irrigation canals due to flooding;
- Aquatic weed fragments occlude irrigation systems and filters at water purification works;
- Aquatic weed fragments occlude cooling systems of transfer pumps; and
- The mechanical removal of the biomass is extremely labour intensive, expensive and overall ineffective.

The serious nature of this problem contributed to the forming of a Departmental Advisory Committee by the Department of Water Affairs and Forestry in 1991, to investigate aquatic weed problems in the South African water supply systems and to generate solutions to the problem. These investigations included the implementation of chemical control methods at a number of irrigation schemes. Financial considerations and concerns about the impact of these chemicals on the environment, personnel, crops, as well as the optimum operational capacity of the relevant systems, brought about investigations to look for more economic, safe and environmental friendly alternative control methods.

The Department of Water Affairs and Forestry approached the Water Research Commission (WRC) to fund investigations into alternative methods to control aquatic weeds in irrigation canal systems. The registration of five WRC funded research projects was the result, two projects on the distribution and the physiology of the problem species (WRC No. K5/426 and K5/600) and another two programs to investigate the possible application of pathogens as bio-control agent on *Cladophora* species (WRC No. K5/669 and K5/918).

This project, which contains an investigation into the application of triploid grass carp (*Ctenopharyngodon idella*) as a biological control agent for the overabundant growth of aquatic weeds in irrigation canals (WRC No. K5/816), is the fifth project in the series of WRC funded investigations to address the problem of aquatic weed infestations in water conveyance systems.

The aims of this study were:

- To investigate the suitability of a concrete-lined irrigation canal as grass carp habitat;
- To test the efficacy of sterile grass carp as bio-control agent on filamentous algae (*Cladophora glomerata*) in concrete-lined irrigation canals;
- To evaluate the economic feasibility of this biological control method against the current chemical, physical and mechanical control methods; and
- To propose a management plan for the operational application of triploid grass carp as bio-control agent in irrigation canals.

CHAPTER 2

BACKGROUND

2.1 EXISTING METHODS OF AQUATIC WEED CONTROL IN IRRIGATION CANAL SYSTEMS

In 1991 the Department of Water Affairs and Forestry (DWAF) gave serious attention to the mechanisms to control the excessive growth of undesired aquatic weeds (pondweeds and algae) in the irrigation systems. This problem has a history that stretches over decades.

The development of control strategies for the excessive growth of undesirable aquatic weeds is based on the manipulation of variables that plays a roll in the growth requirements of the relevant species (Figure 2.1). These variables can be adapted to establish conditions that are unfavourable for growth and proliferation of problem organisms. This does however, becomes more complicated when taken into consideration that an acceptable quality of water and in specific quantities, should be supplied to the users over a certain time period.

The approach to the implementation of available control mechanisms is binary. The treatment of the *source of the problem* (thus the primary chemical factors, i.e. water quality and/or secondary physical factors) or *act symptomatic* (treatment of the problem after it visibly occurs).

In the Southern African context it seems to be an impossible task to lower nutrient concentration to a cost-effective level to limit aquatic weed growth. Physical factors such as light intensity and temperature have been used as an effective control measure. Du Plessis and Van der Merwe (1991) solved the problem of algal (*Cladophora glomerata*) growth in structures of pipeline networks, by covering the dividing structures with shade cloth.

Through the selective withdrawal of cold water from the hypolymnion (bottom part) of a reservoir, the growth of aquatic weeds in the first section of a canal could be inhibited. In the warm local climate this option has not been applied successfully because the water temperature rises quickly when exposed to the surface. Additionally, the water quality in the hypolimnion is lower; and characteristically more favourable for the proliferation of aquatic weeds, when released into an irrigation canal. Flow velocities play a definite roll in the *growth rate of aquatic weeds.*

The control measures currently applied by the Department of Water Affairs and Forestry are predominantly symptomatically orientated. The problem is thus treated as soon as it visibly influences the operation of the system. A variety of mechanical control measures have been applied, e.g. the mechanical removal of biomass out of canals, draining (or fluctuations in the water levels) for certain periods and the application of automatic apparatus that scoop out algal biomass on a continuous basis. The practical problem experienced with these methods have lead to the development of more efficient chemical control measures and the possible application of biological control measures.

According to Du Plessis and Davidson (1996) the design of any aquatic weed management strategy the Department of Water Affairs and Forestry maintains the following aims:

- the developed control methods must allow for the normal operation of the affected system with the minimum disruption thereof;
- the control method must be developed site-specifically after the evaluation of each systems unique character;
- the proposed control measure should be safe for all the users of that specific water - if there is a risk involved in the safe application of the water, the treated water should be withheld from the user until safe for application;
- the control method must be applied under the supervision of a suitable trained specialist in the field of aquatic weed control; and
- the chosen control measure must be cost-effective.

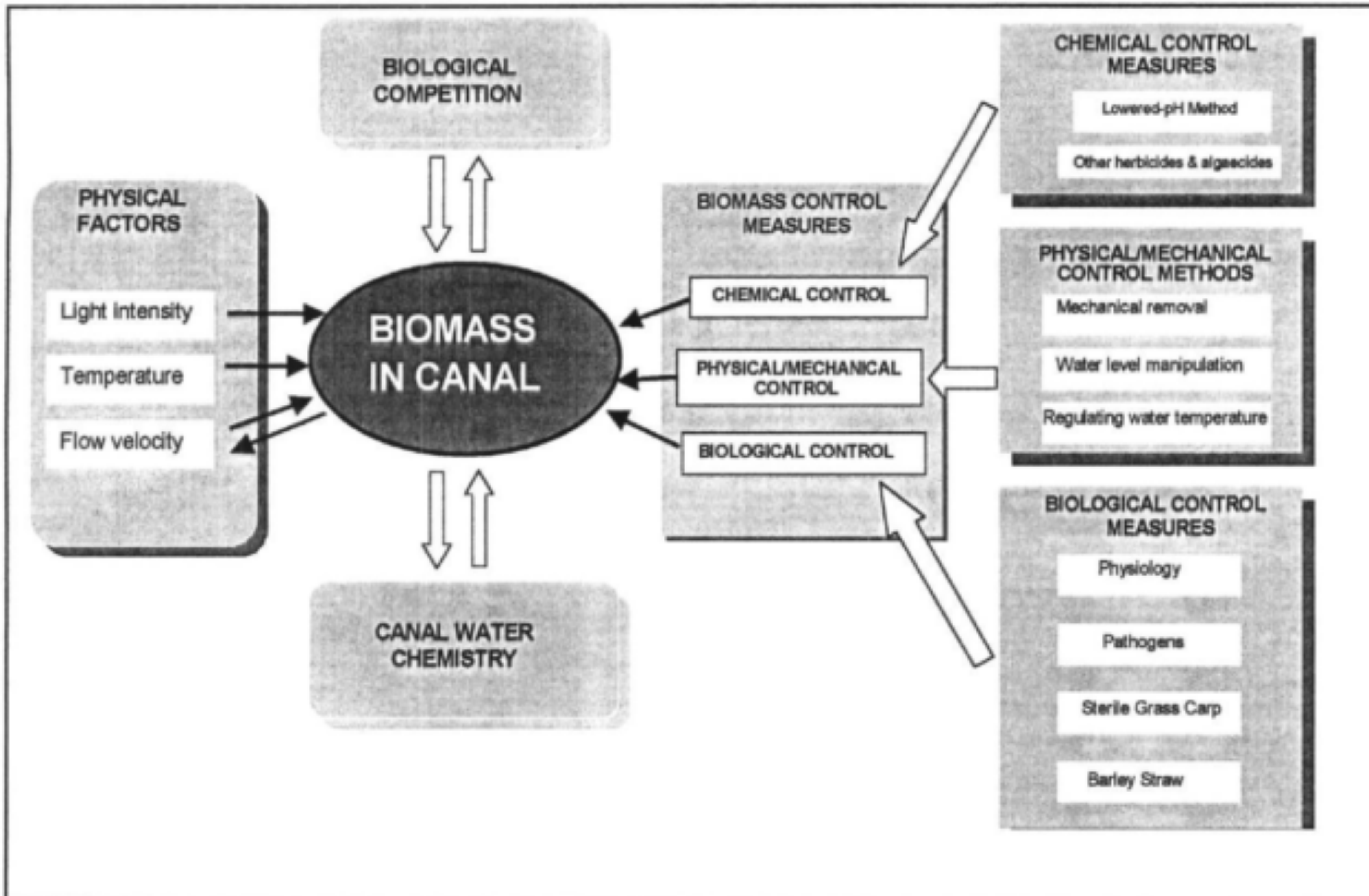

Figure 2.1: A diagrammatic presentation of control measures for the overabundant growth of aquatic weeds as anticipated by the Department of Water Affairs and Forestry (from Du Plessis and Davidson, 1996).

2.2 MECHANICAL CONTROL METHODS

Traditionally the algal biomass was removed mechanically from canals of departmental irrigation schemes. It quickly appeared that mechanical removal of the biomass was not only extremely labour intensive, but that in the peak summer months the biomass could not be removed efficiently. As many as 40 labourers were employed fulltime in 1990 to remove algae *physically* out of the Hartbeespoort-GWS canals with rakes. Canals of the Lower-Orange River-GWS were also periodically drained and cleaned with *front-end loaders*. So literally tonnes of biomass were removed from departmental canals.

As the supply of water was insufficient and unreliable in critical irrigation periods as a result of the excessive growth of algae and aquatic weeds in canals, the DWAF could not comply with the water demand at certain irrigation schemes. No realistic or economic engineering solution could be found for this problem. Out of efforts to find a solution for the overabundant growth of aquatic weeds, an *automatic algae rake* was designed, that periodical scoops free floating algae fragments out of the canal of Roodeplaat Dam close to Pretoria. At present this automatic algae rake is manned 24-hours a day. Although the algae rake is effective for the removal of free floating algal filaments, it cannot be used to remove biomass on the sides of the canals.

Draining is used at present as a successful control measure in the operation procedure of the Njelele-GWS. This scheme has a water shortage because of continuous droughts. As a savings measure the canals are drained every 7 days and this inhibits the excessive growth of algae effectively. Problems are however, expected when the scheme is operated at full capacity.

Attempts to control the biomass mechanically in systems that continuously supply water, seem to be unsuccessful and uneconomic. In 1990 a work study program revealed that 47 000 man-hours were spent to remove 10 000 m^3 of algae biomass out of the 120 km of the Hartbeespoort-GWS canals. The running costs for 1989 came to R190 000 (Du Plessis and Davidson, 1996). According to the Hartbeespoort Irrigation Scheme's manager, the mechanical removal of algal biomass by farm labourers, cost the Scheme R 2 800-00/km in 2001 (Fourie, pers. comm., 2001), that is R 300 000-00 for the system.

2.3 CHEMICAL CONTROL METHODS

Copper sulphate in the penta-hidrate formulation has been used in the USA as a herbicide in the canal systems for quite a while. In 1962 the copper sulphate dosing in the USA was implemented by the bag-method in the canals of Nebraska and Kansas (Schachterle, 1962). A technique to continuously apply a copper sulphate solution in irrigation canals was described by Bartley (1969). The disadvantages of the methods used for continuous dosing of copper sulphate in the USA are that the concentration of the active ingredient was not controlled. Where concentrations were controlled, a mush higher concentration was used than the locally prescribed criteria. The DWAF went on the basis that the application of copper formulations for algal control in canals should firstly be inside the current South African Water Quality Guidelines for domestic use (0.5 mg/l Cu^{2+}). Secondly, that the operation of the irrigation scheme should be disrupted as little as possible while the chosen control measures are being applied.

The dosing methodology of copper sulphate in irrigation canals has been revised from 1991 to 1994, that at present it is used as a very effective algaecide in local irrigation canals. The optimum pH for copper sulphate dosing is 6.0 (Bruwer, 1991; Du Plessis, 1992a, 1992b). This is based on the highest pH where copper is maximally dissociated into its ionic form, and the pH is high enough so it does not influence the cement component in the concrete lining of the canal. To ensure that the pH of the water is lowered to the optimum, the pH is lowered with concentrated commercial sulphuric acid. After lowering the pH, the copper sulphate solution is added with a final concentration of 0.5 mg/l Cu^{2+} to the canal water with an 8-hour dosage period.

Copper has been combined with different compounds i.e. EDTA, tri-ethanolamien as well as certain organic acids to form chelated chemical compounds. However, no economical alternative for the copper sulphate dosing technique has been found in copper chelates at this stage, since these compounds are considerably more expensive than copper sulphate and the effectivity of these compounds in high alkaline waters are low. Compounds such as EDTA are toxic for micro-organisms and there is thus a greater environmental risk involved in using chelated copper formulations.

2.4 BIOLOGICAL CONTROL METHODS

In the preceding paragraphs, it can be observed that there are a large amount of problems experienced with the traditional mechanical control measures removing the biomass from water supply systems. These problems could be ascribed to the exponential growth patterns of some species of undesirable aquatic weeds. As a result, the biomass increased at an immensely fast rate in a relatively short time frame.

At present, very effective results were gained with the application of chemical control measures; this includes the dosing of canals with copper sulphate with the Lowered-pH Method (Du Plessis, 2001). Although very effective, there are certain disadvantages associated with chemical control measures:

- Cost implications – Although cheaper than mechanical control, a single chemical dosage presently costs round about R 750-00 to R 900-00/km. If a medium-sized scheme has a very bad season as a result of aquatic weed infestation, there could be an estimated cost of R 200 000-00 per season.
- Stationary water systems i.e. reservoirs and balancing dams, cannot effectively be treated, at a safe concentration, with the Lowered-pH Method.
- There are fixed risks associated with the use of chemicals such as sulphuric acid and copper. Firstly there is the possibility of injury to the officials that manage the dosing and secondly there is the problem of the transference of these chemicals to non-target areas (the natural environment).
- Chemical control measures are short-term management strategies - follow-up treatments need to be done at six to eight week intervals.

Against this background the DWAF undertook investigations parallel to the chemical control measures, to investigate potential new tools for aquatic weed management. As a result of the initiative of the Department Advisory Committee for the Control of Aquatic Weeds in Water Supply Systems, as well as the interest shown by tertiary education establishments, five research projects on possible biological control measures have been registered and funded by the Water Research Commission (WRC).

These projects handled different investigations on the distribution of problem algae species in South Africa (WRC project: K5/426), the physiology of undesirable macroscopic algae in canal systems (WRC project: K5/600), biological control measures to investigate the application of pathogenic organisms on *Cladophora* spp. (WRC projects: K5/669 and K5/918), and this project for the application of herbivore fish (sterile grass carp) as a biological control measure in the management of aquatic weeds in irrigation canals (WRC project K5/816). As a result of the successes in Britain, the DWAF also investigated the potential application of barley straw as a biological control measure against aquatic weeds.

2.4.1 Investigations on the Distribution and the Physiology of Problem Macroscopic Algae:

The Department of Botany at the University of Cape Town completed an investigation to the presence, distribution and variables that play a roll in the growth and increase of macroscopic algae in fresh water (Joska and Bolton, 1994a). This investigation was financially funded by the WRC under project number: K5/426. The above mentioned project produced a handy key to assist in the identification of macroscopic algae in South African fresh water systems (Joska and Bolton, 1994b). The project was followed by a WRC project (WRC: K5/600) with the title of: *"Problematic growth of macroscopic algae: An investigation to the causal factors, seasonal variation with regard to the establishment and growth as well as the effectiveness of the current control measures"*. The aim of this project (WRC project: K5/600) was to investigate all variables that effect the proliferation and decaying of the relevant species. The rationale was to identify weak spots in the lifecycle of the specific algal species, and to use this information to optimise current control methods and to identify possible new fields of research.

2.4.2 Investigations to the Application of Pathogens as a Biological Control Measure for Undesirable Aquatic Weeds:

Plant pathogens have been applied with success as a biological control measure on various terrestrial and aquatic weeds. Two basic approaches with the application of this control measure are followed: the "classic", where exotic organisms (pathogens) from their country of origin are released in the country where there exists a problem with the host of these pathogens, and the "bio-herbicide" approach where an indigenous pathogenic organism is produced in mass to be applied as a herbicide on the target species.

The Water Research Commission funded two research projects on the application of pathogenic organisms on *Cladophora* spp. (WRC projects: K5/669 and K5/918). The aim of the first was to survey for indigenous pathogens on *Cladophora* spp. The latter, which was recently completed, investigated the efficacy of selected organisms to control *Cladophora glomerata* under laboratory and field conditions.

The results of the investigation to find and effective pathogen on *Cladophora* were unfortunately not very encouraging. In the search for an effective biological control method on aquatic weeds in canal systems this research programme on the application of sterile (triploid) grass carp (*Ctenopharyngodon idella* Val.) as bio-control agent on aquatic weeds (WRC K5/816), was initiated in 1997.

2.5 BIOLOGICAL CONTROL OF SUBMERGED AQUATIC WEEDS IN IRRIGATION CANALS WITH GRASS CARP (*CTENOPHARYNGODON IDELLA*, VAL.).

2.5.1 International history of grass carp as bio-control agent:

Abundant aquatic vegetation can impede the flow of water and reduce capacity in irrigation waterways and reservoirs. Aquatic plants can be controlled by chemical and mechanical means, but biological control methods are advantageous because they are relatively inexpensive and long lasting. Grass carp (*Ctenopharyngodon idella)* are an effective biological control measure for aquatic plants and have been widely used to reduce submerged aquatic vegetation in lakes and reservoirs. Their use in lotic systems in the U.S.A. has been less widespread, but they have been used in irrigation canals in Colorado, Florida and California (Stocker and Hagstrom, 1986; Sutton *et al.*, 1986; Thullen and Nibling, 1986).

In Egypt weed control in irrigation canals with grass carp especially, gave promising results since it can be used without any side effects and it provides an extra source of protein. Additionally, it is also used indirectly to control the intermediate hosts of bilharzia parasites. It proved to be a cost effective aquatic weed management method, since it costs less than half of conventional means (Khattab and El-Gharably, 1986). In fact, according to above authors, if the fisheries resulting from grass carp stocking is considered weed control with grass carp will result in net profit. Above results are in accordance with data from other countries (Jahnichen, 1974; Stott and Buckley, 1978; Van Zon *et al.*, 1978).

The utilisation of grass carp in Egyptian irrigation canals was the direct result of a Dutch technical assistance project, which was set up in 1976–1985 and included experimental work with grass carp. The objectives of the above project had the following phrasing:

- A research programme to study all aspects of artificial propagation, nursing, raising, food production, transportation and stocking of grass carp under Egyptian circumstances and to find solutions for all major constraints.

- A production programme to take care of breeding grass carp on a large scale and raising the fish to a size suited for stocking canals and drains.

Artificial propagation, mass breeding, disease control and local food production have all been standardised, and are carried out be Egyptian personnel on a routine basis (Ghoneim *et al.*, 1982; Siemelink *et al.*, 1982). A large-scale production unit, the Delta Breeding Station in El Kanatar, 30 km north of Cairo, produced its first batches of fish in 1982 and 1983 (50 000 and 200 000 fish), respectively. Stocking has been carried out on a number of occasions, since 1977 (Dubbers *et al.*, 1980; Gharably *et al.*, 1982), but the first large scale stocking activities took place in 1983.

In the Netherlands problems with aquatic weeds have been reported as early as the 13th century. Aquatic weed control in the Netherlands is necessary to ensure proper water flow in their numerous waterways. The Netherlands has about 150 000 ha of surface water of which a large proportion is canals and drainage ditches. These waterways remove water from land and are used for transportation and recreation. Much of Holland is below sea level with dikes to hold back the North Sea and the Rhine River. Water must be constantly pumped from the polders to permit growth of terrestrial plants (Sutton *et al.*, 1977). The use of grass carp for biological control of aquatic weeds has become common in the Netherlands. Many drainage authorities, municipalities and individuals have used this fish instead of conventional chemical and mechanical control and found it an attractive alternative; both from an ecological and economic point of view (Van Zon, 1984).

In the USSR only 10% of the land is arable because of the vast areas occupied by tundra, forests and dry land. Huge irrigation systems were built to bring more freshwater to the dry lands in the south to increase the amount of land suitable for cultivation.

One such system is the Kara Kum Canal system in Turkmenia. Soon after construction, *Phragmites* and pondweeds began growing in sufficient quantities to interfere with water flow and other uses of the system. Phytophagous fishes, including the grass carp were stocked in the canal in an attempt to control these weeds. The number of grass carp stocked was in the millions. Weeds in the main canal of the Kara Kum system were initially controlled through use of integrated approach using the grass carp and mechanical methods. The Soviets estimated their mechanical cleaning costs at that time as $12 500 per km of canal (Sutton *et al.*, 1977). Mechanical control was no longer necessary in the main canal after implementation of grass carp, except to re-establish bank configuration.

Various methods have been used successfully to control aquatic weeds in irrigation canals. In all cases mechanical removal, chemical treatment or grass carp introduction has one common result: the aquatic vegetation is removed. With mechanical and chemical methods, there can be serious impacts, beyond vegetation elimination, directly attributable to the methods employed. Grass carp have little additional direct impact.

2.5.2 Reproduction and breeding requirements of grass carp:

The factor limiting the use of grass carp has been the fear of uncontrolled spread and reproduction (Thiery, 1990). This concern has now been addressed by the development of the triploid grass carp, which is, for all practical purposes, sterile (Van Eenenam *et al.*, 1990). The utilisation of triploid grass carp is in contrast with the approach in Egypt and the USSR. Even though the Kara Kum Canal is one of the few systems where the grass carp manages to reproduce naturally, it has to be stocked frequently to maintain an sufficient population density (Sutton *et al.*, 1977). The grass carp's native range includes the Amur River in the eastern part of the USSR. This fish has been stocked widely through the USSR and have reproduced in the (1) Syr Darya River, (2) Kara Kum Canal system, (3) Volga River, (4) Kuban River and (5) Ili River. The grass carp constitutes up to 5% by number of the natural fish populations in these rivers where it has become acclimatised.

Spawning of grass carp in Russian rivers coincides with a change in water level greater than 1 meter. Accompanying the change in water level is a flow rate of at least 1 m/sec., accompanied by very turbid water. Spawning has been triggered by artificial manipulation of the water level by regulated releases of water from reservoirs. Spawning presumably also occurs in turbulence generated in the confluence of two rivers. Two other situations that generate turbulence are the areas downstream of rapids, and areas below the sluice gates of dams.

In late spring when the snow and glacier ice begins melting, the water level rises in the Amy Darya River but the sluice gates in the canal are partially closed to maintain a relatively constant flow in the canal. During peak flow, the water is about 2m in height above the dam creating a flow of 6 to 8 m/sec. through the sluice gates. The fish are unable to swim against this strong current and thus gather just below the dam. The fish attempt to jump the dam and contact with each other apparently stimulates these fish and they spawn below the dam. The fertilised eggs are carried in the current to the Kelif Reservoir, which is approximately 100 km downstream from the dam. The location of this reservoir downstream corresponds to natural systems where the grass carp spawns successfully.

Flowing water is essential for egg-laying in grass carp. A water current of 1 m/sec. is generally associated with turbulent water. The turbulence is critical in maintaining the eggs in the water column during their negatively buoyant water-hardening phase.

Secondly, below the area of turbulence a sustained average flow of 1 m/sec. is required for approximately 100-170 km river distance depending on the speed of embryonic development, which is controlled by water temperature. A lake or reservoir some distance from the egg-laying site is critical for survival of the young grass carp. If the embryos reach the reservoir prior to hatch, they will sink to the bottom and die. If the embryos do not reach the reservoir when the yolk is absorbed, they will starve because micro-zooplankton is inaccessible within the canal (Sutton *et al.*, 1977).

2.5.3 Tolerance of flow velocity:

From the above-mentioned information, it can be concluded that the grass carp is a stream fish displaying rheotactic behaviour and is capable of handling currents in excess of 1 to 1.5 m/sec. Furthermore, it is evident that grass carp will not spawn in standing water and the habitat requirements are extremely specific for natural spawning.

In a study with triploid grass carp in a Colorado irrigation canal, the movement and habitat preference were documented. Mean column velocity varied between 0-1.3 m/sec. Grass carp utilised all of these velocities but displayed a preference for 0.8 m/sec. (Beyers and Carlson, 1993). In South Africa, current velocities in irrigation canals vary between 0.50-1.5 m/sec., with a mean velocity of approximately 0.8 m/sec. (Du Plessis, 1997).

In South Africa one of the major concerns with regard to the utilisation of grass carp in irrigation canals was that the species would not be able to cope with the currents within these systems. According to our experience and knowledge from the literature, this concern was not justified. The Cuban River in the USSR, for instance, has a very fast current during the early stages of its journey, often in excess of 2 m/sec. and an annual discharge of 12 km^3 (Sutton *et al.*, 1977), yet the grass carp manages to survive under these conditions and even reproduce, consequently maintaining a viable population.

2.5.4 Food preferences:

Another concern prior to the initiation of this project was serious doubt about the ability of grass carp to efficiently consume large quantities of *Cladophora* species. This type of noxious underwater weed is the major menace in irrigation canals in South Africa and it was feared that due to its morphology, it would not be palatable to grass carp and therefore not be consumed efficiently.

Although grass carp can be selective towards certain aquatic plant species if they occur in a mixture of various species, they are known to consume a wide variety of plants, which are not yet fully realised by aquatic scientists. *Cladophora* (a filamentous algae) is for instance not listed in the comprehensive list of Miller and Decell (1984) Table 1, but does occur in the list of other authors (Avault, 1965; Pentelow and Stott, 1965; Stott *et al.*, 1971; Michewicz *et al.*,1972; Fowler and Robson, 1978; Mitchell, 1980; Swanson and Bergersen, 1988; personal observation, EWC, 1991; Chilton and Muoneke, 1992) (Table 2).

However prior to submission of the original research proposal to the Water Research Commission the authors have tested the consumption of *Cladophora* by triploid grass carp and obtained a positive result.

TABLE 2.1: Feeding preference list, in approximate order of preference, for triploid grass carp in Florida, Illinois and Oregon-Washington (compiled from Miller and Decell, 1984; Hestand and Carter, 1978; Osborne,1978; Nall and Schardt, 1980; Van Dyke *et al.*, 1984; Sutton and Van Diver, 1986; Bowers *et al.*, 1987; and Leslie *et al.*, 1987).

FLORIDA	ILLINOIS	OREGON - WASHINGTON
PREFERRED PLANTS		
Hydrilla verticilla	*Najas flexilis*	*Potamogeton crispus*
Potamogeton illinoiensis	*Najas minor*	*Potamogeton pectinatus*
Potamogeton spp.	*Chara*	*Potamogeton zosteriformis*
Najas guadalupensis	*Potamogeton foliosus*	*Elodia canadensis*
Egeria densa	*Elodea canadensis*	*Vallisneria sp.*
Elodia canadensis	*Potamogeton pectinatus*	
Chara spp.		
Lemna spp.		
Nitella spp.		
Ceratophyllum demersum		
Eleocharis acicularis		
Pontederia lanceolata		
Wolffia spp.		
Wolffiella sp.		
Typha spp.		
Azolla sp.		
Spirodela sp.		
VARIABLE PREFERENCE (MAY EAT)		
Myriophyllum spicatum	*Potamogeton crispus*	*Myriophyllum spicatum*
Bacopa sp.		*Ceratophyllum demersum*
Polygonum spp.		*Uticularia vulgaris*
Utricularia spp.		*Polygonum amphibium*
Cabomba spp.		
Fuirena spp.		
Nymphaea spp.		
Brasenia schreberi		
Hydrococotyl spp.		
Panicum repens		
Stratiotes aloides		

NON-PREFFERED (Does not eat)		
Nuphar luteum *Vallisneria americana* *Myriophyllum brasiliense* *Eichhornia crassipes* *Alternanthera philoxeroides*	*Ceratophyllum demersum* *Myriophyllumm spp.*	*Potamogeton natans* *Brasenia schreberi* *Egeria densa*
Pistia stratiotes *Nymphoides spp.* *Phragmites spp.* *Carex spp.* *Scirpus spp.* *Ludwigia octovalis* *Colocasia asculentum*		

TABLE 2.2: Hydrophytes commonly consumed by grass carp. Information from Avault, 1965; Stott and Robson, 1970; Michewicz *et al.*, 1972; Fowler and Robson, 1978; Mitchell, 1981; Swanson and Bergersen, 1988; Sample, 1990; personal observation, EWC, 1991; Chilton and Muoneke, 1992.

SCIENTIFIC NAME	COMMON NAME
Alternanthera philoxeroides	Alligator weed
Azolla spp.	Water fern
Callitriche sp.	Water starwort
Carex nigra	Black sedge
Carex pseudocyperus	Sedge
Ceratophyllum demersum	Coontail
Chara sp.	Stonewort
Cladophora sp.	Cladophora
Eichornia crassipes	Water hyacinth
Eleocharis acicularis	Least spike rush
Elodea canadensis	Broad waterweed
Elodea (Egeria) densa	Waterweed
Groenlandia densa	Pondweed
Hippuris vulgaris	Mare's-tail
Hydrilla verticillata	Hydrilla
Hydrocharis morsus-range	Frog bit
Juncus effuses	Soft rush
Lemna minor	Lesser duckweed
Lemna trisulca	Star duckweed
Myriophyllum brasiliense	Parrot-feather
Myriophyllum exalbescens	Water milfoil
Myriophyllum verticillatum	Whorled water milfoil
Najas guadalupensis	Southern naiad
Nasturtium officinale	True watercress
Nitella sp.	Musk grass
Nuphar luteum	Yellow water-lily
Phragmites communis	Common reed
Pithophora spp.	Pithophora
Polygonum amphibium	Water smartweed
Polygonum praelongus	Smartweed
Polygonum pusillus	Smartweed
Potamogeton berchtoldii	Pondweed
Potamogeton crispus	Curly pondweed
Potamogeton illinoesis	Illinois pondweed
Potamogeton pectinatus	Sago pondweed
Potamogeton richardsonii	Pondweed
Ranunculus trichophyllus	Water buttercup
Ruppia maritime	Widgeon-grass
Sagittaria spp.	Arrowhead
Scirpus spp.	Bulrush
Spirodela polyrhiza	Greater duckweed
Spirogyra sp.	Frog spit

2.6 THE HISTORY OF GRASS CARP IN SOUTH AFRICA

2.6.1 Importation of grass carp to South Africa:

The Chinese grass carp (*Ctenopharyngodon idella)* is recognised world wide as a voracious aquatic weed eater and for this reason is highly acclaimed as a tool for aquatic weed control. For this reason grass carp was imported into Natal from Malaysia in 1967 by the Natal Parks Board (Pike, 1990). Since 1974 grass carp was bred in the Umgeni Fish Hatchery. Progeny of these fish (grass carp) that were later bred at the Umtata Fish Hatchery, Transkei (Schoonbee and Prinsloo, 1984) have been stocked into many farm dams in Natal for the purpose of controlling the growth of aquatic plants (Pike, 1990).

Due to limited breeding success with the 100 fish imported from Malaysia, the Natal Parks Board could not supply the demand of the former Transvaal Nature Conservation at the time. Thus, leading to another import of 320 fish from Günsberg in Germany, to the Provincial Fish Hatchery at Marble Hall in the Transvaal (Brandt and Schoonbee, 1980). Artificially induced spawning of the grass carp was refined at Marble Hall Fish Hatchery (Schoonbee, Brandt and Bekker, 1978; Brandt and Schoonbee, 1980) and further adapted at Umtata Fish Hatchery in the Transkei (Schoonbee and Prinsloo, 1984). Grass carp fingerlings from the 1977 breeding season at Marble Hall were made available for stocking on an experimental basis to control aquatic weeds in the Belfast, Dullstroom, Lydenburg, Ohrigstad, Vereeniging and Krugersdorp areas (Brandt, 1980). Some of these fish were also translocated to Umtata Fish Hatchery in the Transkei and were later used as broodstock for further experimental work on hatchery techniques for this species (Schoonbee and Prinsloo, 1984).

2.6.2 Application of grass carp as bio-control agent in South Africa:

The fist large-scale application of Chinese grass carp as bio-agent for the control of aquatic vegetation in South Africa, was implemented in Germiston Lake during 1982. Biological control of *Potamogeton pectinatus* in Germiston Lake was fist tried with the only indigenous, freshwater fish in South Africa that feeds on aquatic macrophytes, the Red breasted Tilapia

(*Tilapia rendalli*). This species (*T. rendalli*) was introduced into experimental enclosures in the lake at a density of 1 fish/m^2 during 1973. At this density, *T. rendalli* reduced the infestation of *P. pectinatus* and maintained the weed at acceptable levels during summer. However, the programme failed because *T. rendalli* did not survive through the winter when temperatures in the lake dropped below 10 °C (Schoonbee, 1991).

Following the failure with *T. rendalli*, the phytophagous, Chinese grass carp *Ctenopharyngodon idella* was selected for further attempts at biological control of the weed. Although it is a warm water species, this fish tolerates cold temperatures and has been successfully used to control submerged aquatic macrophytes elsewhere (e.g. Vinogradov and Zolotova, 1974; Krzywosz *et al.,* 1980). Germiston Lake has a surface area of 59 ha and was successfully controlled at a stocking density of 86-grass carp/ha (Schoonbee *et al.*, 1985). Based on above observations, 10 000 *T. rendalli* ha^{-1} was necessary to achieve similar control and was only restricted to summer and a restocking would have been necessary each year.

2.6.3 Local restrictions and impact on non-target species:

The grass carp, *C. idella,* is the most efficient phytophagous freshwater fish in the world with a versatile application as it has a wide tolerance range for temperature and it is adapted for Riverine conditions although it is mainly utilised in lake ecosystems (Swingle, 1957; Sutton, 1977). It is for this reason that the Nature Conservation authorities in South Africa placed restrictions in 1989 on the use of fertile grass carp to control aquatic weeds. This decision was in line with the approach of other conservation authorities world-wide as it is recognised that grass carp could have a serious destructive effect on aquatic ecosystems if population sizes cannot be regulated. Criticism towards the uncontrolled spreading of grass carp is based on the following issues:

- Destruction of the natural biological filter which maintain water quality;
- benthic erosion and consequently high turbidity;
- demise of breeding habitats and shelter of indigenous aquatic species.

Although all above issues of concern are valid, the effects can be controlled and managed if recruitment can be prevented, subsequently in 1991 the Transvaal Directorate of Nature and Environmental Conservation adopted the principle that sterile (triploid) *C. idella* may be introduced in that province for aquatic weed control purposes. Soon after this decision, other provinces except KwaZulu Natal followed, and it is *now required that only sterile (triploid), internally marked grass carp may be released in South African waters.*

2.6.4 Production of triploid (sterile) grass carp:

Sterile grass carp were developed to solve the problem of unwanted reproduction. Early attempts at using sterile fish involved hybrids, but these animals had lower feeding efficiencies and fertile diploids could occur. A solution to the problem involved the production of pure (unhybridized) triploid grass carp. Hydrostatic pressure or high temperature techniques are used to produce nearly 100% triploids.

Since no known procedure can produce 100% triploidy consistently, and because external observations cannot accurately separate the diploids and triploids, fish producers must verify that fish sold are triploid. One technique is to use a Coulter Counter to examine a drop of blood taken from a sample of fish. Triploid red blood cells are larger than diploids, and the Coulter easily verifies cell size. Triploids are apparently functionally sterile, and there is an extreme low probability that triploids can be a source for a large population of reproducing diploids.

Triploidy (sterility) is induced by manipulating the second polar body during early embryonic development and triploid individuals are then selected by blood analysis testing for erythrocyte nuclear content with a Coulter Counter Multisizer. Sterility should then be verified by marking each individual with an internal electronically detectable tag.

2.6.5 Stocking densities:

Adoption of above principles soon resulted in various aquatic weed control programmes across South Africa, of which Germiston Lake (Schoonbee, Vermaak and Swanepoel, 1985), Florida Lake (Venter and Schoonbee, 1991), Potchefstroom Dam (Du Preez, Steyn and Erlank, 1994) and Leeu Pan is publicly known of.

Worldwide a considerable amount of research has been undertaken to determine the optimum number of fish required to bring different aquatic weed species under control (e.g. Stott and Robson, 1970; Kilgen and Smitherman, 1971; Edwards and Moore, 1975; Beach *et al.*, 1976; Gasaway and Drda, 1977; Osborne and Sassic, 1979; Krzywosz *et al.*, 1980; Mitchell, 1980; Shireman and Maceina, 1981). These investigations clearly show that each situation is unique and no generalities can apply.

The number of fish to be stocked is an important factor in the use of grass carp. Their feeding activity and impact on vegetation is affected by water temperature, length of the warm-water season, type of plants, size of fish stocked, and pre-stocking plant control activities. It is easy to over stock when the dominant plant species are highly palatable. When unpalatable plants dominate, stocking rates have to be higher and palatable plants will be removed first.

Stocking densities should thus be carefully considered before introductions of *C. idella* are made into other water bodies (Schoonbee, 1991). A comparison of Germiston Lake and Potchefstroom Dam is a good example of this. The two lakes are almost the same size (± 60 ha) and are situated ± 100 km from each other and the magnitude of the weed contamination was similar. Yet, Germiston Lake was successfully controlled with a stocking density of 85 fish/ha as opposed to Potchefstroom Dam with a stocking density of only 35 fish/h. The duration of efficient biological control in Germiston Lake lasted for 15 years after which restocking had to be done. The low stocking densities and time duration at which biological control is achieved with triploid grass carp makes this method particularly attractive as a bio-control agent for noxious underwater vegetation.

An integrated aquatic weed approach utilising low stocking densities, combined with initial chemical or mechanical control, could be effective and could circumvent the ecological disruptive use of high densities of grass carp, followed by total plant eradication, which could be a problem in natural ecosystems such as lakes.

CHAPTER 3

Technical note:

To be submitted for publication in Water SA.

AN EVALUATION OF THE SUITABILITY OF A CONCRETE-LINED IRRIGATION CANAL AS GRASS CARP HABITAT - THE CHARACTERIZATION OF FLOW DISTRIBUTION IN THE RAMAH CANAL SYSTEM

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Abstract

The overabundant proliferation of aquatic weeds in South African irrigation canals has motivated the Department of Water Affairs and Forestry to explore all possible means to optimize current control methods, and to investigate potential new tools for aquatic weed management. The biological control of filamentous algae (*Cladophora glomerata*) and pond weeds (*Potamogeton* spp.), with sterile grass carp (*Ctenopharyngodon idella* Val.) was investigated with the aim to supplement current physical, mechanical en chemical control methods.

As the majority of local irrigation canals are concrete-lined, skepticism existed amongst local scientists if the fish will be able survive in canals with a presumed high constant flow and low diversity of hydraulic biotopes. As part of the study to investigate the possible application of sterile grass carp as bio-control agent in irrigation canals, the suitability of concrete-lined canals as habitat for this herbivorous fish specie was investigated.

The study found that, contradictory to the general perception that local concrete-lined canals are fast flowing conduits, flow velocities in the Ramah Canal System did not exceed 1 m/s under high flow conditions (full capacity) of more than 5 m^3/s. The study also found that civil obstructions in the canal, such as long-weirs and roll-grids provide niches of low flow were the fish could rest. The investigators are also of the opinion that civil structures, such as culverts, super-elevated canals and bridges will provide the fish with sufficient protection against possible predators.

Free migration of the fish throughout the canal system could pose an operational problem, as the in and outlets of balancing dams will restrict movement. This can however, be overcome by sectional stocking of the fish in each canal reach.

3.1. INTRODUCTION

The overabundant proliferation of submerged aquatic weeds in South African irrigation canals does not only result in extensive operational problems, but contributes also to an increase in water losses (Du Plessis and Davidson, 1996). Over the previous two decades, the Department of Water Affairs and Forestry (DWAF) has initiated investigations into the optimization of current physical, mechanical and chemical aquatic weed control measures as well as investigations into potential new methods of aquatic weed control.

Grass carp (*Ctenopharyngodon idella* (Val.)) have been used successfully as a biological control mechanism for the management of aquatic weeds in irrigation canals in several parts of the world (Stocker and Hagstrom, 1986). In Egypt and the Netherlands grass carp have controlled pondweed (*Potamogeton* sp.) at stocking rates of 150-300 kg/ha (Khattab, *et al.*, 1981; Van Zon, 1979). The Kara Kum Canal System in the former USSR was the site of an extensive grass carp stocking programme in the early seventies (Kogan, 1974). The use of grass carp in lotic systems in the U.S.A. has been less widespread, but they have been introduced into irrigation canals in Colorado, Florida and California (Stocker and Hagstrom, 1986; Sutton, *et al.*, 1986 and Tullen and Nibling, 1986).

The majority of the literature found on the issue of biological control of aquatic weeds with grass carp as bio-agent can be described as so-called "gray literature". The few available scientific papers on the application of grass carp as management tool for the control of aquatic weeds in canals were found vague regarding the hydrological characteristics of the relevant water distribution systems. This makes it difficult to extrapolate overseas findings to local conditions. The canal systems studied are also not fully comparable with the local structures. No literature could be found on grass carp used in concrete-lined canals.

One of the major concerns with regard to the utilization of sterile (triploid) grass carp in South African irrigation canals was that the fish would not be able to cope with the high flow conditions in local concrete-lined canals. These concerns were based on assumptions that local concrete-lined canals are generally characterized by high flow conditions, have a lower diversity of hydrological biotopes and that these canals provide less cover for fish life than earth lined canals. The uncertainty regarding the adaptability of sterile grass carp to local concrete-lined canals was seen as a major obstacle by some scientists in the initial phases of funding of the project. It was therefore decided by the research team to establish the suitability of local concrete-lined canals as grass carp habitat. The Ramah Canal System was investigated as a representative canal to local conditions. The aims of the study were the following:

- Characterization of the distribution of flow velocities in the Ramah Canal System with specific reference to the Ramah-3 Canal section.
- Compare the flow conditions in the canal with existing information on grass carp tolerances.
- Identify areas or biotopes were the fish could rest and hide to avoid predation.
- Identify areas in the canal were the fish would not be able to cope with flow conditions.
- Identify possible management implications for the application of sterile grass carp as aquatic weed management agent in concrete-lined irrigation canals.

3.2 DESCRIPTION OF STUDY AREA

3.2.1 The study area:

The Ramah Canal System is situated near the towns of Vanderkloof and Orania, on the border of the Northern Cape and Free State provinces in the Republic of South Africa. The canal system conveys water from the bigger Orange-Riet River Canal (former Sarel Hayward Canal) which is in turn fed by the Vanderkloof Dam (former P.K. le Roux Dam) - situated on the Orange River (Figure 3.1).

The Ramah Canal System is concrete-lined, with a total length of 84.3 km. The canal is subdivided into three sections, namely the Ramah-1, Ramah-2 and Ramah-3 sections, by two balancing dams (Balancing Dam No.1 and Balancing Dam No.2). The Ramah-1 Canal is 17.3 km long with a maximum capacity of 9.6 m^3/s. The Ramah-2 Canal is 48.9 km long with a design capacity of 4.2 m^3/s, and the Ramah-3 Canal is 18.3 km long with a maximum capacity of 1.48 m^3/s. The overflow of the Ramah-3 Canal drains back into the Orange River via a seasonal brook, named Sanddraaisloot (farm: Sanddraai 1182).

3.2.2 Location of flow measuring sites:

In order to establish flow velocity distributions, all three sections of the Ramah Canal System were measured near the intakes and outflows. As the experimental section of the project (area where sterile grass carp were stocked) was situated in the Ramah-3 Canal, additional flow measurement sites were selected in this canal to characterize the impact of obstructions in the canal, on flow conditions. The following table (Table 3.1) and map (Figure 3.1) indicate the geographical position of the flow measurement sites on the Ramah Canal System. The co-ordinates were determined with a handheld GPS.

TABLE 3.1: Location of flow gauging sites on the Ramah Canal System.

No.	DESCRIPTION OF GAUGING SITE	LOCATION	
		Latitude	Longitude
1.	Ramah-1 Canal - downstream of Scheiding Pump Station	29°54'08"	24°41'58"
2.	Ramah-1 Canal – upstream of Balancing Dam No.1	29°52'00"	24°35'52"
3.	Ramah-2 Canal – downstream of Balancing Dam No.1	29°51'14"	24°36'04"
4.	Ramah-2 Canal – upstream of Balancing Dam No.2	29°45'58"	24°27'19"
5.	Ramah-3 Canal – downstream of Balancing Dam No.2	29°45'03"	24°26'21"
6.	Ramah-3 Canal – at Super No. 184	29°43'07"	24°23'13"
7.	Ramah-3 Canal – up- and downstream of Roll-grid	29°41'52"	24°22'29"
8.	Ramah-3 Canal – at Long-Weir	29°40'42"	24°23'22"
9.	Ramah-3 Canal – outlet to drain	29°40'39"	24°24'10"

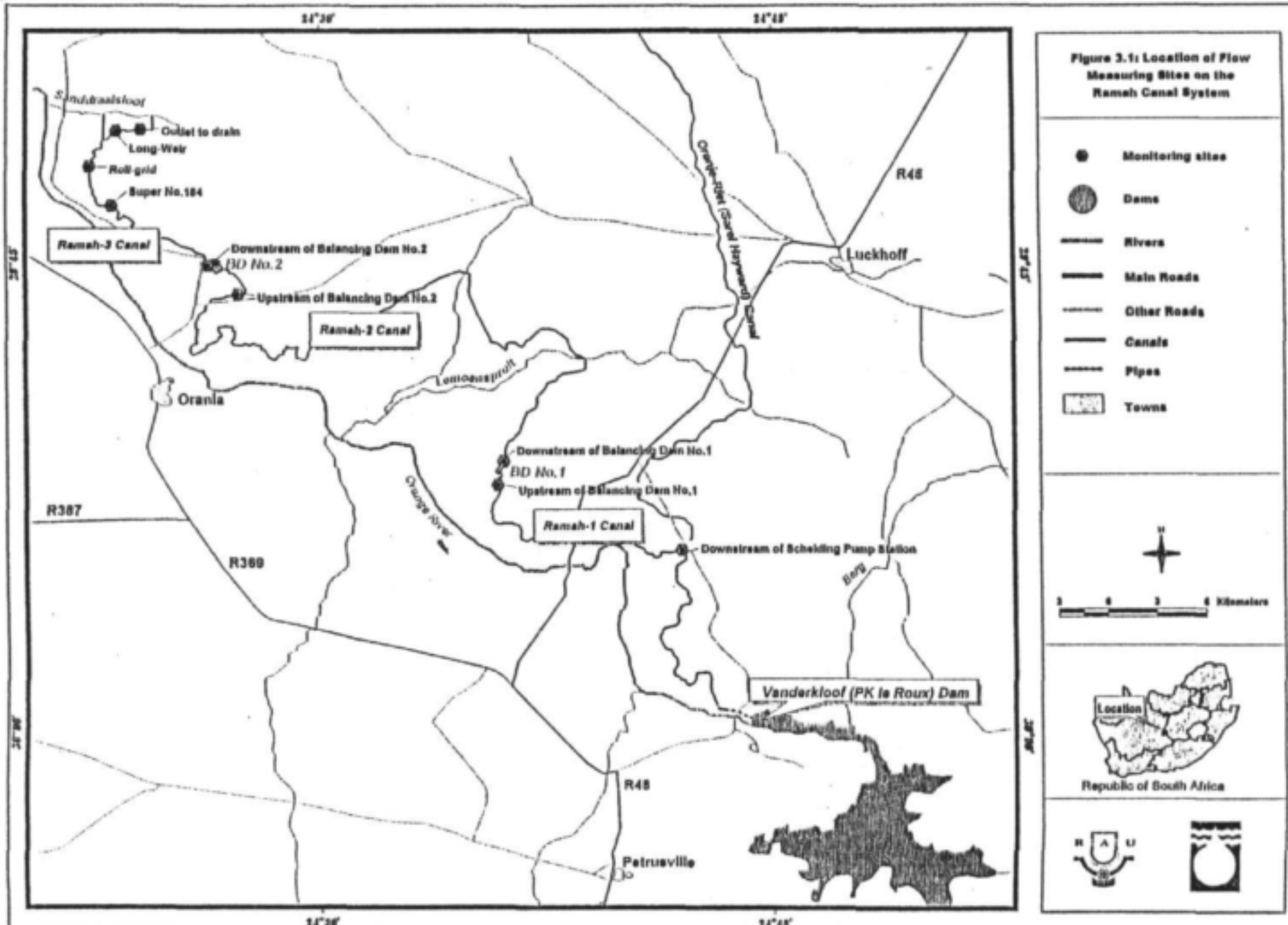


Figure 3.1: Location of Flow Measuring Sites on the Ramah Canal System

3.3. MATERIALS AND METHODS

3.3.1. Background to flow measurements:

3.3.1.1. Conventional flow measurements:

The term conventional current gauging is used to denote velocity-area gauging, where the determination of velocity is done by using an instrument able to measure water velocity at a specific point. A conventional current gauging is based on the following simple principle:

Q = A x V

Where:
Q = discharge
A = cross-sectional area
V = velocity

The velocity of flowing water in a cross-section ranges from high in the middle to low at the sides and bottom of the conduit, due to friction of the canal sides. It is therefore not correct to assume that only one velocity measured in the middle of the section will represent the average velocity to be used in the above equation (DWAF, 1999).

To solve the problem of finding an applicable average velocity, a number of velocity observations, well distributed throughout the cross-section, have to be made. To facilitate the process, the cross-section is divided into a number of increments or panels. To calculate the average flow velocity at a cross-section the above formula can be modified to read:

$$Q_{Total} = \sum_{i=1}^{n}(a_i v_i)$$

Where:
N = number of panels
A_i = area of panel i
V_i = average velocity in panel i

A conventional current gauging is a velocity-area method of flow gauging and therefore the two main steps to be taken during actual observations are:

- Measurement of area
- Measurement of velocity

These actions might be described in short as follows: a section perpendicular to the direction of flow is chosen at the point where discharge is to be measured. This section is then divided into a number of sub-sections separated by imaginary vertical lines, commonly called "verticals". These verticals are the positions where depth and velocity will be measured. The horizontal distance from a reference point on the bank to each vertical is measured, as well as the depth and velocity at each vertical. The results of the completed fieldwork only produce a number of distances, depth and velocity values, which should then be reduced to a total discharge for the site-specific measurement. Two methods of approach for the calculation of the incremental (panel) discharges have been developed:

- The Mid-section Method (Figure 3.2)
- The Mean-section Method

The Mid-section Method is the more accurate method of the two and is adopted by the Department of Water Affairs and Forestry as the standard method of calculations for the determination of flow velocity in open conduits (DWAF, 1999).

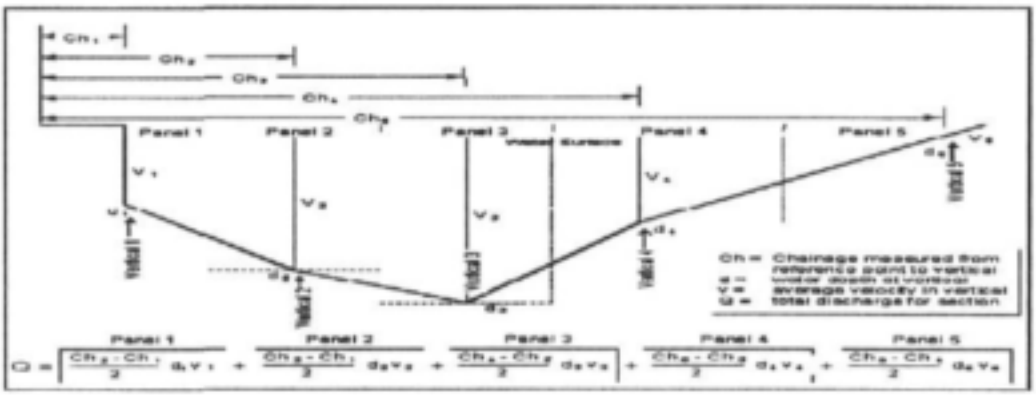


Figure 3.2: Diagrammatic presentation of the Mid-section Method for the calculation of incremental discharges.

3.3.1.2 *Available methods for current gauging:*

A current meter measures the velocity of water only at a specific point. The method of measuring the discharge in a cross-section however involves the determining the *average velocity* in the section, which as previously mentioned, cannot be deduced from only one point velocity. The section is therefore divided into a number of segments separated by verticals, which must first be determined. This is obtained by measuring the velocity at a number of points in a vertical plain, or it may be approximated by only measuring the velocity at a few points (or only one point), and then using a known relation between those velocities and the mean velocity in the vertical.

The more common methods of determining the mean velocity in a vertical are:

- Vertical velocity curve Method
- Two point Method
- Six-tenths depth Method
- Three point Method
- Two-tenths depth Method
- Sub-surface velocity Method

Other standard methods, which are currently not utilized in South Africa, because it requires special equipment and techniques, are:

- Surface velocity Method
- Integration Method

Less commonly used are the following multi-point methods of determining mean vertical velocity:

- Five point Method
- Six point Method

For the purpose of this exercise only the Two-point and Six-tenths depth methods are discussed in more detail.

3.3.1.3 Different methods for flow measurement:

3.3.1.3.1 The Two-point Method:

With the Two-point Method of measuring velocities, observations are made in each vertical at 0.2 and 0.8 of the depth below the surface (Figure 3.3). The average of these two observed velocities is taken as the mean velocity in the vertical. Experience has shown that this method gives consistent and accurate results that *are within 1 percent of the true mean velocity* if the vertical velocity curve is substantially parabolic in shape.

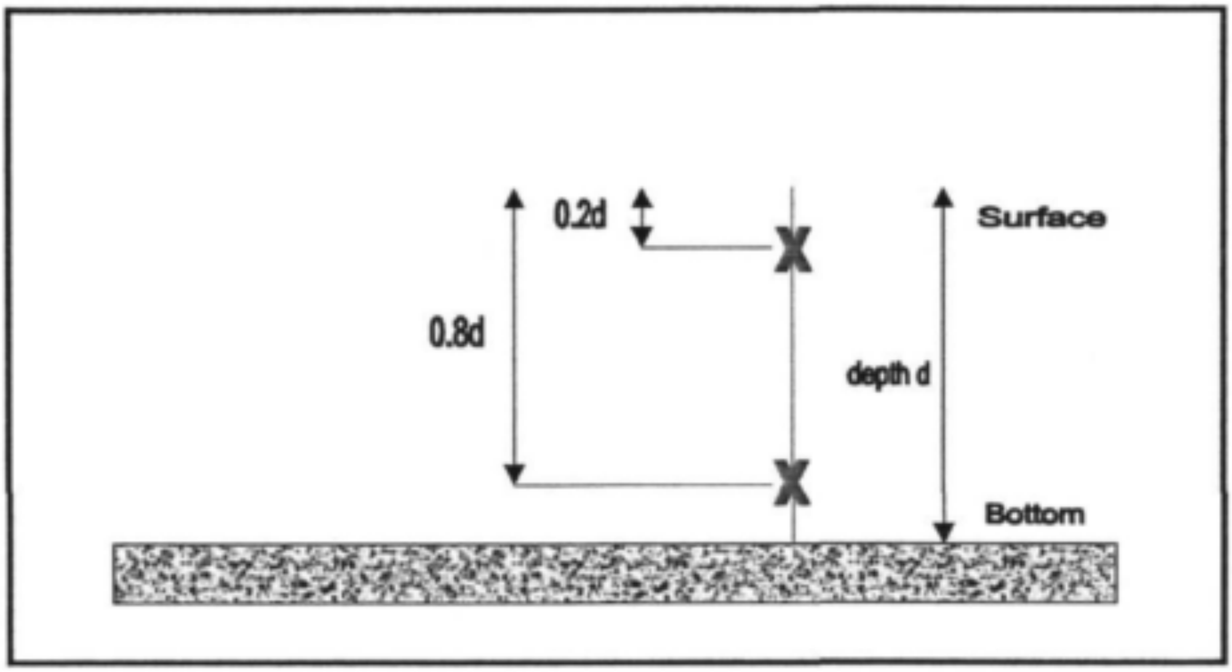


Figure 3.3: Diagrammatic presentation of the Two-point Method for the measurement of flow velocities.

The Two-point Method is not generally suitable for depths of less than 0.75 meters, because the meter would then be too close to the water surface and the streambed to give dependable results.

The vertical velocity curve could however, be distorted by overhanging vegetation that is in contact with the water or by submerged objects such as large rocks and aquatic growth. If this interference is in close proximity, either in the upstream or downstream direction, to the vertical in which velocity is being measured, the Two-point Method will not give a reliable value of the mean velocity in the affected vertical. This necessitates that an additional velocity observation at 0.6 of the depth should be made. The three observed velocities should then be used in the Three-point Method. A rough test of whether or not the velocities at the 0.2 and 0.8 depths are sufficient for determining mean velocity is given in the following criterion: the 0.2 depth velocity should be greater than the 0.8 depth velocity, but less than twice as great.

3.3.1.3.2 *The Six-tenths Method:*

In the Six-tenths Method, an observation of flow velocity made at 0.6 of the depth below the surface in a vertical is used as the mean velocity in the vertical (Figure 3.4).

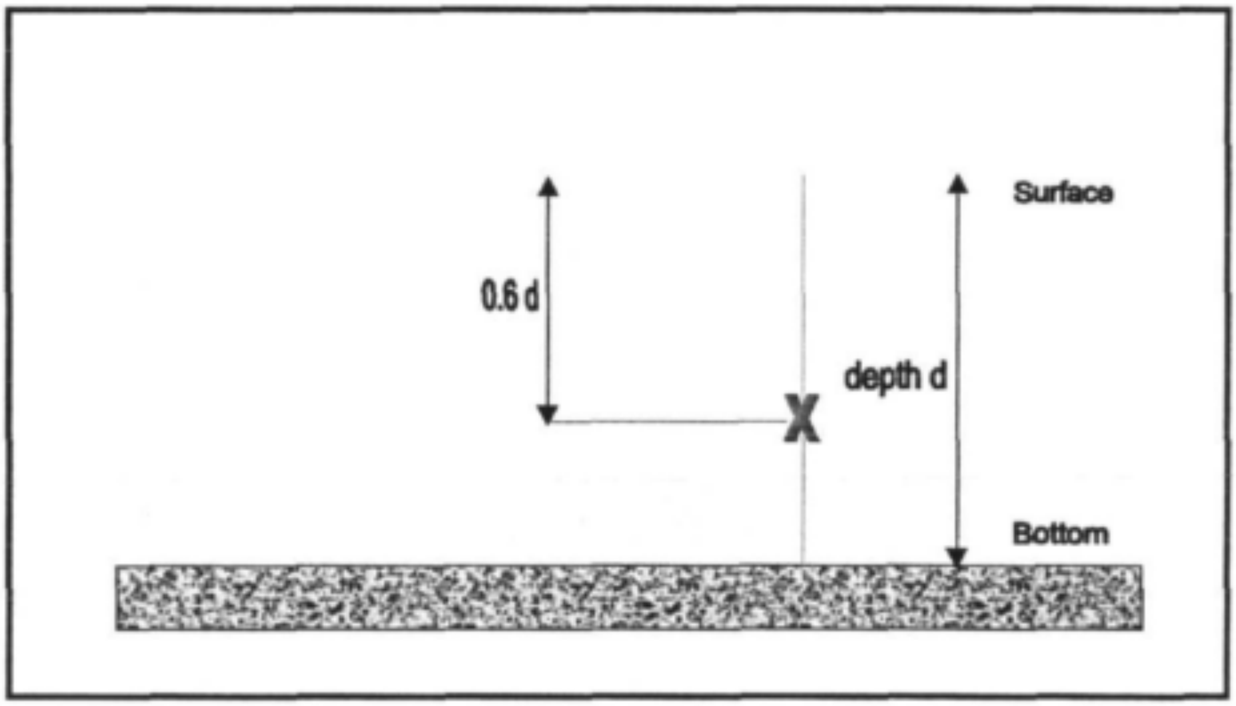


Figure 3.4: Diagrammatic presentation of the Six-tenths Method (One-point Method) for the measurement of flow velocities.

The Six-tenths Method is generally used under the following conditions:

- Whenever the depth is between 0.100m and 0.750m.

- When large amounts of debris make it impossible to observe the velocity accurately at the 0.2 depths, as this situation prevents the use of the Two-point Method.
- When the water level in a stream is changing rapidly, and a measurement must be made quickly.

3.3.1.4 *Factors to consider in site selection for flow measurements:*

The first step in carrying out a conventional current meter measurement of discharge is to select a measurement cross-section of desirable qualities. The observer should look for a cross-section in a canal with the following characteristics:

- The cross-section lies within a straight reach and streamlines are parallel to each other.
- Flow velocities are greater than 0.15m/s and depths are greater than 0.15m.
- The streambed is relatively uniform and free of boulders and heavy aquatic growth.
- Flow is relatively uniform and free of eddies, slack water and excessive turbulence.
- The measurement section is relatively close to the gauging control to avoid the effect of tributary inflow between the measuring section and control, and to avoid the effect of storage between the measurement section and control during periods of rapidly changing stage.

It will often be impossible to meet all of the above criteria, and when this is the case, the observer must exercise his own judgement in selecting the best of the sites available for the discharge measurement.

3.3.1.5 Factors influencing the accuracy of flow measurements:

3.3.1.5.1 Equipment:

Accurate measurements require measuring equipment to be properly assembled and maintained in good condition. To avoid damage during transport, the equipment should be packed in appropriate containers or compartments of the vehicle used by the observer. Current meters are especially susceptible to damage when in use, as measurements must often be made while floating debris is present in the stream.

3.3.1.5.2 *Measurement section:*

The basic characteristics of the measuring section affect measurement accuracy. The attributes desired in a measuring section are those that is listed in Section 3.3.1.4. If possible, the section should be deep enough to permit use of the Two-point Method of measuring velocity.

3.3.1.5.3 *Spacing of observation verticals:*

The spacing of the observation verticals in the measurement section can influence the accuracy of the measurement. Twenty-five to thirty verticals should normally be used, and the verticals should be spaced in such a way that each segment will give approximately the same discharge. However, a measurement vertical should be located fairly close to each bank and at sudden changes in streambed elevation.

3.3.1.5.4 *Measurement of depth and velocity:*

Inaccuracies in the placement of the current meter are most likely to occur in those sections having great depths and high flow velocities.

3.3.1.5.5 *The wind factor:*

Wind may effect the accuracy of a discharge measurement by obscuring the angle of the current, by creating waves that make it difficult to sense the water surface prior to sounding the depth, and by affecting the 0.2 depth velocity observations in shallow depths.

3.3.1.5.6 Aquatic growth:

Aquatic growth in the section or debris can affect the velocity measurements at a given point. Aquatic growth can cause turbulence upstream or drastically reduce the velocity at a specific panel. Debris or algae (Figure 3.5) that float downstream can tangle around the instrument, which will reduce the revolutions of the propeller of the flow velocity meter and therefore the velocity measured.

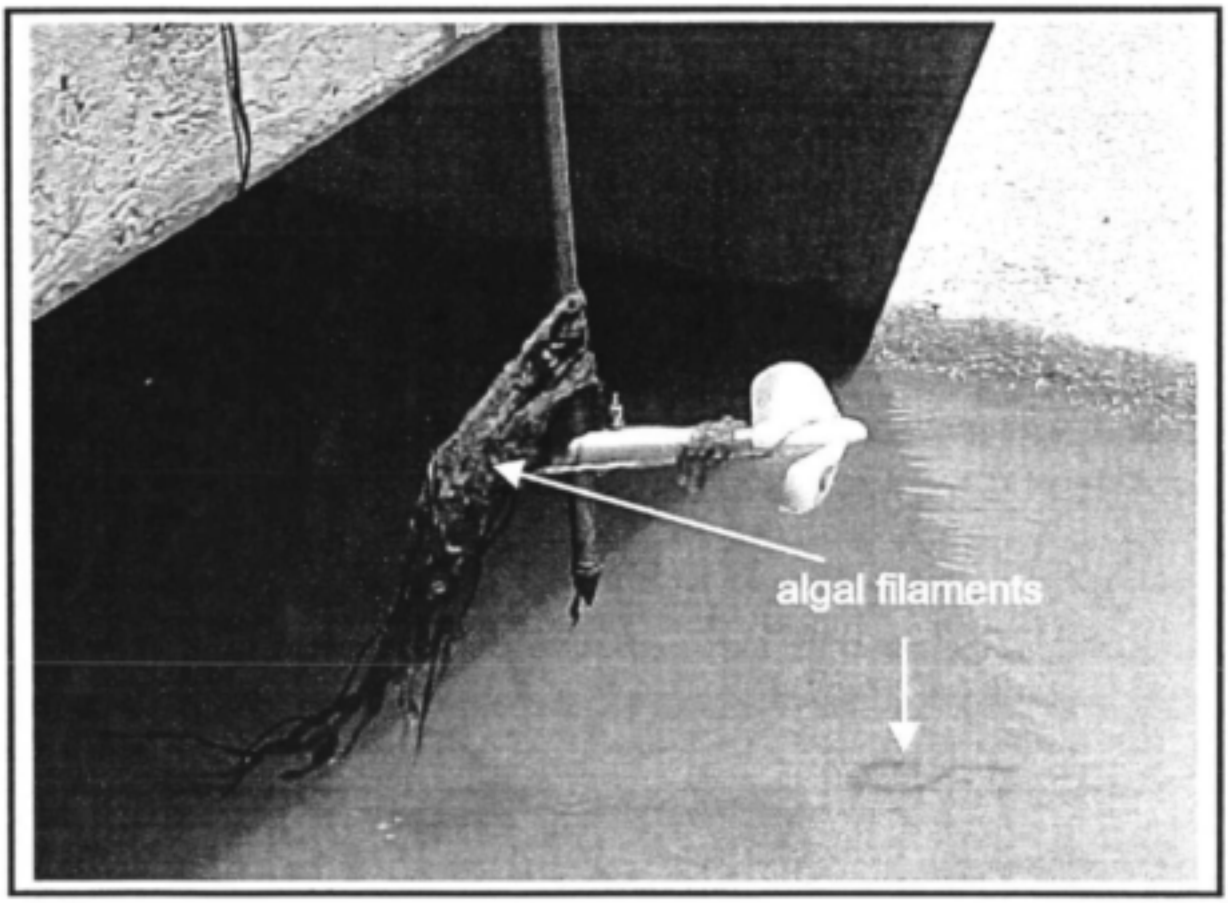


Figure 3.5: Filamentous algae *(Cladophora glomerata)* tangled around the propeller of a flow meter during flow velocity measurements in the Ramah Canal System.

3.3.2 Site selection for flow measurement in the Ramah Canal System:

The site selection for the different current gauging sites and flow distribution sites were pre-determined with the following aims:

- Characterizing each of the three sections of the Ramah Canal System by measuring the flow velocity at the upstream and downstream reaches of each section.
- Establish the flow velocity distribution, horizontally and vertically at each measuring site in order to calculate the mean, minimum and maximum flow velocities at each measuring site.
- Determine the impact of obstructions in the Ramah-3 Canal on the flow velocities by flow measurements upstream and downstream of these obstacles.
- Evaluate all the above-mentioned information to establish the adaptability of sterile grass carp to this artificial environment.

The final selection for the sites, especially for the current gauging sites, were done according to the methodology as set out in paragraph 3.3.1.4.

3.3.3 Operational teams:

Because current gauging is a time-consuming process, it was decided to make use of four teams that operate independently from each other. One team was assigned to each of the three sections of the Ramah Canal System, and the fourth team was responsible for the measurements at the different obstructions in the Ramah-3 Canal. The latter was used as experimental site for sterile grass carp stocking.

3.3.4 Equipment for flow measurement:

Each team was equipped with identical flow measurement equipment, as listed in Table 3.2.

TABLE 3.2: The equipment used for flow measurements.

FLOW MEASUREMENT EQUIPMENT	SURVEYING EQUIPMENT
OTT C20 Current Meter with rods	Level
OTT Z30 & OTT Z215 Counter	Tripod
Gauge plates	Staff Gauge
50m measuring tape	Staff Bubble
5m measuring tape	
Shovel	

The flow velocity meter that was decided on to do current gauging with, was the OTT-C20 Current Meter. This instrument is well suited for low flow conditions. The OTT-C20 Current Meter is equipped with a 125 mm-diameter propeller, and is fitted to a ranging rod with 0.1m increments, and a total length of 3 meters.

A OTT-Z30 and OTT-Z215 counter was used with the OTT-C20 Current Meter that has 30-second time intervals, which made it possible for observations over a 30 and 60 seconds time frame. Each current meter and propeller have however, their own unique number and formula (Table 3.3) that were assigned to it for calibration purposes. These formulas are used to convert the individual instruments' revolutions measured in a specific time frame, to point velocity.

A clamp that fits on a bridge rail or super was designed to ensure that the instrument is in the correct position and depth, and that the ranging rods are absolutely vertical.

3.3.5 <u>Chosen methods for flow measurement:</u>

The current gauging method that was decided on for this project was a combination of the Two-point and Six-tenths Method. Two factors that influenced this decision were the available time to conduct the fieldwork and the character of the different canal sections.

The Two-point Method delivers the best results in the shortest time possible for current gauging. Other methods like the five and six point are more accurate but are also much more time-consuming. The average time span it took to complete a current gauging using the two-point method was about 2 hours at the Ramah canals. If the Five or Six-point Methods were used it would have taken up to three or four times as long.

TABLE 3.3: Calibration formulas for the different OTT-C20 Current meters used during the survey.

SITE	INSTRUMENT NUMBER	PROPELLER NUMBER	CALIBRATION FORMULA
Ramah-1 Canal			N < 0.66 v= 0.2243 x n + 0.020
In- and outflows	82770	1-87103	N < 0.66 v= 0.2440 x n + 0.007
Ramah-2 Canal			N < 0.67 v = 0.2216 x n + 0.023
In- and outflows	70121	1-69849	N < 0.67 v = 0.2455 x n + 0.007
Ramah-3 Canal			N < 0.81 v = 0.2267 x n + 0.031
In- and outflows	117477	1-112639	N < 0.81 v = 0.2477 x n + 0.014
Ramah-3 Canal			N < 0.81 v = 0.2267 x n + 0.031
Obstructions	117474	1-112638	N < 0.81 v = 0.2477 x n + 0.014

The difference in character (capacity and depth) of the different sections in the Ramah Canal System were also a deciding factor. The methods that were used to determine flow velocities have all restrictions especially with the minimum flow depth. The current gauging were performed in such a manner that the first part of the section was done by the Six-tenths Method until a depth of 0.750m was reached and then the Two-point Method was used.

3.3.6 WATER LEVEL MEASUREMENTS

Gauge plates were installed at each flow velocity-measuring site to determine any fluctuations in the water level during the current gauging. The water levels are important to establish if the water level is constant and to compare the different current gauging with each other. Electronic data loggers (STS Pressure Transmitter) were also used to gather water level data during the current gauging at the different sites.

3.4. RESULTS AND DISCUSSION

3.4.1. Conditions during period of flow measurements:

The flow in the Ramah Canal System was approximate 50% of the canal capacity during the first day of flow observations (04 December 2001). Although the flow was constant, strong winds and thunderstorms influenced the flow measurements. The wind factor also influenced the flow velocity in such away that velocities measured on the left bank (facing down stream) were found less than on the right bank.

After the heavy rains on the 4th of December 2001, the flow in the Ramah Canal System fluctuated from the 5th of December to the 6th December 2001, between 90% and 110% of the canal capacity. The flow in each of the three canal reaches was therefore not constant due to the overflow conditions experienced at the time of measurement. The already full flow conditions, high algal infestations *(Cladophora glomerata)*, with additional storm water that drained into the canal system because of the previous night's rainfall, were the obvious reasons for the overflow.

To prevent structural damage to the conduits of the system, the scheme manager reduced the outflows from the two balancing dams as a precautionary measure. This action provides the ideal situation to characterize both medium and high flow conditions in the Ramah Canal System.

3.4.2 Flow distribution in the Ramah-1 Canal:

Flow velocities in the 17.3 km long Ramah-1 Canal was measured at its intake, downstream of the Scheiding Pump Station and upstream of its outlet to Balancing Dam No. 1 (near the end point of the Ramah-1 Canal)(Figure 3.1). Flow velocity distribution patterns were investigated in the Ramah-1 Canal with a design capacity of 9.6 m^3/s, both under medium (2 - 2.4 m^3/s) and high (4.7 – 5.2 m^3/s) flow conditions. The results of the flow velocity measurements and flow distribution patters are presented in figures 4.6 and 4.7, respectively.

Due to wind interference, lower flow velocities were measured at the left bank of the Ramah-1 Canal, downstream of the intake, than at the right bank. At this measuring site, which represents the upstream reach of the Ramah-1 Canal, flow velocities from a minimum of 0.30 m/s to a maximum of 0.72 m/s were measured under medium flow conditions (~ 2.4 m^3/s)(Figure 3.6).

As could be expected, the areas were the lowest flow velocities where measured, were situated near the sides and bottom of the canal due to friction (adhesion forces) between the water and the canal lining. The area of highest flow velocity was found to be in the middle of the cross-section of the canal. The reason for the higher flow velocities measured in the middle section of the canal is that the water in the middle of the canal is only decelerated by its own cohesion forces.

During high flow conditions (5 - 5.2 m^3/s), the minimum flow velocity measured at the upstream flow velocity measuring site was 0.52 m/s and the highest 0.93 m/s. The minimum flow velocity was measured near the left bank, relatively near the bottom of the canal, and the highest flow velocity near the middle of the canal. ***The maximum flow velocity of 0.93 m/s was also the highest flow velocity recorded in the whole of the Ramah Canal System.***

At the downstream flow measuring site of the Ramah-1 Canal, just upstream of Balancing Dam No. 1, a minimum flow velocity of 0.19 m/s and maximum flow velocity of 0.31 m/s was measured under medium flow (~ 2 m^3/s) conditions. Under high flow (4.78 m^3/s) conditions, the minimum flow velocity increased to a value of 0.35 m/s and the maximum flow velocity to a value of 0.65 m/s respectively.

3.4.3 Flow distribution in the Ramah-2 Canal:

The flow velocity distribution pattern of the Ramah-2 Canal was characterized by flow measurements at its intake, downstream of Balancing Dam No. 1 (FSC = 340 000 m^3), and upstream of its outlet to Balancing Dam No. 2 (FSC = 248 000 m^3). The Ramah-2 Canal has a design capacity of 4.2 m^3/s, which is 56% less than the capacity of the Ramah-1 Canal. Flow velocity distribution patterns were investigated under medium (~ 1.4 m^3/s) and high (~ 3.65 m^3/s) flow conditions.

At the flow velocity measuring site downstream of Balancing Dam No. 1, which represents the upstream reach of the Ramah-2 Canal, flow velocities from a minimum of 0.33 m/s to a maximum of 0.57 m/s were measured under medium flow (1.39 m^3/s) conditions (Figure 4.8). As could be expected, the areas were the lowest flow velocities where measured were situated near the sides and bottom of the canal due to friction of the canal sides. The area of highest flow velocity was found to be in the middle of the cross-section ranges.

When looking at the flow distribution patterns represented in figure 3.9, for the upstream reach of the Ramah-2 Canal under medium flow conditions, it is interesting to note that more than 50% of the cross-sectional area of the canal has flow velocities of lower than 0.5 m/s. Under high flow (3.84 m^3/s) conditions, the situation changes to a minimum flow velocity of 0.38 m/s near the right bank of the canal, to a maximum flow velocity of 0.70 m/s in the middle-left side of the canal (Figure 3.8).

Flow velocities from a minimum of 0.52 m/s to a maximum of 0.73 m/s were measured under high flow (2.60 m^3/s) conditions (Figure 3.8) at the measuring site upstream of Balancing Dam No. 2, which represents the downstream reach of the Ramah-2 Canal. The area of highest flow velocity was found to be near the middle-right of the cross-section.

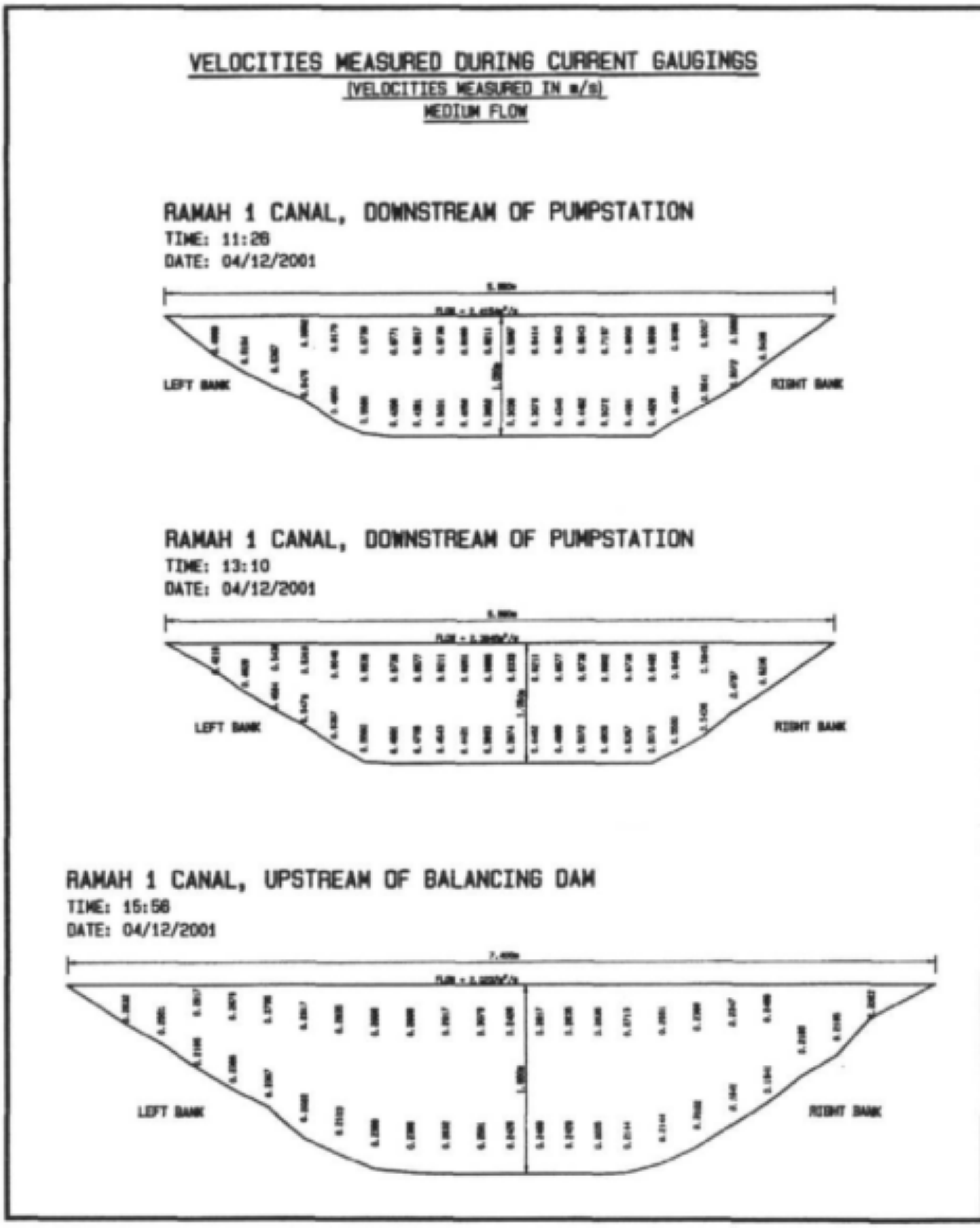


Figure 3.6a: Flow velocities measured at the intake and outflow of the Ramah-1 Canal during medium and high flow conditions.

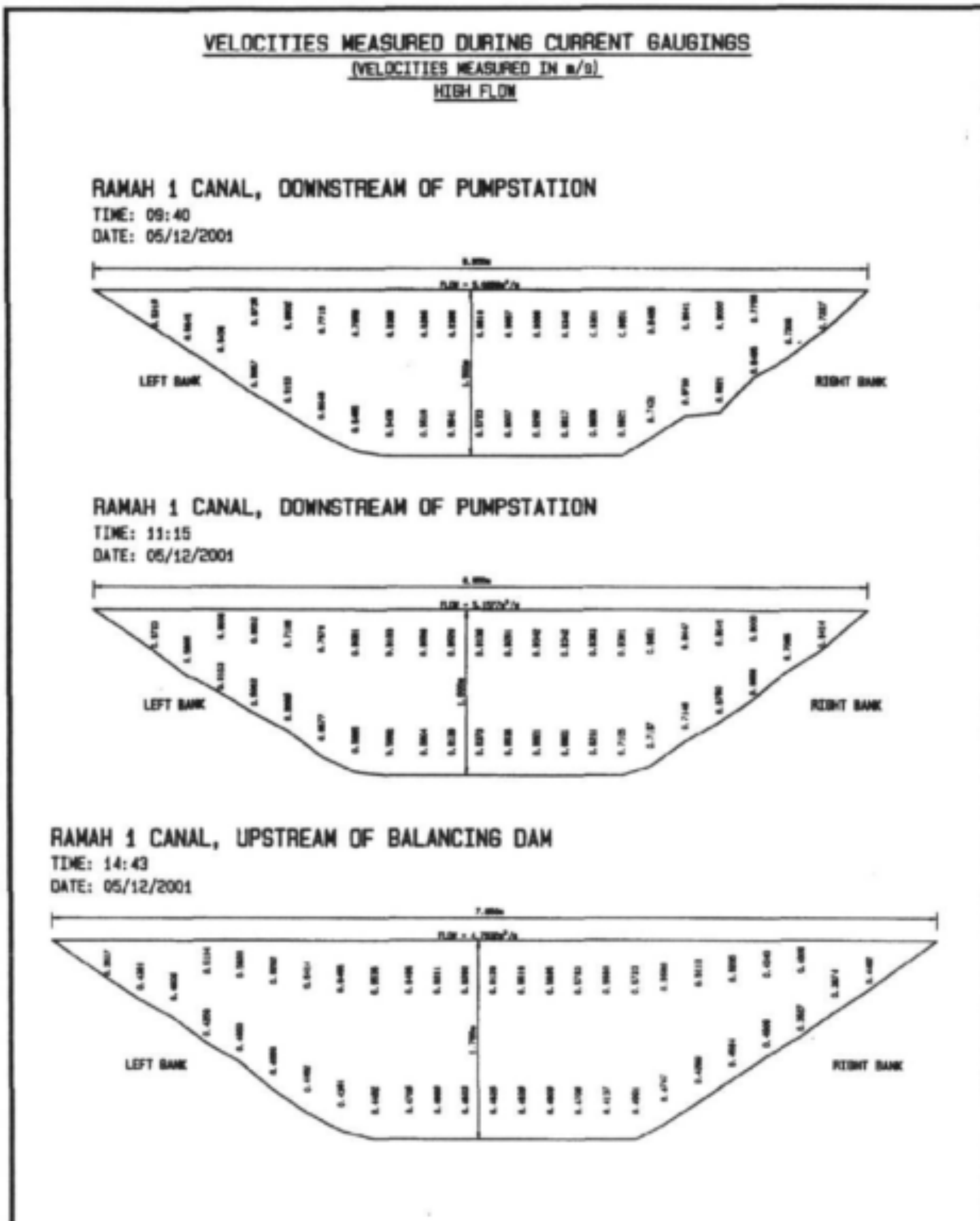


Figure 3.6b: Flow velocities measured at the intake and outflow of the Ramah-1 Canal during medium and high flow conditions.

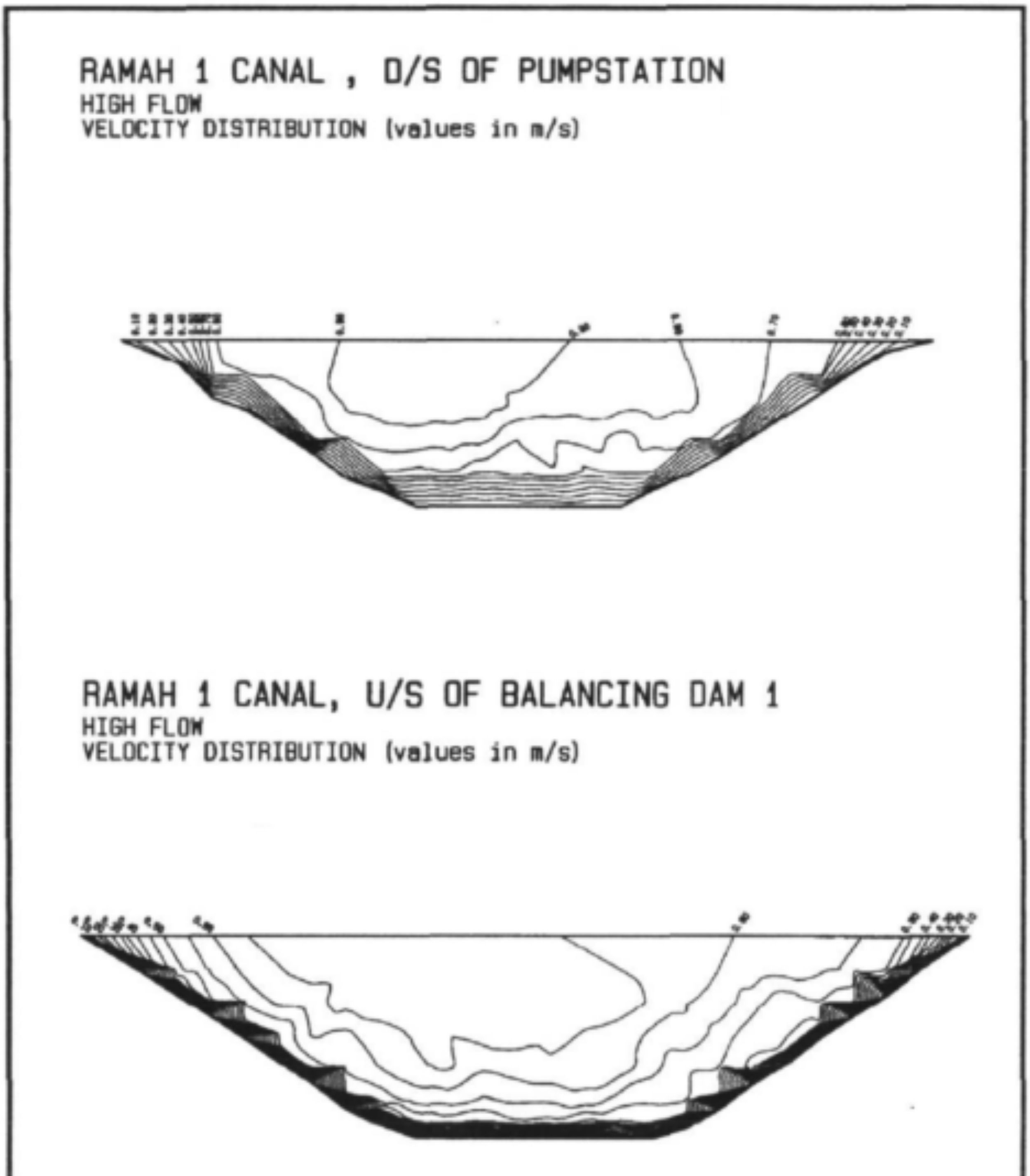


Figure 3.7: Flow distribution patterns at the intake and outflow of the Ramah-1 Canal calculated at high flow conditions.

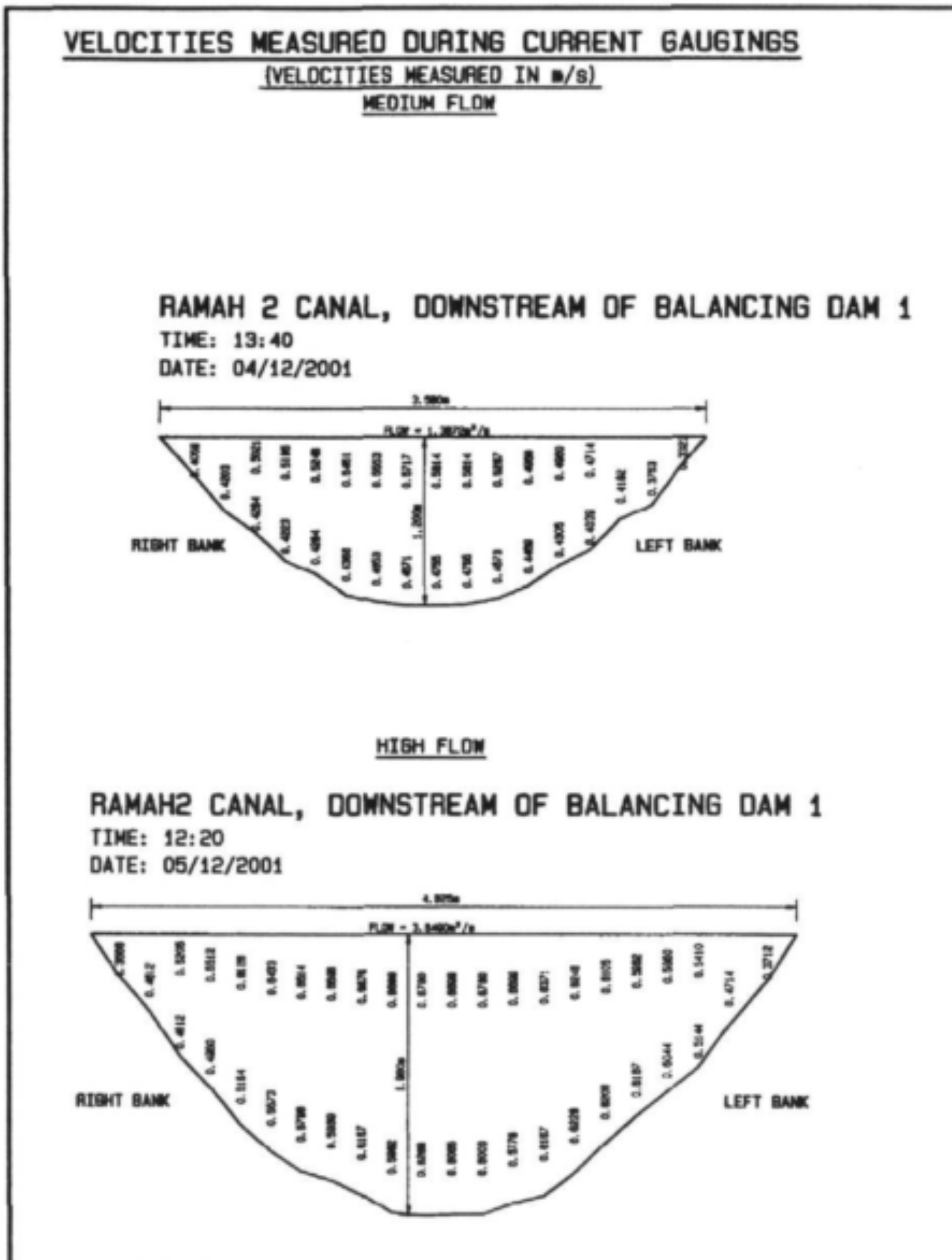


Figure 3.8a: Flow velocities measured at the intake and outflow of the Ramah-2 Canal during medium and high flow conditions.

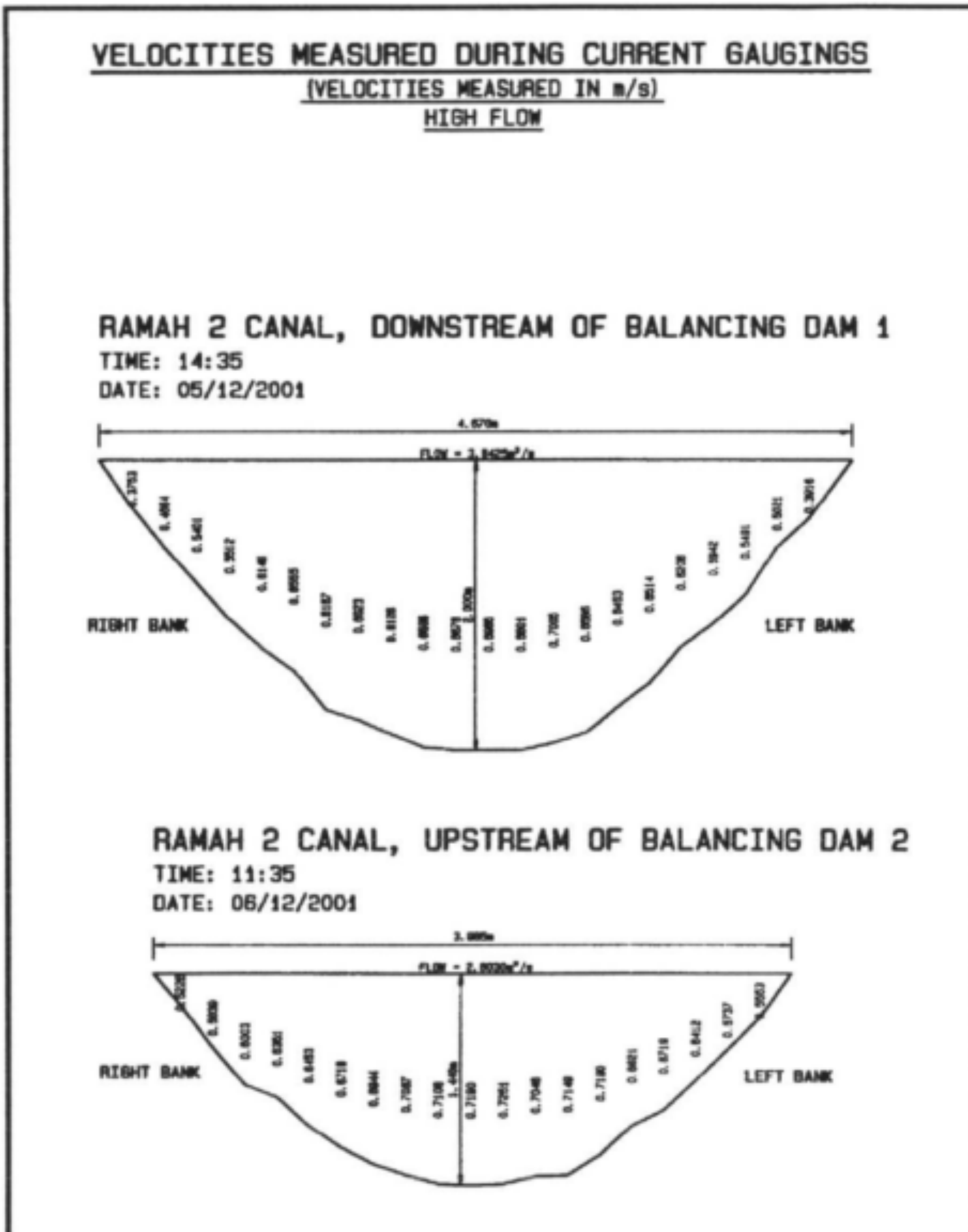
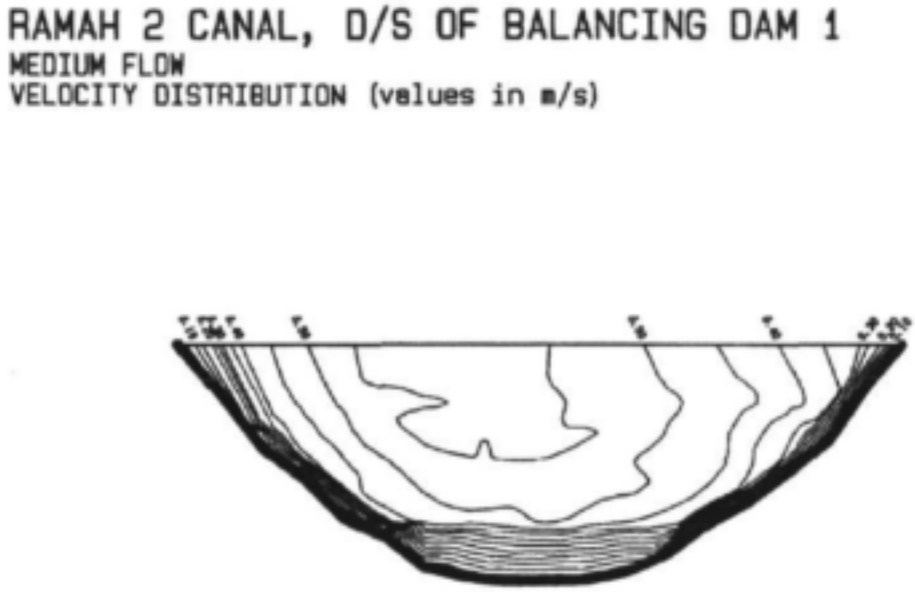


Figure 3.8b: Flow velocities measured at the intake and outflow of the Ramah-2 Canal during medium and high flow conditions.



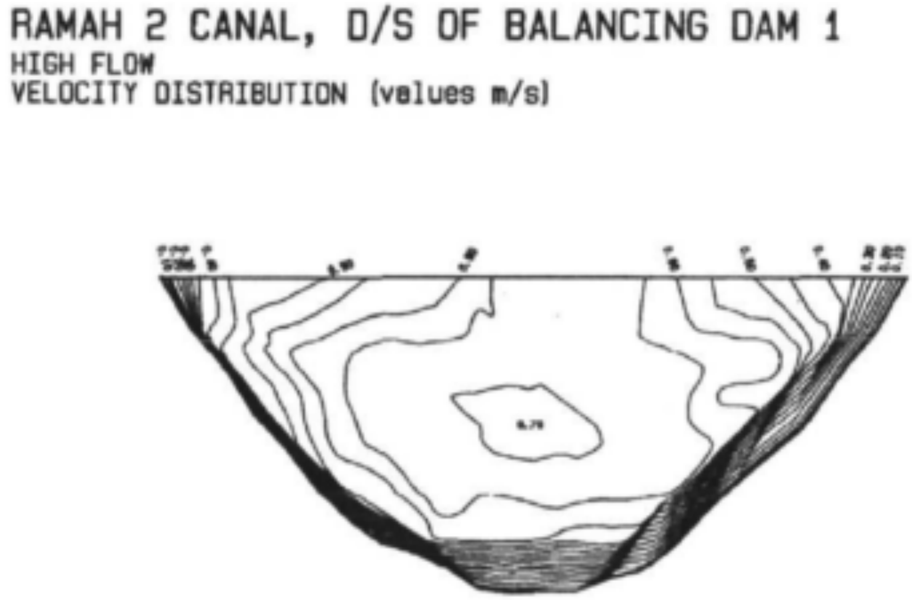


Figure 3.9: Flow distribution patterns at the intake of the Ramah-2 Canal calculated at medium and high flow conditions.

3.4.4 Flow distribution in the Ramah-3 canal:

As the Ramah-3 Canal was utilized for the experimental work to evaluate the effectivity of triploid grass carp (*Ctenopharyngodon idella* Val.) on filamentous algae (*Cladophora glomerata*), flow distribution in this canal reach was measured more intensively than the Ramah-1 and Ramah-2 canals. Five sites for the determination of flow velocity were selected on the 24 km long Ramah-3 Canal. Flow velocity distribution patterns were characterized at the intake to the canal (downstream of Balancing Dam No. 1), near the outlet, and more or less in the middle of the canal at Super-184 (a super-elevated canal) (Figure 3.1). To establish the impact of civil obstructions in the canal on flow distribution through the cross-section of the canal, additional flow measurements were taken at locations up and downstream of a long-weir (Figure 3.15) and a roll-grid (Figure 3.16).

3.4.4.1 Flow conditions in the open canal areas:

Flow velocities were measured in the Ramah-3 Canal at medium (~ 0.87 - 0.92 m^3/s) and high (~ 1.3 - 1.4 m^3/s) flow conditions (Figures 3.10 and 3.11). The Ramah-3 Canal is a relative small canal with a cross-section surface span of approximately 3 meters and a maximum depth of 1.8 meters. Considering these dimensions, flows of 0.8 m^3/s could be regarded as medium flow conditions and flows of 1.4 m^3/s up to 1.48 m^3/s, as high flow conditions. The design capacity of the Ramah-3 Canal is 1.48 m^3/s.

The minimum flow velocity measured at the *canal intake* (downstream of Balancing Dam No. 2) under medium flow conditions (0.87 m^3/s) was found less than 0.40 m/s. This value was measured near the left bank of the canal. As mentioned earlier, lower flow velocities were measured at the left bank of the canal, at several measuring sites throughout the Ramah Canal System, due to wind interference during the period of measurement. Under high flow conditions (1.40 m^3/s) the minimum flow recorded was 0.41 m/s at exactly the same location. This is a marginally higher flow velocity as measured under medium flow conditions, although the flow was found 40% higher. The maximum flow velocities recorded under medium and high flow conditions were 0.63 and 0.73 m/s respectively.

Near the end point of the Ramah Canal System, just upstream of the Ramah-3 Canal outlet to the drainage canal, recorded flow velocities were found to vary from as low as 0.22 m/s to 0.42 m/s under high flow conditions. The end point of the canal is structural the smallest in dimensions. A high flow outlet of 1.4 m^3/s at Balancing Dam No. 2, only resulted in a flow of ~ 0.42 m^3/s at the end of the canal (Figure 3.12).

Flow distribution patterns were also established for the middle reach of the Ramah-3 Canal (Figure 3.11). At the flow measuring site (beneath Super-184 - a super-elevated canal), minimum flow velocities of 0.37 m/s were measured under medium flow conditions (0.9 m^3/s), and maximum flow velocities of 0.74 m/s at high flow conditions (1.4 m^3/s).

3.4.4.2 Flow conditions at typical obstructions in concrete-lined irrigation canals:

To establish whether there exists niches of very low flow velocities in a concrete-lined irrigation canal where fish can rest, flow velocities were measured up and downstream of two typical canal obstructions. Flow distribution patterns were established at both a long-weir and a roll-grid in the Ramah-3 Canal (Figure 3.1).

3.4.4.2.1 <u>Flow conditions at long-weir:</u>

The structure of a typical long-weir is shown in Figure 3.15. The purpose of a long-weir in a canal system is to regulate the water level at an outlet sluice or pipe, in order to generate a uniform flow through the outlet structure. Long-weirs can be totally or partly (if equipped with a water level control sluice) submerged. The long-weir causes a damming effect upstream, which in fact creates a rise in water level and has a backwater effect that reduces the approach velocity towards the long-weir itself.

The distribution of flow up and downstream of the long-weir is illustrated in Figure 3.14. Measurements were recorded only during high flow conditions (1.4 m^3/s released at the intake to the Ramah-3 Canal). Very low flow conditions were recorded upstream of the

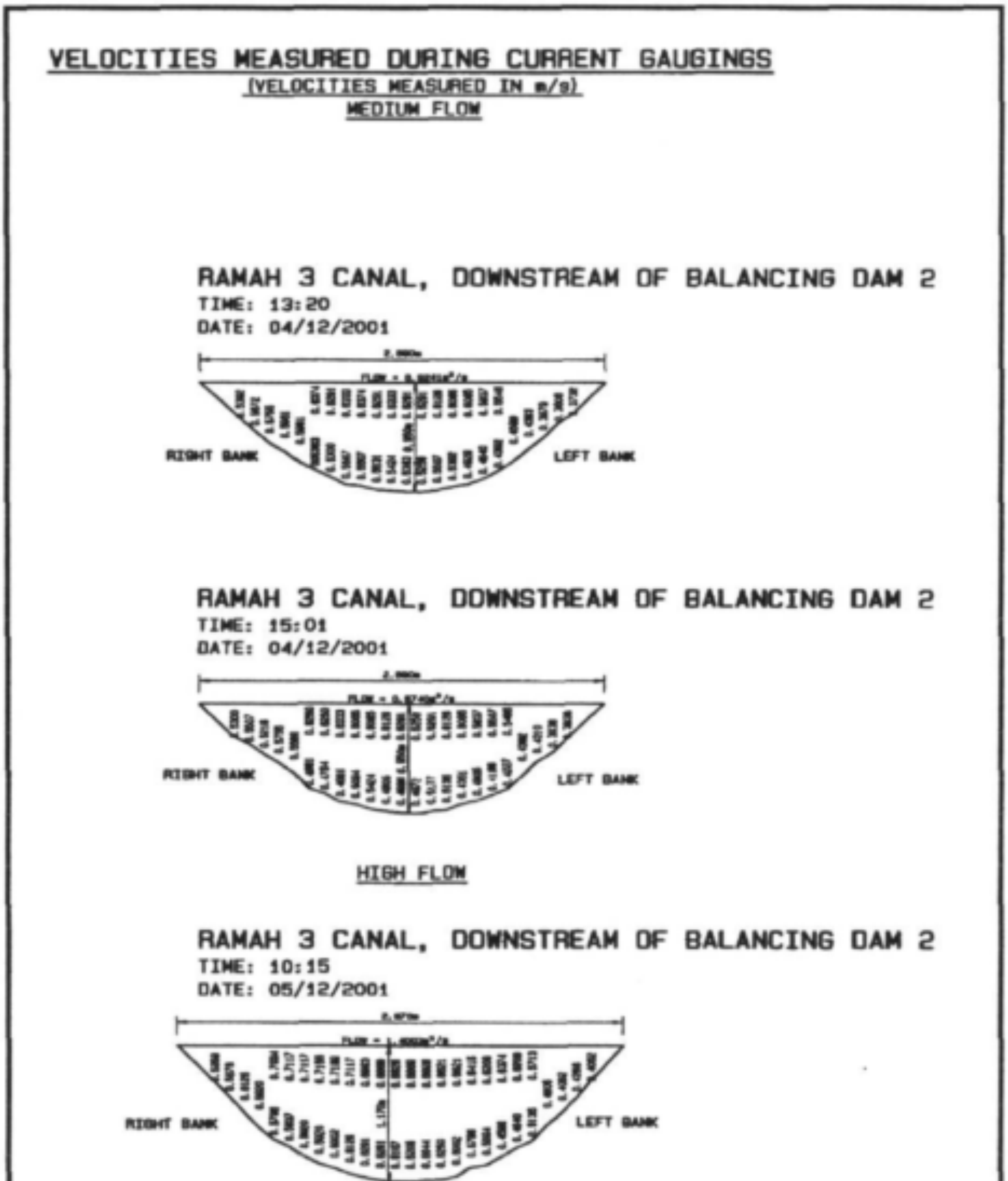


Figure 3.10a: Flow velocities measured at the intake and outflow of the Ramah-3 Canal during medium and high flow conditions.

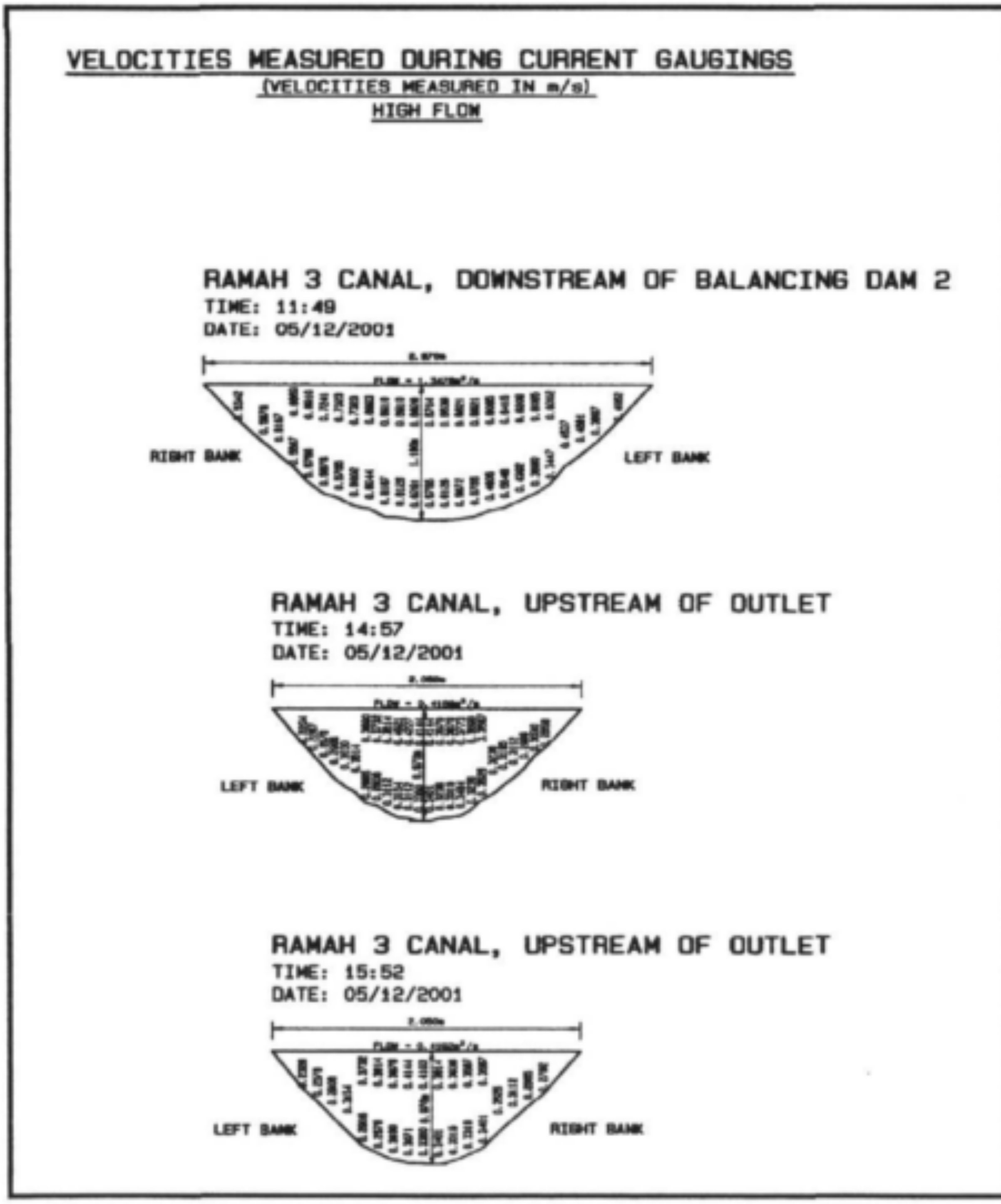


Figure 3.10b: Flow velocities measured at the intake and outflow of the Ramah-3 Canal during medium and high flow conditions.

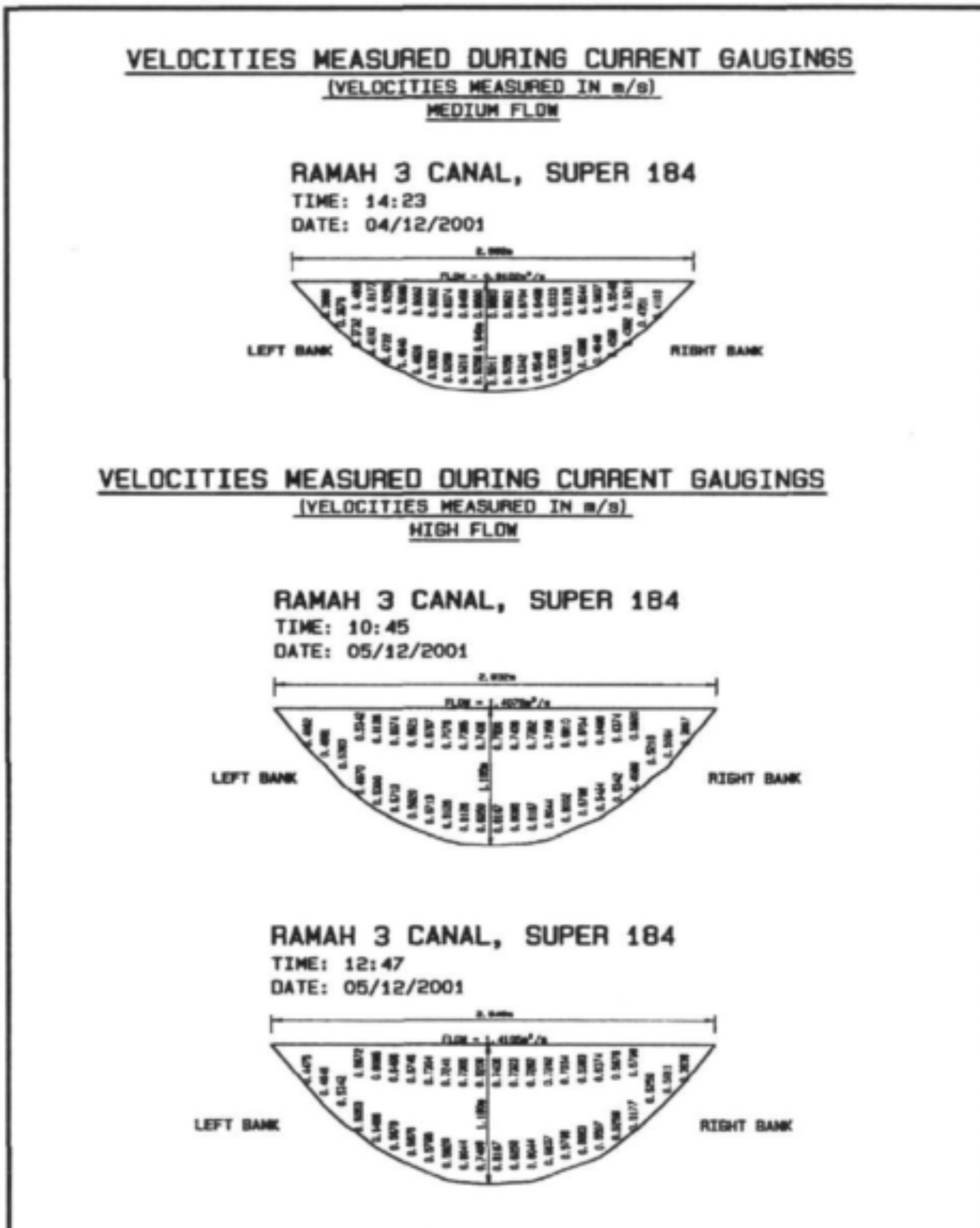


Figure 3.11: Flow velocities measured at the middle reach of the Ramah-3 Canal (Super-184) during medium and high flow conditions.

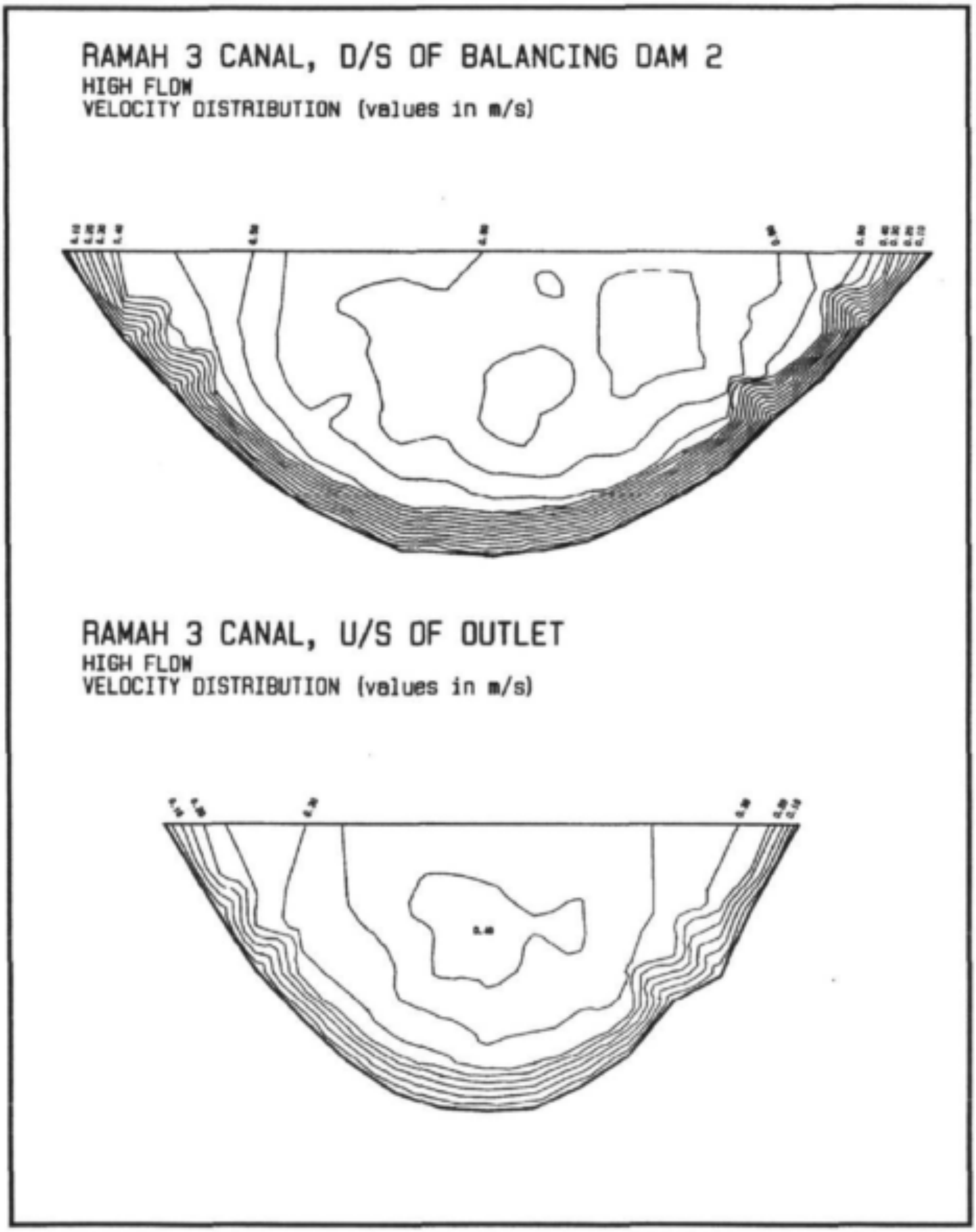


Figure 3.12: Flow distribution patterns at the intake and outflow of the Ramah-3 Canal calculated at high flow conditions.

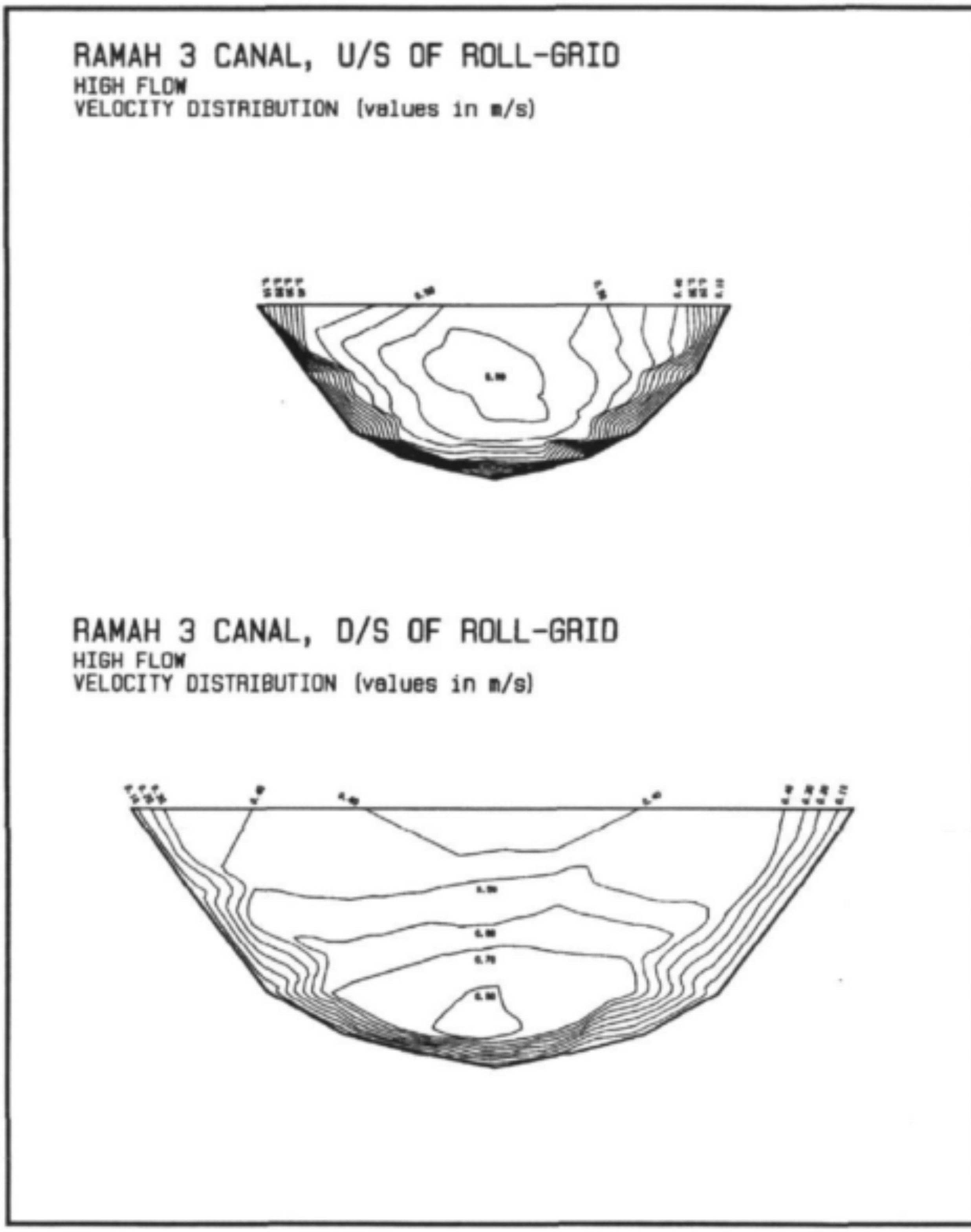


Figure 3.13: Flow distribution patterns at the roll-grid calculated under high flow conditions.

long-weir, ranging from 0.10 to 0.33 m/s. More than $^2/_3$ of the cross-section area of the canal upstream of the long-weir has a flow velocity of lower than 0.3 m/s.

As can be expected, slightly higher flow velocities were recorded downstream of the long-weir. Minimum flow velocities of 0.1 m/s were measured near the sides of the canal, whilst the maximum flow velocity of 0.48 m/s was measured near the middle of the canal at a point of 0.38 meter below the water surface.

3.4.3.2 Flow conditions at roll-grid:

Roll-grids are used in open conduits to prevent debris and algae from entering outlet structures such as pipes, with the aim to reduce the possibility of blockages in these structures (Figure 3.16). Some roll-grids are designed to remove free floating algal filaments and debris (such as roll bushes) from the water and throw it on a platform or conveyer belt, from where it is removed out of the system. Other roll-grids merely prevent the biomass from entering the conduit they are protecting.

The flow pattern at the roll-grid was found typical of that of an obstruction that is not totally submerged. As in the case of the long-weir, the roll-grid also causes a damming effect upstream of the structure. This creates a rise in the water level and as a result, a reduction in the approach velocity of the water column towards the roll-grid.

The distribution patterns of flow up and downstream of the roll-grid are illustrated in Figure 3.13. Measurements were recorded only during high flow conditions (1.4 m^3/s released at the intake to the Ramah-3 Canal). Upstream of the roll-grid a maximum flow velocity of 0.65 m/s was recorded at a micro location of 2.315 meters from the left bank and a depth of 0.450 meters below the water surface.

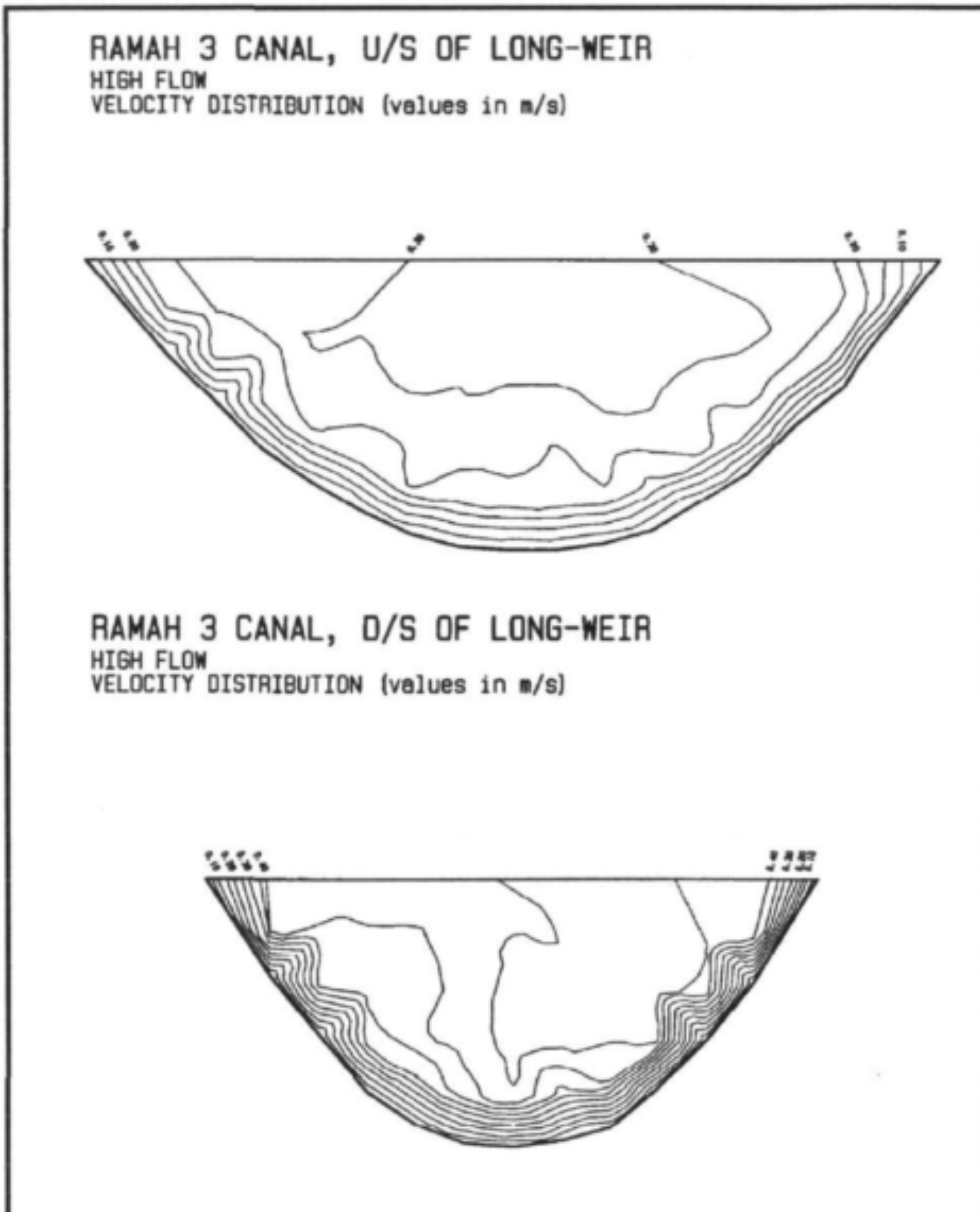


Figure 3.14: Flow distribution patterns at the long-weir in the Ramah-3 Canal calculated at high flow conditions.

Figure 3.15: An example of a typical long-weir in the Roodeplaat Canal, North of Pretoria.

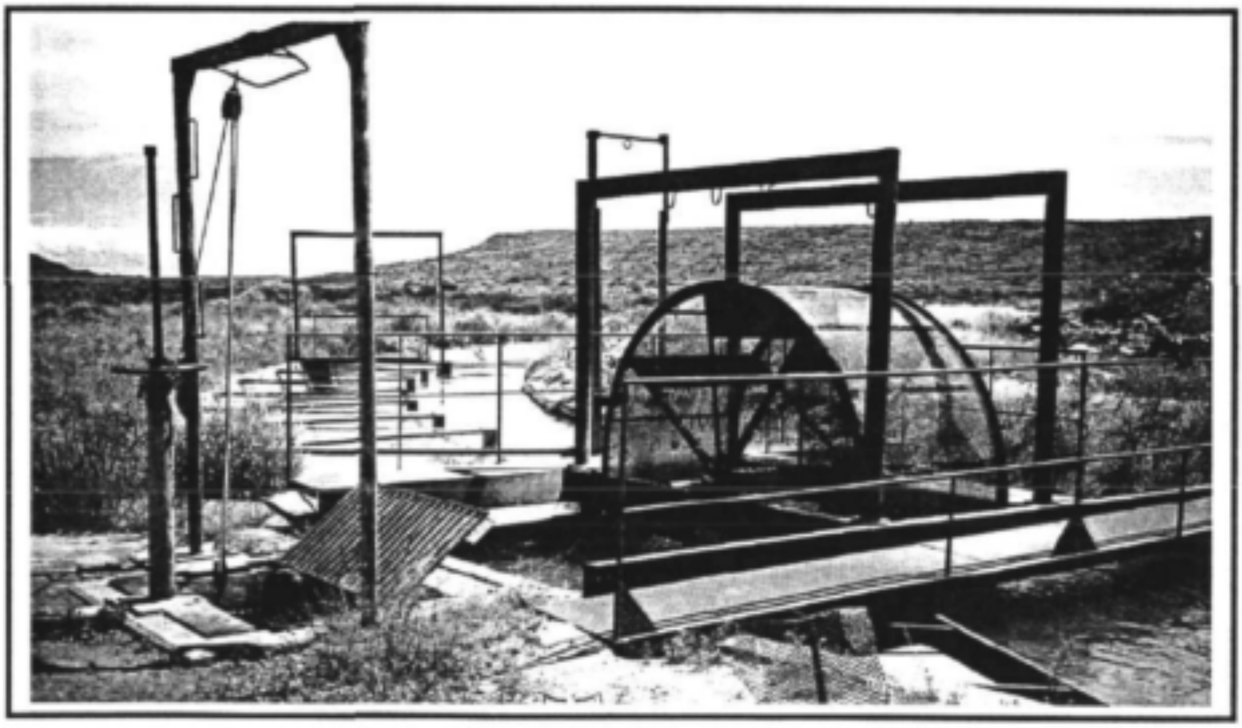


Figure 3.16: An example of a typical roll-grid, in the Ramah Canal System.

Downstream of the roll-grid much higher velocities were measured on the bottom of the canal, between the bottom end of the roll-grid and the canal lining. At this point water is forced through a narrow opening between the roll-grid and the bottom of the canal. A flow velocity of 0.81 m/s was measured at this point. At the middle and top of the canal, back flow was found present for about 4 to 6m downstream of the structure. Flow velocities in this area fluctuated between 0.4 and 0.6 m/s.

3.5 CONCLUSIONS AND MANAGEMENT IMPLICATIONS

3.5.1 Flow distribution patterns and velocity in the ramah canal system:

The maximum flow velocity measured in the Ramah Canal System over a three-day period never exceeded 1 m/s. The average flow velocities in each of the sections were found to be nearer to 0.6 m/s than 0.8 m/s, as was speculated before the commencement of the investigation.

The highest and lowest flow velocities recorded in the three sections of the Ramah Canal System were the following:

- *Ramah-1 Canal:* The minimum flow velocity recorded was 0.19 m/s just upstream of the canal outlet and the maximum flow velocity recorded was 0.93 m/s near the intake (downstream of Scheiding Pump Station). The impact of civil structures in this canal was not evaluated as it fell outside the experimental area.

- *Ramah-2 Canal:* The minimum flow velocity recorded was 0.33 m/s, and the maximum flow velocity recorded was 0.72 m/s (outflow to Balancing Dam No. 2). This canal also fell outside the experimental area, and therefore the impact of civil structures on flow velocity was not evaluated.

- *Ramah-3 Canal:* The minimum flow velocity recorded was 0.10 m/s and the maximum flow velocity recorded was 0.81 m/s. The latter was measured in the accelerated flow underneath the roll-grid. The slowest movement of water was measured upstream of civil structures such as long-weirs and roll-grids.

The highest flow velocities were found in the open canal areas near the middle of the cross-section through the conduit, whilst the lowest flow velocities were recorded on the surface of the canal lining near the sides and the bottom. Specific locations of low flow were identified upstream of canal obstructions, such as long-weirs and roll-grids.

3.5.2 The suitability of a concrete-lined irrigation canal as grass carp habitat:

The assumptions of some local environmental scientists that South African concrete-lined canals would be too fast flowing for grass carp to survive and/or be effective as biological control agent of aquatic weeds, was proven to be unfounded. According to colleagues at the Center for Aquatic Plants at the University of Florida, flow velocities of 1.0 to 1.5 m/s are regarded as "usually a good flow rate for grass carp" Stocker (Pers. Comm., 1997).

Stocker (Pers. Comm., 1997) who used sterile grass carp (produced at their own facility at the University of Florida) for 18 years to control aquatic weeds (hydrilla, Eurasian water milfoil, pondweeds, etc.) in earth-lined and concrete-lined canals in California, has noticed that water velocities greater than about 2 m/s usually sweep the grass carp downstream. This will occur unless there are in-stream areas of slower flow that the fish can find (Stocker, pers. Comm., 1997). Stocker (Pers. Comm., 1997) also found that if flow rates are variable, and the fish can move freely, they will move back upstream after the flow rate diminish.

At the relatively low flows (< 1 m/s) measured in the Ramah Canal System, the research team was confident that the fish would migrate up and downstream with ease. This assumption was verified during the field tests in the Ramah-3 Canal where sterile grass carp was used to control the filamentous algae, *Cladophora glomerata*, effectively (discussed in Chapter 4 of this document).

Obstructions, such as long-weirs and roll-grids in the canal, will provide adequate *in situ* resting areas for the fish. Very low flow velocities of less than 0.2 m/s was measured upstream of these obstructions. These obstructions generate the ideal low flow niches for the fish to rest when they are not feeding. Culverts and siphons could provide shelter and possible habitat for survival during short dry periods, providing that oxygen depletion does not become a problem. Structures over the canal, such as bridges and supers (super-elevated canals) will provide *in situ* areas of protection against predators of the fish.

The general conclusion can therefore be made that flow velocities throughout the entire Ramah Canal System are well within the tolerance range of sterile grass carp to survive and to operate effectively as biological control agent on the aquatic weeds. As gradients of medium and large South African irrigation canals are typically within the 1:1 000 to 1:5 000 range, flow velocities encountered under normal conditions of flow will vary between 0.8 and 1.5 m/s (Butler and Legge, 1980).

3.5.3 Possible management implications:

The ability of the fish to move freely through the target canal system, is an important consideration. Many gravity flow systems, for instance, allow fish to move downstream over structures, but restrict upstream movement back up over the same structures. This could very quickly lead to downstream accumulation.

Balancing dams: As balancing dams are placed at low geographical locations in a canal system, in and outlets are usually high concrete structures equipped with sluices. In many cases these structures will not allow fish to migrate between the balancing dam and the canal. To overcome this obstacle fish would have to be stocked up and downstream of balancing dams. If the impoundments are infested with aquatic weeds, these structures should be stocked separately from the conduit areas, and calculations on stocking densities should be adapted to lenthic conditions.

Roll-grids: Theoretically the fish would be able to negotiate the flow velocities (0.8 m/s) underneath the roll-grid to migrate up or downstream. The possibility exists however, that the associated noises and vibrations of the continuous rotating roll-grid will discourage the fish to move through the structure. If roll-grids prove to restrict movement, inline fishways could be the answer to this potential problem.

Long-weirs: These structures will not restrict grass carp movement at all, and will act as resting-place for the fish.

Siphons: Siphons and culverts will definitely act as hiding places for the fish. During periods of no flow in the canal (dry periods for maintenance) fish do tend to accumulate in siphons, as these structures does not drain completely. Overcrowding of fish in small or short siphons could lead to oxygen depletion, which in turn can result in a fish kill.

Mechanisms and possible adaptations to a canal system to overcome operational problems in the application of sterile grass carp as tool for the biological control of aquatic weeds in canal systems, will be discussed in Chapter 6 of this document.

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CHAPTER 4

Technical note:

To be submitted for publication in Water SA.

BIOLOGICAL CONTROL OF THE FILAMENTOUS ALGAE, *CLADOPHORA GLOMERATA,* IN CONCRETE-LINED IRRIGATION CANALS WITH TRIPLOID GRASS CARP, *CTENOPHARYNGODON IDELLA (VAL).*

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Abstract

The infestation of concrete-lined canals with aquatic weeds (i.e., pondweeds and algae) give rise to substantial operational problems and water losses in South African irrigation schemes.

Sterile or triploid grass carp (*Ctenopharyngodon idella*) was evaluated for its ability to control filamentous algae, *Cladophora glomerata,* in concrete-lined irrigation canals. Experiments were done in the Ramah-3 Canal of the Orange-Riet River Canal System, below the Vanderkloof Dam. It was found that grass carp thrived under these artificial conditions at flow rates ranging from 0.48 to 0.80 meter/second, moving with ease upstream and downstream in a 16 km long experimental section of the Ramah-3 Canal.

Cladophora was efficiently controlled at stocking rates of 3 to 7 fish per km canal. Triploid grass carp retrieved from the canal system after a six-month experimental period were in an excellent physiological condition and displayed a mean weight increase of more than 300%.

The study found that the sterile grass carp controlled the algal biomass in the canal to significant levels. The authors are of the opinion that this bio-control technique will contribute to the current herbicidal and mechanical control programmes of the Department of Water Affairs and Forestry.

4.1 INTRODUCTION

During the past four decades the grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844), has received much attention around the world, primarily owing to its potential for its use as a biological control agent of aquatic vegetation. The fish was first introduced into North America in 1960 in Mexico to control water hyacinth *(Eichhornia crassipes)* (Sutton, 1977). In South Africa the fish was introduced in 1967 into Natal by the Natal Parks Board (Pike, 1974), and later also into the former Transvaal and Transkei (Brandt and Schoonbee, 1980; Schoonbee and Prinsloo, 1984).

The use of grass carp to control aquatic vegetation generated much excitement for two basic reasons: firstly, the cost of stocking phytophagous fish is lower than the cost of herbicidal or algaecide control, and secondly environmentalist groups would prefer to use biological rather than chemical control methods. However, ecologists continued to pose questions as to the wisdom of grass carp introductions and its possible impact on fish communities (Edwards, 1973; Greenfield, 1973). Of particular concern is the possibility of unwanted reproduction (Chilton and Muoneke, 1992). This possibility can however completely be ruled out if triploid (sterile) grass carp is used. Since Malone (1983) announced the successful reproduction of triploid grass carp, the possibility for the uncontrolled spreading and possible negative impacts caused by this species is eliminated.

Nature Conservation authorities in South Africa placed restrictions in 1989 on the use of fertile grass carp to control aquatic weeds. Since then, the stocking of only triploid grass carp was allowed. The responsible use of grass carp as a bio-control agent and the protection of this species for this purpose by future generations is however dependent on the maintenance of strict regulations and effective law enforcement.

In Germiston Lake, South Africa, the biological control of *Potamogeton pectinatus* (pondweed) was first attempted with the only indigenous, freshwater fish which feeds on aquatic macrophytes, the redbreast tilapia, *Tilapia rendalli* (Wager, 1968; Jubb, 1967;

Potgieter, 1974). This species was introduced into experimental enclosures in the lake at a density of one fish/m^2 during 1973. At this density, *T. rendalli* reduced the infestation of *P. pectinatus* within the enclosures and maintained the weed at acceptable levels during summer. However, the programme failed because *T. rendalli* did not survive through winter when water temperatures in the lake dropped to below 10 °C (Schoonbee, 1991).

In contrast, the grass carp is a hardy animal and has a wide tolerance range for temperature extremes. In Arkansas in the U.S.A. for instance, it was shown that grass carp survived under ice during winter followed by a maximum temperature of 35.6 °C in the following summer months (Stevenson, 1965).

Triploid grass carp has been used successfully for more than a decade, for the biological control of aquatic weeds in South African impoundments. The ability however, of grass carp to utilise habitats within concrete-lined canals, at flow rates of 0.5-1.0 m/seconds was questioned. Furthermore the consumption of *Cladophora* species (which is according to Du Plessis and Davidson (1996) the main aquatic weed problem in South African irrigation canal systems) by grass carp, is not well documented. Consequently, from the controversy surrounding these two aspects, this investigation focussed firstly on the ability of triploid grass carp to control *Cladophora* investations, and secondly on its ability to survive under these artificial circumstances.

4.2 MATERIALS AND METHODS

4.2.1 <u>Preparation of triploid grass carp:</u>

Triploidy was induced in grass carp (*Ctenopharyngodon idella*) to obtain sterility according to the procedures of Malone (1983). Triploid fish were identified and selected by erythrocyte nuclear content analysis with a Coulter Counter Multisizer to obtain a 100% triploid stock. Sterile fish were tagged by manually inserting an internal laser etched magnetic tag into the nose of the fish, which can be detected electronically (Willemse and

Steyn, 1994). Tagging was done to verify sterility, and to identify fish from a certain batch. Fish were grown out for a period of one to two years during which it was fed on a diet of *Potamogeton pectinatus* (fennel-leafed pondweed) and commercial fish pellets. On separate occasions tagged fish were translocated to the Ramah-3 Canal below the Vanderkloof Dam. The necessary releasing permits were obtained from the relevant conservation authorities prior to stocking.

4.2.2 Experimental area:

Experiments with triploid grass carp as bio-control agent for *C. glomerata* was conducted in the Ramah Canal System. The Ramah-3 Canal is situated below the Vanderkloof Dam (formerly the P.K. le Roux Dam) in the Free State Province (formerly Orange Free State), near the town of Orania. It receives water from the Vanderkloof Dam via the 112 km long Orange-Riet River Canal (formerly the Sarel Hayward Canal). The system is divided into three sections namely, Ramah-1, Ramah-2 and Ramah-3 canals, which drain back into the Orange River. Ramah-1, -2 and -3 is separated from each other by two separate balancing reservoirs (Figure 4.1).

All bio-control experiments were conducted in the Ramah-3 Canal, a 24 km long, concrete-lined irrigation canal that is 3 metres wide at its widest point, and 1.180 m deep. The canal was divided into two sections that were separated from each other by a vertical bar mechanical grid with 3-cm spaces to contain the fish within a specific section (Figure 4.2). Vertical bar fish grids (Figure 4.5) were also fitted below Balancing Reservoir No: 2 and at the fall out of the Ramah-3 Canal to prevent fish migration.

Division of the Ramah-3 Canal for experimental purposes resulted in a short (8km) and a long (16km) experimental section. Abstraction points in the canal were protected with roll-grids (Figure 4.3) and pivot abstraction grids (Figure 4.4), that were cleaned on a 24-hour basis. The Ramah-3 Canal, supplies irrigation water to mainly wheat and corn farmers that rely on pivot irrigation. This canal is heavily infested with the filamentous algae, *Cladophora glomerata*, and to a lesser extent with pondweed (*Potamogeton pectinatus*).

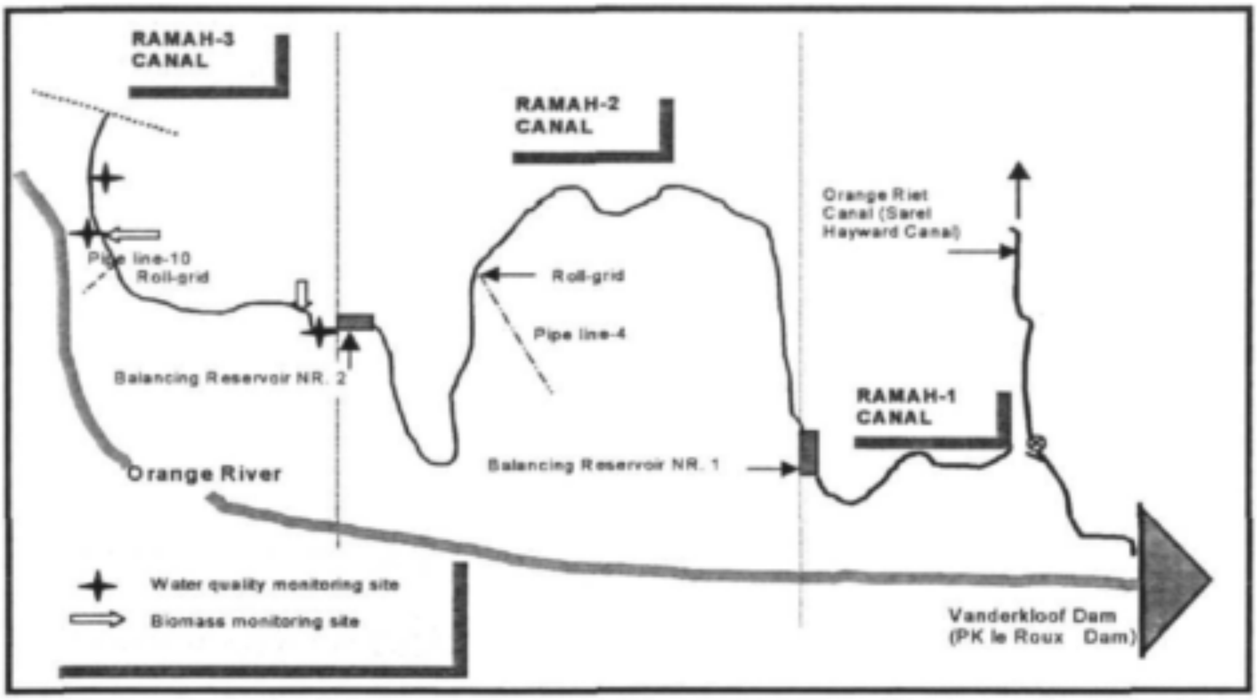

Figure 4.1: A diagrammatic presentation of the Ramah Canal System of the Orange-Riet River Government Water Scheme.

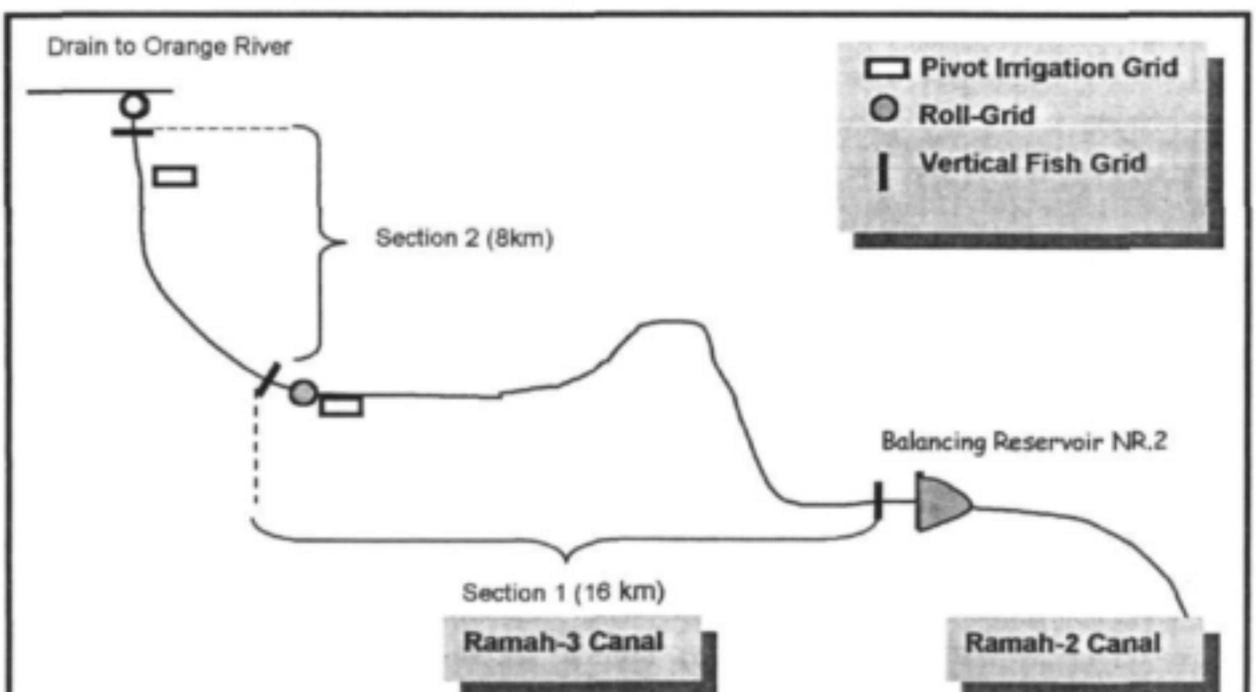

Figure 4.2: Experimental outlay of the Ramah-3 Canal into two sections, separated from each other by vertical fish grids.

4.2.3 Biological control with triploid grass carp:

The effectivity of sterile grass carp as bio-control agent on Cladophora glomerata was evaluated on two occasions from 1998 to 2000. Experiment 1 was executed over a six-month period, from October 1998 to April 1999. The second experiment was done from November 1999 to April 2000.

On 29 October 1998, large (mean weight = 1 930g) triploid grass carp (n=58) were stocked into Section 2 of the Ramah-3 Canal (Figure 4.2). The experimental section was fitted with an upstream and downstream vertical bar fish grid to contain grass carp within the experimental section. Section 2 was 8 km long and served firstly to determine the stocking density and secondly, to identify and mitigate experimental problems associated with the maintenance of the grass carp population in the canal. The feasibility of the implementation and maintenance of a continuous biomonitoring program was also evaluated. The specimens of triploid grass carp were individually weighed prior to stocking. At the end of the experiment on 01 April 1999 when the canal was drained for annual maintenance, grass carp were weighted again and fork lengths were determined.

A year later another stocking (Experiment 2) was done on 17 November 1999 in Section 1 of the Ramah-3 Canal (Figure 4.2). A vertical bar fish grid was installed below Balancing Reservoir NR 2 and between sections 1 and 2 to confine movement to within the experimental area. During this stocking, 52 fish (mean weight = 841g; mean length = 41.13 cm) were enclosed in a 16-km experimental canal (Section 2 of Ramah- 3 Canal). The triploid grass carp were weighed again and the fork lengths determined prior to stocking and again at the end of the experiment, on 24 April 2000 when the canal was drained for annual maintenance.

4.2.4 Fish community structure in the canal:

During the second bio-control experiment in Section 1 of the Ramah-3 Canal, the fish community that survived and thrived in the artificial canal habitat, was documented. Fish, which were small enough to be transported with the current through the 3-cm vertical bar fish grid, were allowed to move through the experimental section. When the canal was drained for maintenance on 24 April 2000, all the fish recovered were identified, weighed and the fork lengths were measured.

Figure 4.3: A photograph of a typical roll-grid in the Ramah Canal System.

4.2.5 *Cladophora* biomass determination and control experiments:

Primary production (algal biomass yield) was determined by two methods. Firstly, biomass deposits on irrigation abstraction grids were measured, and secondly the biomass yield on the canal lining was determined by sampling through the cross section of the canal. The biomass of *Cladophora glomerata* was determined in the control section (without grass carp) and the experimental section (under bio-control in order to determine the efficiency of grass carp as a bio-control agent for *Cladophora* sp. in concrete-lined, irrigation canals.

While the fish was stocked into Section 2 of the Ramah-3 Canal (Experiment 1: October 1998 – April 1999), the *Cladophora* fragments that accumulated on the pivot irrigation abstraction grids (Figure 4.4) were monitored. A pivot abstraction grid was selected in Section 2 under bio-control and another identical grid was selected in Section 1 as a control (without grass carp). For the duration of the experiment, both grids were serviced on a daily basis. With this procedure, *irrigation grid yields* were used as an indication of *Cladophora* biomass production. Irrigation grid yields were dried in the sun on a specially prepared concrete slab for a period of seven (7) days at each sampling site. Dry mass yields collected over a 14-day period was pooled, weighed and expressed in the nearest gram.

Another method, in which primary production was measured in the second experiment, was by sampling *Cladophora* in a 410-mm stretch over the entire width of the canal, at three randomly selected sites in the control and experimental areas. *Cladophora* biomass was drained of excessive water and weighed within a 12-hour period. This sampling technique was executed by pulling a garden rake (410 mm x 80 mm) from top-to-top through the entire cross-section of the canal. The mean wet biomass was calculated and expressed in terms of biomass units. During this experiment, both the bio-control and control experiments were done in the same canal section (Section 1) but in consecutive years. Section 1 was under bio-control during the period September 1999 – April 2000. The control evaluations were done over the same period in the following year (September 2000 – April 2002).

4.2.6 Physio-chemical variables of the canal:

Flow determinations were done at several localities in Section 1 of the Ramah-3 Canal. Determinations were done with an OTT C2 Small Current Meter, at a depth of 20 cm in the middle of the cross-section of the canal. For a detailed flow characterisation of the Ramah Canal System, please refer to the previous chapter.

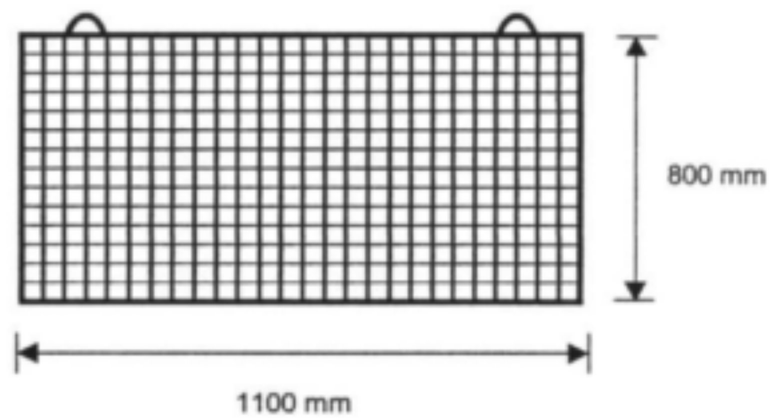

Figure 4.4: A diagrammatic presentation of a standard pivot abstraction grid in the Ramah-3 Canal.

Figure 4.5: A photograph of the vertical bar fish grid used to separate the experimental and control areas.

Site-specific water quality variables were measured every fortnight to coincide with biomass production determinations (see sampling locations in Figure: 4.1). Site-specific water quality parameters included dissolved oxygen (mg/l and % saturation), pH and water temperature (°C). The time of the determinations was also documented.

4.3 RESULTS AND DISCUSSION

4.3.1 Biological control of *Cladophora* with triploid grass carp:

The primary production measured in terms of irrigation grid yields and associated site-specific water quality parameters are given in Table 4.1. During this approach, both the control experiment (without grass carp) and bio-control experiment (with grass carp) were done during the same year (1998-1999) in different canal sections. The primary production measured in terms of *Cladophora* yields based on biomass units, and associated site-specific water quality variables are given in Tables 4.2 and 4.3. *Cladophora* growth increased rapidly in September months when the water temperature had risen above 20 °C. The temperature ranges where *Cladophora* displayed active growth (20 °C - 26.8 °C) coincide with the optimal feeding temperature range of grass carp. According to Cooke *et al* (1987), feeding is irregular at 3 °C - 6 °C, becomes steady at about 14 °C, peaks at 20 °C - 26 °C, and may decrease in the area of 33 °C.

In both bio-control experiments [Experiment 1 (1998-1999); Experiment 2 (1999-200)], the presence triploid grass carp resulted in a significant reduction of *Cladophora* yields (Figures 4.6 & 4.7). To realise the full impact of biological control of *Cladophora* in these experiments, one should take into consideration that the canal level was lowered on several occasions (November 1999, February 2000, Table 4.1; February 2001; Table 4.3) as a means of physical control.

The control experiment (without biological control) was executed from September 2000 to April 2001. This experiment measured *Cladophora* productivity in terms of biomass units, a maximum yield of 312g was obtained in January 2001 (Table 4.3). When triploid grass carp was present in the same canal section, a maximum *Cladophora* yield (in terms of biomass units) of only 30g was obtained during February 2000 (Table 4.2).

When *Cladophora* productivity was measured in terms of irrigation grid deposits (Experiment 1), there was also a significant lower yield in the section under biological control (Table 4.1). The true potential of biomass yields in the control canal however has not been reached due to the impact of the lowering of the water level of the control section. Even under these circumstances, the canal under bio-control yielded consistently less grid deposits.

TABLE 4.1: *Cladophora* productivity measured in terms of irrigation grid yields. A comparison between canal sections with and without triploid grass carp as bio-control agent (Experiment 1: 1998-1999).

DATE	CONTROL CANAL			CANAL WITH BIO-CONTROL AGENT		
	Water Temperature (°C)	pH (log [H^+])	Grid deposit (g)	Water Temperature (°C)	pH (log [H^+])	Grid deposit (g)
13 Sept	17.8	8.8	400	17.6	9.0	160
27 Sept	20.4	8.8	1 250	20.1	9.1	1 380
11 Oct	23.2	8.5	4 000	23.0	8.7	6 000
24 Oct	22.8	9.1	5 600	22.8	8.6	4 300
10 Nov	26.9	8.9	3 950	24.8	9.3	1 900
21 Nov*	Canal drained for *Cladophora* control					
05 Dec	27.7	9.9	10 500	25.9	9.0	0
21 Dec	24.4	9.3	7 000	24.7	9.2	2 500
03 Jan	24.0	9.1	13 000	24.1	9.0	1 600
17 Jan	23.2	9.3	18 000	22.8	9.3	3 000
01 Feb*	Canal drained for *Cladophora* control					
15 Feb	23.6	9.3	30 500	24.4	9.9	13 000
02 Mar	24.1	9.1	22 500	24.2	9.0	18 600

* *canal was drained for the physical control of Cladophora.*

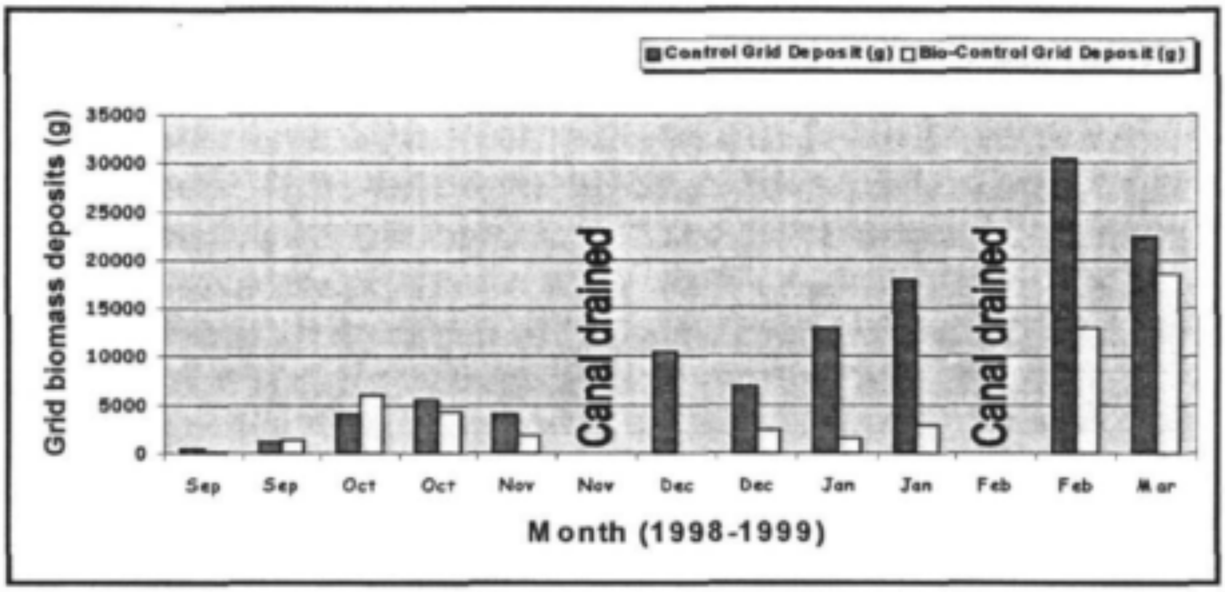

Figure 4.6: The effect of bio-control on the productivity of *Cladophora glomerata*, based on irrigation grid yields (Experiment 1: 1998-1999).

TABLE 4.2: *Cladophora* biomass and site specific water quality variables in the Ramah-3 Canal during biological control with triploid grass carp (Experiment 2: 1999 – 2000).

DATE	TIME	BIOMASS UNITS (g)	WATER TEMPERATURE (°C)	pH (log[H⁺])	DISSOLVED OXYGEN CONCENTRATION	
					mg/l	% Saturation
10 Sept	17:00	6	17.6	9.0	7.5	94
29 Sept	18:15	90	20.1	9.1	7.3	91
10 Oct	15:00	10	23.0	8.7	7.6	95
28 Oct	17:15	20	22.8	8.6	7.3	91
14 Nov	15:15	6	23.4	9.0	8.1	100
21 Nov	17:30	19	25.9	9.0	7.4	93
05 Dec	16:30	20	24.7	9.2	8.9	111
15 Dec	18:30	18	24.1	8.0	8.2	103
03 Jan	15:45	20	22.8	9.3	9.1	115
14 Jan	17:15	10	24.9	9.6	9.3	116
01 Feb*	Canal drained for *Cladophora* control					
14 Feb	17:15	30	24.4	9.9	8.3	104
02 Mar	17:00	10	24.2	9.0	8.6	108
16 Mar	17:15	20	26.3	9.2	8.7	109
01 Apr	17:00	0	23.7	9.2	8.6	108
14 Apr	16:30	20	23.0	9.0	8.6	109

* *canal was drained for the physical control of Cladophora.*

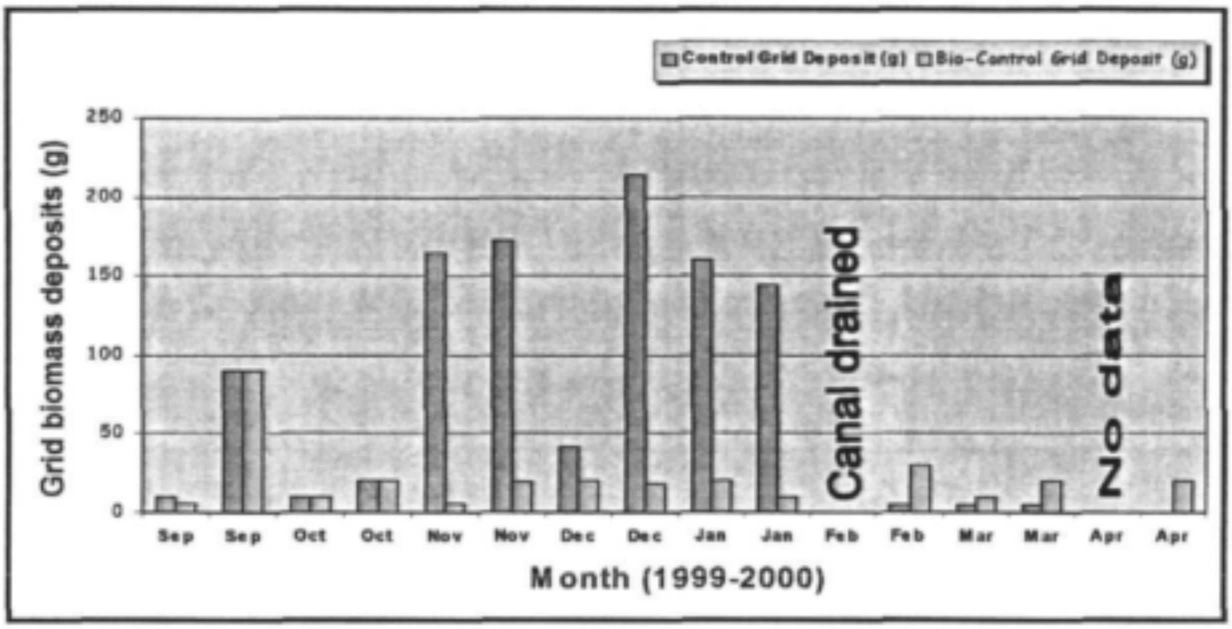

Figure 4.7: The effect of bio-control on the productivity of *Cladophora glomerata*, based on instream biomass assessments (Experiment 2: 1999-2000).

TABLE 4.3: *Cladophora* biomass yields and site specific water quality variables in the Ramah-3 Canal during the control experiment not stocked with grass carp (Experiment 3: 2000 –2001).

DATE	TIME	BIOMASS UNITS (g)	WATER TEMPERATURE (°C)	pH ($log[H^+]$)	DISSOLVED OXYGEN CONCENTRATION	
					mg/l	% Saturation
07 Sept	16:00	10	17.8	8.9	7.8	98
14 Sept	18:15	90	20.1	9.1	7.3	91
01 Oct	15:00	10	23.0	8.7	7.6	95
13 Oct	17:00	20	22.8	8.6	-	-
02 Nov	13:00	164	23.5	9.1	8.9	114
14 Nov	13:30	170	26.8	9.4	9.2	115
04 Dec	12:15	215	26.0	8.9	8.4	105
15 Dec	10:30	40*	25.0	9.0	8.3	104
04 Jan	12:20	312	25.5	9.1	8.7	108
16 Jan	16:15	161	23.8	9.2	9.1	114
01 Feb*	Canal drained for *Cladophora* control					
14 Feb	16:15	5	25.8	8.5	8.4	105
02 Mar	14:30	15	21.0	8.8	8.6	108
15 Mar	10:50	30	20.0	8.6	9.7	121

* *Value abnormally low due to low flow as a result of low water demand owing to the stage of ripeness of crops (corn).*

The maximum irrigation grid yield for instance, even after lowering the level of the control canal was 30 500 g as opposed to 13 000 g in the bio-control canal (Table 4.1, Figure 4.5).

From above results, it is evident that grass carp was not stocked at the optimum density. Stocking rate in experiment 1 does not truly reflect the efficient stocking density, as *Cladophora* fragments from the control canal (Section 1) was carried into the experimental canal (Section 2). This accumulation effect was not possible during experiment 2 as Section 1 (experimental canal) was receiving uncontaminated water directly from the balancing reservoir (balancing Reservoir No: 2). Although the fish was stocked at 3.25 fish/km canal length during experiment 2, the operational density was assumed approximately 2.25 fish/km canal. This assumption was made due to observations concerning the escape and theft of fish during the recovery procedure. A canal official maintaining the fish grids and roll-grids, witnessed on a few occasions, grass carp jumping over the fish grid. Furthermore, during draining for the recovery of the grass carp and canal maintenance, grass carp were stolen by local people living close to the canal. One person was caught in the act and the fish was recovered. The fish survived this excursion.

4.3.2 Growth and survival of grass carp in a concrete-lined canal:

The numbers of fish stocked initially and recovered at the end of the experiments are listed in Table 4.4. The triploid grass carp had a mean weight of 1 930 g when they were stocked for the first experiment that served as a trial run. At commencement of the second experiment, the mean weight of the grass carp was 841 g. In experiment 1 only 25 of the 59 fish initially stocked, could be recovered, thus resulting in a loss of 59%. In experiment 2, only 21 of the initial 52 fish could be recovered, thus resulting in a loss of 60%. Losses experienced during these experimental trials are unacceptable and mainly due to fish escaping over the grids, and theft during drainage operations. Such losses can be prevented by adapting the grid design as well as by improved management practices. The use of radio telemetry to track and identify fish could be of a major attribute in this respect.

TABLE 4.4: Length and Mass of triploid grass carp prior to stocking and after recovery in the Ramah-3 Canal.

Variable	At Stocking	At Draining	Percentage Loss (-) or Gain (+) (*n*)
Experiment 1 October 1998 – April 1999			
n	59	25	- 59 (34)
$\bar{x}$ Mass (g)	1 930	3 520	+ 83%
$\bar{x}$ Length (cm)	*	62.30	*
Experiment 2 November 1999 – April 2000			
Variable	**At Stocking**	**At Draining**	**Percentage Loss (-) or Gain (+) (*n*)**
n	52	21	- 60 (31)
$\bar{x}$ Mass (g)	841	3 607	+ 313%
$\bar{x}$ Length (cm)	41.13	55.52	+ 35%

* No data available

4.3.3 Fish community structure in the canal:

The mean fork lengths and weights of the stocked sterile grass carp and the other fish species present in the Ramah-3 Canal is presented in Table 4.5. Interestingly, it was found that the canal ecosystem sustains a variety of the larger species that are present in the Orange River System. It was generally believed that a concrete-lined canal ecosystem will not sustain a fish community. This perception is based on the flow conditions in such a system, limited hydraulic biotopes and the lack of a food source.

From the results obtained from the study of the fish community structure (Figure 4.8), it is concluded that in the case of the Ramah-3 Canal (at flow velocities between ~0.5-0.8 m/second) the availability of food is the major determining factor influencing the presence and distribution of other species than triploid grass carp.

TABLE 4.5: Morphometrics of the fish community associated with triploid grass carp stocked into an irrigation canal.

Species	*n*	$\bar{x}$ mass (g)	$\bar{x}$ fork length (in cm)	Maximum length (in cm)	Maximum mass (g)	Minimum length (in cm)	Minimum mass (g)
Labeo capensis	108	616	36.01	45	1223	29	313
Cyprinus carpio	23	770	30.21	44	1700	15	78
Labeo umbratus	3	767	41.00	43	837	39	635
Barbus kimberleyensis	1	2750	53.00	53	2750	53	2750
Barbus aneus	1	536	35.00	35	536	35	536
Clarias gariepinus	1	2000	60.00	60	2000	60	2000
Ctenopharyngodon idella	21	3607	55.52	74	6900	45	2000

True stream fish i.e. *Barbus kimberleyensis* and *Barbus aeneus* only comprised 0.6% of the fish community, while the common carp (*Cyprinus carpio*) which is not recognised as a stream fish, contributed to 14.6% of the fish community. *Labeo umbratus* represented 1.9% of the fish community, while *Labeo capensis* contributed to 68.4% of the fish community. The fish community structure, and the contribution that the plant and detritus feeders (*C. idella, C. carpio* and *L. capensis*) made to the catch composition, indicates to a system able to sustain these species. In contrast, fewer piscivores were sampled. However, low numbers of the larger piscivores may not necessarily indicate to an unbalanced ecosystem. Their presence rather indicates to the presence of forage fish (smaller prey species), and because the large piscivores have a low turnover, it is expected that less of these specimens should be sampled in the fish community.

Due to the grid design with 3-cm vertical spaces, small fish was allowed to wash through the canal. However, if they find a suitable food source they will utilise that niche and grow to proportions where they cannot escape through the vertical bar fish grids. The only *B. kimberleyensis* found during the survey, for instance, reached a weight of 2.75 kg, while

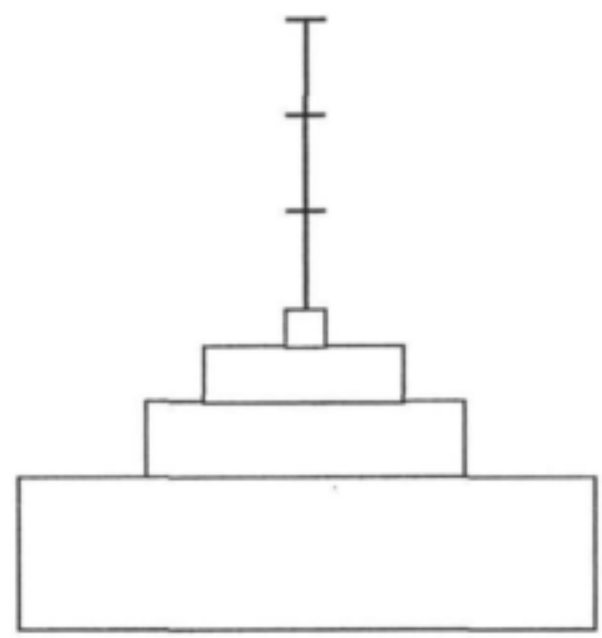

Figure 4.8: Fish community structure in the Ramah-3 Canal (April 2000).

Labeo capensis reached a maximum weight of 1.2 kg. The maximum weight for *Cyprinus carpio* documented in the canal was 1.7 kg. From our results, it appears that triploid grass carp creates a detritus chain, which are utilised by *L. capensis* and *C. carpio*. In this respect the primary production (filamentous algae) that would otherwise have been lost, is efficiently utilised by *C. idella* and made available to the rest of the fish community in the canal, as detritus through their faeces.

4.3.4 Physico-chemical variables of the canal:

A minimum flow of 0.48 m/second was measured as opposed to a maximum flow of 0.8 m/second. This is in accordance with the findings of Du Plessis (1997) whom stated that the current velocity in South African irrigation canals generally varies between 0.5-1.5 m/second with a mean velocity of approximately 0.8 m/second.

Water temperatures varied between 17.6 °C and 27.7 °C and displayed a definite influence on *Cladophora* growth (Tables 4.1 and 4.3). Exponential growth occurred between 20 °C and 26 °C. Dissolved oxygen concentrations varied between 91% and 121% saturation as the season progressed. Super saturation with oxygen occurred when *Cladophora* biomass was high, due to active photosynthesis and when the measurement was taken later in the day (higher water temperatures).

Hydrogen ion concentration fluctuated between pH8.5 up to as high as pH9.9 during the experimental periods (Tables 4.1, 4.2 and 4.3). In general, surface water pH values typically range between pH4 and pH11. In South Africa most fresh water systems are relatively well buffered with a pH range between 6 and 8 (South African Water Quality Guidelines, 1996). The Ramah-3 irrigation canal is efficiently buffered due to high alkalinity values and the presence of $CaCO_3$ in the concrete lining, hence the lower level of the pH range measured in the region of pH8. However, extreme rates of photosynthesis and the consequent CO_2 consumption by *Cladophora* during the day, drives the carbonate species equilibrium toward carbonic acid, resulting in pH levels close to pH10. This especially happened later in the season when *Cladophora* productivity was found to be high (Tables 4.1 and 4.3).

4.4 CONCLUSIONS

Fish were found to migrate freely up and downstream in the experimental canal, and to negotiate measured flow velocities of 0.48 to 0.80 m/s with ease. It can be concluded that grass carp adapted to the artificial conditions experienced in a typical South African concrete-lined canal, and thrived to reach biomass increases of more than 300% in a period of 6 months.

In both bio-control experiments, the use of triploid grass carp resulted in a significant reduction in *Cladophora* yields. The ability of the grass carp to utilise the filamentous algae, that otherwise would have been lost to the fish community present in the canal, resulted in a detritus chain which is utilised by other fish species, such as *Labeo capensis* and *Cyprinus carpio*. This observation may validate the potential application of certain aquaculture methods in South African irrigation canal systems.

High losses of sterile grass carp due to theft and escapes over blocked mechanical grids should be addressed before triploid grass carp can be put into full-scale operation as bio-control mechanism for aquatic weeds in irrigation canals. The operational problems associated with the blockage of mechanical grids should also receive attention. The possible application of electrical fences to replace the conventional grids could be the answer to this problem. There can however, be no doubt on the value of this aquatic weed control mechanism to the current integrated aquatic weed control programmes of the Department of Water Affairs and Forestry.

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CHAPTER 5

GRASS CARP AS A TOOL FOR AQUATIC WEED CONTROL IN IRRIGATION CANALS - A BRIEF ECONOMIC ANALYSIS.

Abstract

Managers in the field of aquatic weed control make recommendations based mainly on the biology of the aquatic ecosystem; however, actual management decisions are many times based largely or entirely on economics and politics. As the majority of registered aquatic herbicides used in South Africa are imported from abroad, chemical control is progressively becoming an expensive exercise. It is therefore appropriate to seek ways to minimize the cost associated with aquatic weed control.

The use of grass carp alone or as a component of integrated aquatic weed management programmes (IAWMPs) has proven to be an efficient and cost-effective management tool in impoundments worldwide. The literature on the economics of this biological approach to aquatic plant management in water conveyance systems is however scarce. The few case scenarios available are also not directly applicable to the South African situation.

An attempt was made to conduct a brief economic analysis, based on information on expenditures of local irrigation schemes on aquatic weed control in their canals. The outcome of this brief investigation is in line with overseas findings (although based on impoundment management figures) that biological control with sterile grass carp will be more economical than the currently applied aquatic weed control methods of herbicidal and mechanical or physical control. As there is currently no local canal system where grass carp is implemented on a full scale as bio-control agent, no financial data exist to make comparisons. An attempt was made to compare perceived cost of a grass carp programme with current expenditures on herbicidal and mechanical/physical control programmes.

5.1 INTRODUCTION

Chemical or herbicidal control is the most commonly used method of aquatic weed management in irrigation canals around the world. Basically there are four recognised methods of aquatic weed control - chemically (by means of herbicides), mechanically (various devices such as the algae rake in the Roodeplaat canals near Pretoria, and the "skilpad" used at the Middle-Vaal River Government Water Scheme), physical control (water level drawdown, restriction of light penetration and hand removal) and biological control. These methods are used worldwide according to site-specific conditions, opinions, the availability of manual labour, and cost.

The conventional chemical methods of aquatic weed control are increasingly criticized. These objections are based on economic and environmental grounds. The majority of herbicides used on submerged aquatic weeds in South Africa are imported from abroad (mainly from the United States of America). The currently (year 2002) unfavourable Rand-US$ exchange rate of approximately 1:10, make imported chemicals quite expensive. It is appropriate, therefore, to seek ways to minimize the cost associated with aquatic weed control.

Specialists in the field of integrated aquatic weed management recognize the use of grass carp as bio-control agent as a relative inexpensive control method (Van Zon, 1978). For the management of submerged aquatic weeds such as pondweeds and filamentous algae, the use of grass carp is currently the only biological control method available.

The application of grass carp as bio-control agent in South Africa was up to now, restricted to a few impoundments - mostly farm sized dams smaller than 3 hectares. The largest local application of grass carp was until recently the Germiston Lake with a surface area of 59 ha. Grass carp is also now used as part of an integrated aquatic weed management programme in Heyshope Dam (5 000 ha), near Piet Retief, in the Mpumalanga Province.

This project on the application of triploid grass carp as bio-control agent in irrigation canals is the first where sterile grass carp is locally applied as bio-control agent in irrigation canals. Overseas information on cost comparisons are mostly based on aquatic weed control methods used in impoundments, and not in water conveyance systems. Available literature on the application of grass carp in irrigation canals is also based on unlined, earth canals. The far majority of South African irrigation canals are concrete-lined, making comparisons unrealistic.

An attempt was made by the authors to compare cost of the different control methods used by local irrigation schemes. Little background information is given on cost comparisons in impounded water bodies as no reference of cost-benefit analysis in canal systems could be found in the literature. The cost comparison presented in this section should however be valued against the fact that local information on the financial side of mechanical, chemical and physical control is very limited.

5.2 BACKGROUND

Herbicide applications, mechanical and physical control methods and grass carp are the primary means of macrophyte control in many areas throughout the world. Although many of the available contact herbicides are very effective against submerged aquatic plants and algae, it is also relatively expensive.

In the state of Florida (USA), Phillipy *et al.* (1989) found hydrilla established in 59 of the 100 largest lakes and calculated that a 10% (total surface area) fluridone herbicide treatment to control hydrilla in those 59 lakes would cost approximately $48 000 000 (that is R 480 000 000). The use of grass carp alone or integrated with other hydrilla management methods has proven to be an efficient and cost-effective tool (Stott *et al.*, 1971; Stott and Burkley, 1978; Osborne, 1982; Shireman *et al.*, 1986; Sutton *et al.*, 1986; and Cooke *et al.*, 1993).

Cooke *et al.* (1993) presented a cost comparison of these methods and demonstrates that grass carp are the least costly (Table 5.1). Several factors are however, important in this cost comparison. First grass carp are not effective with some plants, including alligatorweed and water hyacinth. For these plant, insects and/or herbicides are the least costly approach, as well the most effective, because weed harvesters are too slow in large impoundments. Secondly, grass carp stocking rates are higher in colder climates, and greater numbers of fish are needed in canal systems dominated by non or low preferable plants.

Table 5.1: Ranges of Costs for Grass Carp, harvesting and herbicide treatments for Aquatic plant management (Adapted from Cooke *et al*, 1993).

CONTROL METHOD	MIDWEST (R/ha)	FLORIDA (R/ha)
Harvesting	3 850 - 10 780	8 610 - 417 440
Herbicides	5 840 - 10 650	4350 - 10 130
Grass Carp	2 000	700 - 11 900

Note: Data from Cooke *et al* (1993). U$ converted to South African Rand with an USD:Rand exchange rate of 1:10. Calculations assume 25 cm fish costing R 80-00 each with an 8 year longevity. Stocking rates for Florida lakes ranged from 59 fish to 101 fish/ha for hydrilla and the rate for Illinois was 170 fish/ha for *M. spicatum*. Costs are for a single treatment in Rand/ha and Rand/ha for harvesting, and in Rand/ha/year for grass carp. Based on 1991 figures.

Also, chemical and mechanical methods may have to be applied more than once per season, depending upon the herbicide used or the harvesting technique employed (mowing vs. root crown removal), making their overall annual cost higher. Finally, the initial grass carp costs are amortized over the effective life of the fish, whereas the other methods must be used at least every year. For example, Shireman (1982) noted that in 1977 the cost of chemically treated 15 000 ha of hydrilla in Florida was about $9.1 million, whereas grass carp stocked at 35/ha would have cost $1.71 million in 1977. The most important point however is that the state of Florida would have had the $9.1 million cost every year, assuming no inflation and the $1.71 million could have provided control for several years.

No cost-benefit analysis on grass carp in concrete-lined irrigation canals could be found in the literature. The few figures on grass carp control in canals in Egypt and Russia are based on diploid fish in earth canals with aquaculture production as a by-product.

These canal systems sustain a diversity of aquatic plants which include floating aquatic macrophytes such as water hyacinth, and are much larger systems than the local concrete-lined canals.

5.3 METHODS

To compare the cost of the different control options (i.e., chemical, mechanical/physical and biological control) the current cost of chemical and physical control in the canals of the Hartbeespoort Irrigation Board and Pienaars River Government Water Scheme (at Roodeplaat) were compared with the proposed cost of biological control with grass carp as based on the experiments in the Ramah Canal System (Chapter 4 of this document).

Projected costs were based on conservative assumptions of a copper sulphate management programme, which comprises the following:

Chemical control method:

- The Lowered-pH Method (Du Plessis, 1992a and b) is used were the pH of the canal water is lowered to pH6.0 (fluctuating between a minimum of pH5.5 to a maximum of pH6.5);
- Copper sulphate is dosed at a final concentration of 0.5 ug/l (Cu^{2+}) at a flow of $1m^3$/sec.;
- Contact period is 8 hours;
- Four chemical dosings per annum would be sufficient to ensure the optimal operation of the system;
- The additional treatment to control the proliferation of pondweed (*Potamogeton pectinatus* in the case of all three canal systems);
- All chemical dosings executed by a professional contractor.

Physical control:

- Removal of aquatic weed biomass by manual labour;
- Mechanical assistance in terms of front loaders and trucks to transport removed biomass to an appropriate dumping site;
- Frequency once every six months, thus two physical cleaning operations per annum;

- Work force of local irrigators are used;
- Irrigators are compensated by credit on their water account.

Biological control method:

- Certified sterile grass carp (*Ctenopharyngodon idella*) will be used at a minimum length of 20 cm to limit predation and escape through barriers out of the target system;
- A concrete-lined sanctuary dam to be build for each canal at a once-off cost of R 250 000 each;
- The cost of mechanical barriers are not included;
- Fish will be stocked at a density of 10 individuals per kilometer canal length irrespective of aquatic weed biomass;
- To compensate for losses out of the target area, fish will be supplemented on an annual basis of 15%;
- The longevity of the bio-control agent is 8 years;
- No monitoring programme is implemented and
- No professional support.

The life span of each control programme was taken as five years. Cost was calculated on an annual basis but multiplied by five to compensate for the long-term effect of a bio-control agent. A general canal length of 50 km and a capacity of 3-4 m^3/sec., was taken as standard.

5.4 RESULTS AND DISCUSSION

5.4.1 Factors to consider when making comparisons:

It must be kept in mind that site-specific conditions will dictate which aquatic weed control option will be the most advantageous for a specific canal system. Each control method has advantages as well as disadvantages (see Chapter 2). It is also envisaged that an integrated approach to aquatic weed control will be followed in most case scenarios.

It is important to note that a concrete-lined canal has to be mechanically/physically cleaned on an annual basis to manage sediment build up and to perform maintenance on civil structures. Mechanical control will therefore be always part of an integrated approach in local irrigation canals. The aim should however be to restrict this costly exercise to the minimum.

5.4.2 Comparison of cost involved in chemical, mechanical/physical and biological control in the Hartbeespoort and Pienaars River Systems:

Both the canal systems of the Hartbeespoort Irrigation Board and the Pienaars River Government Water Scheme are currently accommodated in a chemical canal-dosing programme. The sources of both systems (Hartbeespoort Dam and Roodeplaat Dam) are highly eutrophic systems (high nutrient concentrations). These two systems can be compared to a great extent with each other in terms of the character of water quality as well as geographic variables and therefore environmental conditions. The Ramah Canal System in which the experiments with the sterile grass carp were conducted is however located in a total different system.

The Hartbeespoort and Pienaars River canals receive a highly eutrophied water quality with low turbidity and therefore high light penetration. On the other hand lower nutrient concentrations and higher turbidity values, due to the more turbid water quality of the Orange River System characterize the water quality of the Ramah Canal System.

Larger *Cladophora* yields can therefore, be expected in the Roodeplaat and Hartbeespoort canals, than in the Ramah Canal System.

In Table 5.2 a brief cost comparison is presented between herbicidal, mechanical/physical, and biological control options. This comparison is based on actual cost experienced with herbicidal and mechanical/physical control programmes in the Hartbeespoort and Roodeplaat irrigation schemes, and a proposed figure for biological control, based on the experience in the Ramah Canal System with sterile grass carp.

Cost comparisons were made over a five-year operational period and expressed as a cost ratio, where the least expensive control method (biological control) was taken as 1. This resulted in a cost ratio of 1:3 for biological versus herbicidal control, and 1:4 for biological versus mechanical/physical control. A more accurate cost-benefit analysis can only be made when data are available on the full-scale operation of grass carp as biological control method.

When comparing the cost involved in the available methods of aquatic weed control in irrigation canals it can be concluded that mechanical/physical control is the most expensive. This method is also the least effective as regrowth of *Cladophora* reach problem proportions within two to tree weeks after the cleaning process (Fourie, Pers. comm., 2002). The mechanical cleaning of concrete-lined canals will however, always be part of the operational procedure of a canal system as sediment build up and maintenance on civil structures has to be addressed annually.

5.4.3 Factors influencing the cost of triploid grass carp as aquatic weed management option:

There are still facets that need to be investigated before grass carp can be implemented on full scale as biological control option in South African canals. The practical problems experienced with grids and theft need to be addressed before more accurate predictions can be made regarding the cost of grass carp as an option for aquatic weed control. At this point in time it is anticipated that the following factors may influence the cost of biological control with grass carp.

- *Stocking density:*
  The number of fish to be stocked is an important factor in determining the cost involved in this biological control method. Provision must also be made for losses out of the target system by implementing a supplementing stocking protocol, which should be supported by a monitoring programme.

- *Size of fish:*
  Grass carp is aggressive feeders as it can easily consume its body weight in vegetation biomass on a daily basis. It is therefore expensive to feed them during the outgrow phase prior to stocking. Although it is important to stock a viable size (20-30 cm in length) in order to prevent escape through grids, and minimize predation, the length of the outgrow phase will have a significant impact on the final cost of the fish.

TABLE 5.2: Ranges of cost for grass carp, physical control and herbicide treatments for aquatic weed control.

CONTROL METHOD	EFFECTIVETY	DURATION OF TREATMENT (one application)	INITIAL CAPITAL OUTLAY	COST RAND/km	COST/50 km CANAL LENGTH	COST AS CALCULATED OVER 5 YEAR PERIOD (initial capital outlay included)			
						Number of applications	Operational cost	Total cost	Cost ratio
Physical Control [1,5]	Low	3 Weeks	NIL	R 2 800-00	R 140 000	2 X 5 = 10	R 1.4 mil	R 1.4 mil	1:4
Herbicidal Control [2,5]	High	6 to 8 Weeks	NIL	R 1 000-00	R 50 000	4 X 5 = 20	R 1 mil	R 1 mil	1:3
Biological Control [3,5]	Medium to high	Ongoing	R 250 000	R 800-00	R 40 000	Once-off [4] + 15% per annum	R 90 000	R 340 000	1:1 [5]

NOTES:

1. *Calculations assume 25-cm fish costing R 80-00 each with an 8-year longevity. Stocking rates for eutrophic systems were taken at 10 fish/km, and expressed in Rand/ha/year for grass carp. Based on 2002 figures.*
2. *For a single treatment in Rand/km.*
3. *For a single mechanical cleaning with manual labour and limited mechanical support.*
4. *Once off stocking of 10 fish/km with 15% supplementation per annum.*
5. *Cost of monitoring programmes not included.*

- *Physical character of the canal system:*

  The biggest once-off capital outlay when implementing grass carp, as bio-control agent in a canal system will be the construction of sanctuary dams. Many local canal systems are however, equipped with balancing dams at the end of the canal. These dams may be suitable for this purpose. If no dam structure is available, a new dam will have to be built to accommodate the fish during dry periods.

- *Possible losses out of target system:*

  Provision should be made for losses by theft and escaping through barriers or grids. As the anticipated life span of the animals is taken at eight years, a supplement stocking figure of 15% per annum to the initial stocking density is recommended at this time.

5.5 CONCLUSIONS AND RECOMMENDATIONS

In the local context there are still a few uncertainties, which has to be sorted out before more accurate predictions can be made of the cost involved in the application of sterile grass carp as bio-control agent in concrete-lined canals.

It is anticipated that aquatic weed programmes in canal systems will be tailored on a site-specific basis to each canal system's individual needs. It must also be realized that there are advantages and disadvantages to each control technique (see Chapter 2), and that an integrated approach will be necessary as mechanical/physical maintenance will always be part of the operational rules of concrete-lined canals.

Every canal system will have to be treated separately with a commitment to monitor the effectivity of the control programme and to modify the approach as needed in order to optimize results.

All evidence exists that biological control with sterile grass carp will be more cost-efficient than the other control options. Although there will be an initial capital layout to safely accommodate the fish in a canal system, savings will realize on the medium to long-term.

It is recommended that a thorough cost-benefit analysis should be performed on the first canal system where sterile grass carp is implemented on a full scale as bio-control agent. Attention should also be given at the financial implications of water loss on crop production and canal overflow on structure failure. The successful implementation of triploid grass carp in irrigation canals can have a large economical impact on the future management of irrigation schemes.

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CHAPTER 6

A PROPOSED MANAGEMENT PLAN FOR THE APPLICATION OF TRIPLOID GRASS CARP AS BIO-CONTROL AGENT IN IRRIGATION CANALS.

Abstract

Whenever a biological control programme is implemented in irrigation canals, a sound management plan should form the basis thereof. Efficient logistical structures are essential to guarantee success.

The impact of the existing canal environment on the efficacy of the bio-agent is discussed and recommendations are presented to overcome possible problems in the practical application of grass carp as tool for aquatic weed control. It is recommended that no aquatic weed management programme should be approved by the relevant authorities without an accompanying canal monitoring programme.

A few possible adaptations to the existing canal operation regimes should ensure that triploid grass carp could be managed as an effective biological control agent in concrete-lined canals. This should be determined on a site-specific basis and could include additional civil structures such as sanctuary dams and small fish ladders to ensure free migration throughout the target system.

Site-specific conditions for each irrigation scheme will require a different approach to the aquatic weed problem. It is therefore strongly recommended that suitable qualified specialists should develop all aquatic weed management programmes on a site-specific basis.

6.1 INTRODUCTION

From the results of the field tests, it is evident that triploid grass carp (*Ctenopharyngodon idella* Val.) is an efficient bio-control agent for the biological control of filamentous algae (*Cladophora glomerata*) in irrigation canals.

Although the bio-control agent is efficient, there are many aspects with regard to the preparation, stocking and maintenance of triploid grass carp after introduction that can cause the biological aquatic weed management program to fail. Whenever a biological control program is implemented in irrigation canals, it is essential to actively manage the programme and to have a well-motivated team of irrigation scheme officials that regularly liaise with the programme leader. During the past four years the research team have experienced numerous problems that threatened the successful completion of this project. All these factors should be considered in the proposed management plan.

The goal of an aquatic weed management programme is to *implement and maintain* an effective, ecologically sensitive and economically feasible plan with the minimum impact or disruption, of the normal operation of the target system. This is only possible with careful management of the aquatic weed management programme.

6.2 PROPOSED MANAGEMENT PLAN

6.2.1 Aquatic weed management programme:

6.2.1.1 Advisory Committee:

The majority of aquatic weed management programmes in South African irrigation canals are controlled by the Departmental Advisory Committee for the Control of Aquatic Weeds in Water Supply Systems. This committee is currently chaired by the Directorate: Water Utilisation of the Department of Water Affairs and Forestry in Pretoria.

It is important that all aquatic weed management programmes, whether biological, mechanical or chemical, should be registered with the above-mentioned department.

The Advisory Committee will arrange for the client to make contact with the available consultants in the field of integrated aquatic weed control and guide the applicant in the correct protocol with the various governmental departments to obtain permission to implement an aquatic weed management programme.

6.2.1.2 Project Management Team:

Consisting of well-motivated and trained team members and a leader that believes in the bio-control agent and realize that the fact that the programme is in place to save time, effort and finances.

6.2.1.3 Public Participation:

It is extremely important that the local people and water users are informed about the aquatic weed management programme and the value of the fish for the optimal functioning of the canal system. During the course of the project an unknown amount of fish was lost due to theft. In the Imperial Valley Irrigation District in California (USA) a penalty to the equivalent of R 30 000-00 is fined if a person is illegally in possession of triploid grass carp. There should be looked into the implementation of strict control measures to prevent the theft of fish out of a system.

6.2.1.4 Communication:

It is of vital importance that an effective communication link exists between the supplier of the fish and the project leader of the integrated aquatic weed management programme, and that the supplier is also represented on the project team management. In the event of scheduled canal maintenance, canal drainage or chemical control, the supplier should be consulted.

6.2.1.5 Canal Monitoring Programme:

The implementation of a canal monitoring programme to characterise the water quality and quantity on ongoing basis, is an important component of any aquatic weed management programme. The monitoring programme should also record the progress of the bio-agent on the target flora as well as the impact of biophysical and chemical variables on the fish. The information produced through a monitoring programme is essential to optimise the aquatic weed management programme and to integrate the biological control plan with other aquatic weed control options.

The existing KANNET canal monitoring programme, which is already implemented on a few irrigation schemes, can easily be adapted to accommodate the needs of this programme.

6.2.1.6 Legal Requirements:

6.2.1.6.1 <u>Permit Requirements:</u>

In the Republic of South Africa, a permit is required by law for use or possession of grass carp. Only grass carp certified as triploid (sterile) can be used in an aquatic weed management programme. Irrigation schemes interesting in using sterile grass carp for aquatic weed management should firstly contact the Chairman of the Departmental Advisory Committee for the Control of Aquatic Weeds in Water Supply Systems of the Department of Water Affairs, or the suppliers of the fish at the Department of Zoology of the Rand Afrikaans University in Johannesburg.

The provincial environmental authorities issue permits (Parks Board). Two permits are necessary, one for the export of the fish out of a province, and a second for importing the fish into a province. Strict control over the permit system is essential to ensure that only sterile fish are produced and used as bio-control agent. Fish may also not be transferred between canals or dams without the necessary authority. The integrated aquatic weed management specialist should administer the application for permits to ensure that the correct protocol is followed.

6.2.1.6.2 <u>Environmental Impact Assessment (EIA) Procedure:</u>

The release of any organism outside its natural area of distribution, for the use as biological control agent, is regulated under current South African legislation. The fore-mentioned action is also a listed activity in terms of Regulations 1182 of 1997, Schedule 1 (5), and requires an Environmental Impact Assessment (EIA) as identified under Section 21 of the Environment Conservation Act *(Act 73 of 1989)*. The integrated aquatic weed specialist must ensure that there are adhered to this legislation. An EIA should be performed in each new canal system and an Environmental Management Plan (EMP) will be a prerequisite before the relevant environmental authority will issue an authorisation in the form of a Record of Decision (RoD).

6.2.2 Adaptations to canal operation regime:

6.2.2.1 Containment of Bio-control Agent in Target area:

6.2.2.1.1 Fish traps:

Balancing dams at the downstream end of a canal system or canal reach can serve as a fish trap to restrain fish from escaping downstream. Due to reduced flow electrical or mechanical fish barriers can be developed to be applied at this point, since downstream barriers are the most difficult to implement in terms of fish migration.

Furthermore the reservoir habitat can easily be netted without interrupting the flow regime of the system to recover fish that was otherwise lost. During this project fish loss was one of the major problems associated with triploid grass carp as bio-control agent in canal systems. In each of the bio-control experiments approximately 60% of the stocked fish were lost.

6.2.2.1.2 Sanctuary reservoirs:

Due to the current inability to implement an electrical fish barrier system, fish has to be grown out for at least one year to attain suitable size for mechanical fish barriers. During the outgrow procedure fish has to be fed on aquatic vegetation. During this investigation large numbers of fish was lost due to the huge quantities of vegetation that had to be fed and also to maintain water quality under such an intensive feeding regime. A thousand one-year-old fish for instance, would consume between 1 and 3 tonnes of vegetation each day. To specially grow out fish at the producer's facilities is neither cost-efficient nor practical.

To over come this problem, it is proposed that a sanctuary reservoir (60 X 30 X 1.5m) should be constructed at the lowest point of the canal under bio-control. During canal maintenance periods (dry periods), fish should be allowed to drain naturally into the sanctuary reservoir. Triploid grass carp should then be maintained in the sanctuary reservoir until canal maintenance is completed.

Further more the sanctuary reservoir should serve the purpose to grow out fish to a suitable size prior to stocking to the open conduit areas. Since irrigation scheme officials are servicing the roll-grids, sluices and grids on a continuous basis, vegetation removed can rather be used to feed the fish in the sanctuary reservoir. Under these conditions canal water can also continuously flow through the reservoir without additional consumption, thus maintaining the water quality under intensive feeding conditions.

The sanctuary reservoir or dam should be save guarded against theft and predation by birds and otters. An electric fence and shade netting are recommended to protect the fish.

6.2.2.1.3 Mechanical and electrical barriers:

Algal biomass and debris easily block the current mechanical grids used to restrict the fish to a specific target area. This has lead to numerous overflows of canals at these points. To overcome this problem it will most definitely be of benefit for the future utilization of triploid grass carp to investigate mechanical fish screen design and to develop electrical fish barriers.

The research team is of the opinion that the development of suitable electrical barriers for grass carp management in irrigation canal systems should be addressed as soon as possible.

6.2.2.2 Free movement of bio-control agent through the target area:

The ability of the fish to move freely through the target canal system, is an important consideration in the management of sterile grass carp as bio-control agent in lothic systems. Many gravity flow systems, for instance, allow fish to move downstream over structures, but restrict upstream movement back up over the same structures. This could very quickly lead to downstream accumulation.

6.2.2.2.1 Impacts of balancing dams:

Balancing dams are placed at low geographical locations in a canal system, and outlets are usually high concrete structures equipped with sluices. In many cases these structures will not allow fish to migrate between the balancing dam and the canal. To overcome this obstacle fish would have to be stocked up and downstream of balancing dams. If the impoundments are infested with aquatic weeds, these structures should be stocked separately from the conduit areas, and calculations on stocking densities should be adapted to lenthic conditions.

6.2.2.2.2 Impacts of roll-grids:

Theoretically the fish would be able to negotiate the flow velocities (0.8 m/s) underneath the roll-grid to migrate up or downstream (see chapter on flow). The possibility exists however, that the associated noises and vibrations of the continuous rotating roll-grid will discourage the fish to move through the structure. If roll-grids prove to restrict movement, inline fishways could be the answer to this potential problem.

6.2.2.2.3 Impacts of long-weirs:

These structures will not restrict grass carp movement at all. The fish will be able to jump over these structures and migrate up and downstream of them. The low flow velocity areas upstream of long-weirs will probably be utilized by the fish as resting habitat (see chapter on flow).

6.2.2.2.4 Impacts of siphons:

Siphons and culverts will definitely act as hiding places for the fish. During periods of no flow in the canal (dry periods for maintenance) fish do tend to accumulate in siphons, as these structures does not drain completely. Overcrowding of fish in small or short siphons could however, lead to oxygen depletion, which in turn can result in a fish kill. A possible option is to aerate siphons during dry periods through the service manholes with mobile compressors.

6.2.2.2.5 Impacts of cross-drainage:

As a general rule no storm water outside the servitude area should be allowed to discharge directly into the canal, as this situation will lead to the deposit of silt and other coarser material into the canal, in turn increasing maintenance costs.

Cross-drainage structures such as super-passages (super elevated canals) as in the case of siphons will provide the fish with hiding places against possible predators. It is foreseen that the fish will spend the time they are not feeding underneath structures and leave them when they are looking for food.

6.2.2.2.6 *Impacts of rejects:*

Rejects and reject canals (also referred to as "wasteways") are structures that allow surplus or uncontrolled "waste" water to be automatically or manually diverted from the canal safely into a river or major watercourse. The purpose of reject structures is to enable the operating staff to completely drain the canal downstream of that point for purposes of repair or maintenance, while keeping the upper canal reaches in operation.

Inline, vertically placed grids to a height of 1 meter constructed parallel to the canal should prevent the grass carp from escaping the reject structure.

6.3 BIO-CONTROL WITH TRIPLOID GRASS CARP AS A COMPONENT OF AN INTEGRATED AQUATIC WEED MANAGEMENT PROGRAMME

Since grass carp is a living organism - in contrast to either algaecides, herbicides and mechanical devices used for aquatic weed management - a somewhat different approach is required for using of this fish as a control mechanism.

The chemical dosing of the canal to remove the majority of biomass before stocking of grass carp will enhance the effectivity of the fish, since the fish need to consume only the new emerging algal or pondweed growth. This integrated approach is an efficient and cost-effective way to manage the majority of aquatic weed problems.

Concrete-lined canals have to be mechanically/physically cleaned on an annual basis to manage sediment build up and to perform maintenance on civil structures. Mechanical control will therefore be always part of an integrated approach in local irrigation canals.

When using triploid grass carp in conjunction with mechanical control methods, care should be taken to stock the fish after any negative effects of the mechanical control effort have diminished. For example, a temporary reduction in dissolved oxygen may occur during sediment disturbance when a balancing dam, trap dam, or sanctuary dam is cleaned.

When fish is used in conjunction with a chemical canal dosing programme such as the KANDOS Canal Dosing Programmes, stocking needs to be done prior to weed regrowth, but after any negative effects of these treatments on the water quality have dissipated. It is strongly recommended that all integrated aquatic weed programmes should be only be implemented and executed by an experienced Integrated Aquatic Weed Management Specialists. No dosings should be allowed without prior consultation with the supplier and/or the *Integrated Aquatic Weed Management Specialist.*

In practice the scenario will probably be that it will be cost-effective to manage the aquatic weeds in the larger canals with triploid grass carp and the smaller canals with an appropriate chemical dosing programme. Site-specific conditions for each scheme will require a different approach to the aquatic weed problem. It is therefore strongly recommended that suitable qualified specialists should develop all aquatic weed management programmes on a site-specific basis.

CHAPTER 7

GENERAL DISCUSSION

7.1 ADAPTABILITY OF STERILE GRASS CARP TO A CONCRETE-LINED CANAL HABITAT

Relatively low flows (< 1 m/s) were measured throughout the Ramah Canal System under maximum and super critical flow conditions. During the experimental phase of the project it was quite clear that the fish was able to migrate up and downstream with ease. The assumptions of some local environmental scientists that South African concrete-lined canals would be too fast flowing for grass carp to survive and/or be effective as biological control agent of aquatic weeds, was proven to be unfounded.

Grass carp thrived under these artificial conditions at flow rates ranging from 0.48 to 0.80 meter/second, moving upstream and downstream in a 16 km experimental section of the Ramah-3 Canal. *Cladophora* was efficiently controlled at stocking rates of 3 to 7 fish per km canal. Triploid grass carp retrieved from the canal system after a six-month experimental period presented an excellent physiological condition and displayed a mean weight increase of more than 300%.

The study found that obstructions, such as long-weirs and roll-grids in the canal, will provide adequate *in situ* resting areas for the fish. Very low flow velocities of less than 0.2 m/s was measured upstream of these obstructions. These obstructions generate the ideal low flow niches for the fish to rest when they are not feeding. Structures over the canal, such as bridges and supers (super-elevated canals) will provide *in situ* areas of protection against predators of the fish.

The general conclusion can therefore be made that flow velocities throughout the entire Ramah Canal System are well within the tolerance range of sterile grass carp to survive and to operate effectively as biological control agent on the aquatic weeds.

7.2 COST OF BIOLOGICAL CONTROL COMPARED WITH OTHER AQUATIC WEED CONTROL METHODS

All evidence exists that biological control with sterile grass carp will be more cost-efficient than the other control options. Although there will be an initial capital layout to safely accommodate the fish in a canal system, savings will realize on the medium to long-term. The prognosis was made that biological control with triploid grass carp was approximately a third of that of herbicidal control and a quarter of mechanical/physical control (Chapter 5). It can therefore be concluded that the successful implementation of triploid grass carp in irrigation canals can have a large economical impact on the future management of irrigation schemes.

7.3 MANAGEMENT OF GRASS CARP AS BIO-CONTROL AGENT IN IRRIGATION CANALS

A few possible adaptations to the existing canal operation regimes should ensure that triploid grass carp could be managed as an effective biological control agent in concrete-lined canals. This should be determined on a site-specific basis and could include additional civil structures such as sanctuary dams and small fishways to ensure free migration throughout the target system.

Site-specific conditions for each irrigation scheme will require a different approach to the aquatic weed problem. It is therefore strongly recommended that suitable qualified specialists should develop aquatic weed management programmes on a site-specific basis.

In practice it will probably be cost-effective to manage the aquatic weeds in the larger canals with triploid grass carp, and the smaller canals with an appropriate chemical dosing programme. Site-specific conditions for each scheme will require a different approach to the aquatic weed problem. It is therefore strongly recommended that suitable qualified specialists should develop all aquatic weed management programmes on a site-specific basis.

7.4 RECOMMENDATIONS FOR FUTURE RESEARCH

7.4.1 There can be no doubt that problems with aquatic weed proliferation in water conveyance systems are with us to stay. Although water resource protection is a priority for the Department of Water Affairs and Forestry, it is doubtful if point source management will reduce plant nutrient concentrations to a point where eutrophication levels are low enough to eliminate aquatic weed problems in irrigation canals.

7.4.2 With the new Water Conservation and Demand Management (WCDM) policy almost in place, the monitoring of water conveyance systems need to be phased in as a matter of urgency. A canal monitoring network which accommodate both water quantity and quality will contribute to more effective water management and consequently aquatic weed management in irrigation canals. Canal monitoring networks are already implemented in three canal systems (Roodeplaat, Hartbeespoort and the Ramah canals of the Orange-Riet River System). It is strongly recommended that a canal monitoring programme should be made an integral part of the WCDM programme.

7.4.3 Biological control with triploid grass carp will contribute to a more cost-effective approach to integrated aquatic weed management in irrigation canals. The successful implementation of triploid grass carp as bio-control agent in irrigation canals can have a large economical impact on the future management of irrigation schemes.

7.4.4 The practical application of sterile grass carp as bio-control agent in concrete-lined canals is proofed beyond doubt. However, the two major problems that were identified during the study, at this stage hamper the large scale implementation of this bio-control agent in canals, namely:

- Uncontrolled movement of grass carp within the system, and
- the failure of mechanical grids to contain the bio-control agent within a certain section of the canal.

In order to efficiently manage, grass carp in irrigation canal systems, knowledge of their *movement patterns* is essential. We need to know where they are, how they move through the day, how do they negotiate obstacles such as roll-grids, what do they do at night, do they move is schools, in other words, what are their distribution behavior in a concrete-lined canal.

One of the major problems experienced during this investigation was the impracticality associated with the mechanical grids. As algal biomass and debris of al sorts very easily block mechanical grids, the development of an *alternative grid* should be regarded as a priority.

7.4.5 A follow-up project is recommended to address the above-mentioned shortcomings, in order to apply the concept on a large scale. It is recommended that an *experimental canal* should be made available by the Department of Water Affairs and Forestry in order to:

- to optimize and consolidate all the results emanated from the five completed WRC projects, with the current control methods, into an *Integrated Aquatic Weed Management Programme*; and
- to establish the *distribution behavior* of grass carp in a concrete-lined canal; and
- to design an *effective electrical barrier (grid)* as alternative to the mechanical grids.

The Roodeplaat Canal System is a possible candidate for such an experimental canal. The scheme is situated just North of Pretoria and therefore strategically placed and easily accessible for all concerned. The Canal Monitoring Network (KANNET) is already implemented in this canal system and two seasons of background data is available. Furthermore is the full Canal Dosing Programme (KANDOS programme) in operation in this scheme. This makes this system the ideal experimental canal for the development of a protocol for integrated aquatic weed management programmes in irrigation canal systems.

CHAPTER 8

CONCLUSIONS

8.1 The aims set for this investigation into the application of triploid grass carp as biological control agent for the overabundant growth of aquatic weeds in irrigation canal systems, have successfully been met.

8.2 The fish adapted to the artificial habitat of a concrete-lined canal and controlled the filamentous algae in the canal to a significant extent.

8.3 The maximum flow velocity measured in the Ramah Canal System over a three-day period never exceeded 1 m/s. The average flow velocities in each of the sections were found to be nearer to 0.6 m/s than 0.8 m/s, as was speculated before the commencement of the investigation.

8.4 Fish were found to migrate freely up and downstream in the experimental canal, and to negotiate measured flow velocities of 0.48 to 0.80 m/s with ease.

8.5 In both bio-control experiments, the use of triploid grass carp resulted in a significant reduction in *Cladophora* yields.

8.6 It can be concluded that grass carp adapted to the artificial conditions experienced in a typical South African concrete-lined canal, and thrived to reach biomass increases of more than 300% in a period of 6 months.

8.7 The ability of the grass carp to utilise the filamentous algae, that otherwise would have been lost to the fish community present in the canal, resulted in a detritus chain which is utilised by other fish species, such as *Labeo capensis* and *Cyprinus carpio*. This observation may validate the potential application of certain aquaculture methods in South African irrigation canal systems.

8.8 All evidence exists that biological control with sterile grass carp will be more cost-efficient than the other control options. Although there will be an initial capital layout to safely accommodate the fish in a canal system, savings will realize on the medium to long-term.

8.9 High losses of sterile grass carp due to theft and escapes over blocked mechanical grids should be addressed before triploid grass carp can be put into full-scale operation as bio-control mechanism for aquatic weeds in irrigation canals. The operational problems associated with the blockage of mechanical grids should also receive attention. The possible application of electrical fences to replace the conventional grids could be the answer to this problem.

8.10 There can however, be no doubt on the value of this aquatic weed control mechanism to the current Integrated Aquatic Weed Management Programmes (IAWMPs) of the Department of Water Affairs and Forestry.

CHAPTER 9

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Problem blooms of *Cladophora Glomerata* and *Oedogonium Capillare* in South African irrigation canals

MAP Joska • JJ Bolton • R le Roux

Two problem species of filamentous algae were identified. *Oedogonium capillare* occurred in the lower pH water in the canals of the Breede River System, and *Cladophora glomerata* occurred in alkaline waters elsewhere in the country.

A satisfactory method of monitoring the time and rate of algal invasion was developed during the project. This involved fastening plastic petri dishes to a board suspended in the canals in such a way that they could be detached for laboratory examination.

There were a number of cases of illegal control with copper sulphate, possibly by the farmers themselves, which made the recording of the growth of algae related to environmental conditions frustratingly difficult for the project team. However, it was established that *Cladophora* recruitment can occur throughout the year. During the project *Oedogonium* blooms were confined to only one part of the Breede River System. Control with copper sulphate is easier in this system as the water is naturally slightly acid to neutral, and does not need the pH to be lowered before treatment.

Laboratory culture of Cladophora is difficult, but a technique was developed which gave acceptable results. This allowed some laboratory work on basic growth requirements, as well as determining the relationship between copper uptake and environmental variables. This, *in turn, enabled specific recommendations to be made regarding the use* of copper sulphate in the control of the algae.

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