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The control of benthic algae in Grootdraai water distribution canals

by

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1. INTRODUCTION

The benthic alga *Cladophora glomerata* has caused problems in a number of instances in South Africa. Noteworthy cases are at Hartbeespoort and Roodeplaat canals. Overabundant development of *Cladophora* was also experienced after construction of the water supply canal below Grootdraai Dam.

The purpose of this report is to describe the progress in the development of a control strategy for the *Cladophora* problem at the Grootdraai system.

2. PROBLEMS CAUSED BY *CLADOPHORA*

The major problems reported for Cladophora in South Africa occur amongst mainly at water supply canals below Hartbeespoort, Roodeplaat and Grootdraai Dams.

2.1 Problems caused at Roodeplaat Dam

The overabundant development of *Cladophora* in Roodeplaat canals cause mainly blocking of syphons and to a lesser extent clogging longweirs. Raw water supply problems are experienced as a result of this but no costs of treatment are available.

2.2 Problems caused at Hartbeespoort Dam

Cladophora causes mainly blocking of longweirs, clogging of syphons and miscalibration of pressure weirs at Hartbeespoort canals. This results in water losses from the canal of up to 50 percent. Furthermore as the total force of some 40 labourers engaged continuously for about 4 months in the removal of weed to maintain the carrying capacity of the canal. This weed removal amounts to some R45 000 - R55 000 per year. Chemical treatment has reduced this amount by some R15 000 per year. With more treatments, costs may be further reduced to about R8 000 per year.

2.3 Problems caused at Grootdraai Dam

Significant problems have arisen at the Grootfontein Pumping Station because of the blockage of the trashracks, the rapid lowering of the water in the wet well and the tripping of pumps. These large motors are designed for only about 700 - 1 000 starts and in the starting mode the system is subjected to higher stresses. In addition a higher electricity cost arises due to the peak demand during starting. No hard figures are however available.

At present there are no capacity problems in the canal but this would arise at the final pumping rate of 15 m^3/s. There is no evidence that the weed is causing major problems in the pumps although at Grootfontein the filters of the cooling pumps which use water abstracted from the canal required more frequent cleaning than normal.

At Grootfontein Pumping Station about 6 loads of 5 ton of algae are removed each day. Two labourers were working on the screens before the forebay and three on the screens at the pumphouse. All of the algae for January was placed on one pile and it was estimated that the dry, compacted volume was about 80 m^3. Labourers have to be employed round the clock for the cleaning of the screens. This is a small effort in comparison to that at Hartbeespoort.

3. LITERATURE SURVEY

The occurrence of *Cladophora* in South African water systems is not unique.

Cladophora is probably the most abundant filamentous alga in water systems throughout the world (Whitton, 1967). It causes nuisances in both large water bodies (Herbst, 1969; Dunst *et al*, 1974) and water carrying structures such as irrigation canals (Hayes *et al*, 1976; Bruwer, 1979).

Management problems caused by *Cladophora* in irrigation canals include the following: the resistance to water flow is increased resulting in the reduction of the carrying capacity of the canal; costly cleaning operations are necessary which result from mats of algae that clog trashracks, measuring devices and other water management and distribution equipment (Hayes *et al*, 1976).

Flowing waters provide a comparatively difficult environment for the study of algal communities, reflecting the problems associated with fluctuations in physico-chemical conditions of lotic habitats and the inadequacy of many sampling techniques (Round, 1970; Potter *et al*, 1975; Moore, 1977).

A variety of factors that influence the appearance and disappearance of *Cladophora* in flowing waters have been described, the main ones being temperature, light, nutrients and current velocity. The biology of *Cladophora* in fresh waters has been adequately described (Whitton, 1970).

3.1 Temperature

Temperature appears to be one of the most important features regulating the occurrence of *Cladophora* in flowing waters. Taft and Küshler (1973) observed the replacement of *Cladophora* in the Western Basin of Lake Erie by *Ulothrix* when the water temperature fell below 10°C. Storr and Sweeney (1971) found that their laboratory results agreed well with field observations. They found the optimum temperature for *Cladophora* to be 18°C with 25°C causing cessation of growth. Adams and Stone (1973) found the highest photosynthetic rates for Cladophora when temperatures were between 19 and 25°C, lower rates above 25°C and significantly lower rates when temperatures were between 9 and 16°C. Moore (1978) found at thermal generating stations that Cladophora growth was initiated at approximately 11°C.

Wong _et_ _al_ (1978) found in an analysis of temperature and biological growth occurrence data that _Cladophora_ was dominant up to 18°C and the upper temperature tolerance for _Cladophora_ was 23,5°C whereafter the community switched to _Potamogeton_.

3.2 Nutrients

Wong and Clark (1976) found that the critical nitrogen level for _Cladophora_ lies between 12 and 15 mg N/gram dry weight of algal tissue. They found the critical total phosphorus level to be 1,6 mg P/gram dry weight. From a previous relationship they found that this critical tissue phosphorus concentration corresponded to a phosphorus concentration in the water of 0,06 mg/ℓ (Wong and Clark, 1976).

Pitcairn and Hawkes (1973) on the other hand found that growth of _Cladophora_ in flask culture was significantly reduced by phosphorus concentrations less than 1,0 mg/ℓ but not significantly increased by levels above 1,0 mg P/ℓ. Similar experiments with natural river water resulted in a maximum growth concentration of 2,5 P/ℓ in one case whereas a second collection of river water with a higher nitrogen content resulted in a maximum growth concentration of 0,95 mg P/ℓ.

3.3 Current velocity

Schönborn (1976) states that it has been known for a very long time that the biomass of algae in a stream decreased with an increase in current velocity. It was found on the Saale River that Cladophora can no longer develop at a current velocity of 0,60 m/s (Schönborn, 1976). On the Saale River Cladophora normally begins to develop during April. In a certain part of this river Schönborn (1976) also found that the development of Cladophora was delayed from March/April to sometime during July and this delay could specifically be ascribed to the increased velocity of flow based on the quantity of water.

Horner and Welch (1981) found that periphytic algal accumulation on river stones was enhanced by current velocity increased up to 0,50 m/s provided nutrient availability did not restrict algal growth. This nutrient limitation was found to exist when orthophosphate phosphorus concentration decreased below 40 to 50 ug/ℓ. Velocity increments above 0,5 m/s was found to erode an increasingly greater proportion of periphyton growth.

4. DEVELOPMENT OF A CONTROL STRATEGY

In the development of a control strategy for the control of Cladophora in open concrete canals the following interactive processes were defined from the literature (Figure 1). This is a fairly simple representation but was considered adequate to identify the components that could be manipulated in some way or other to effect a control strategy.

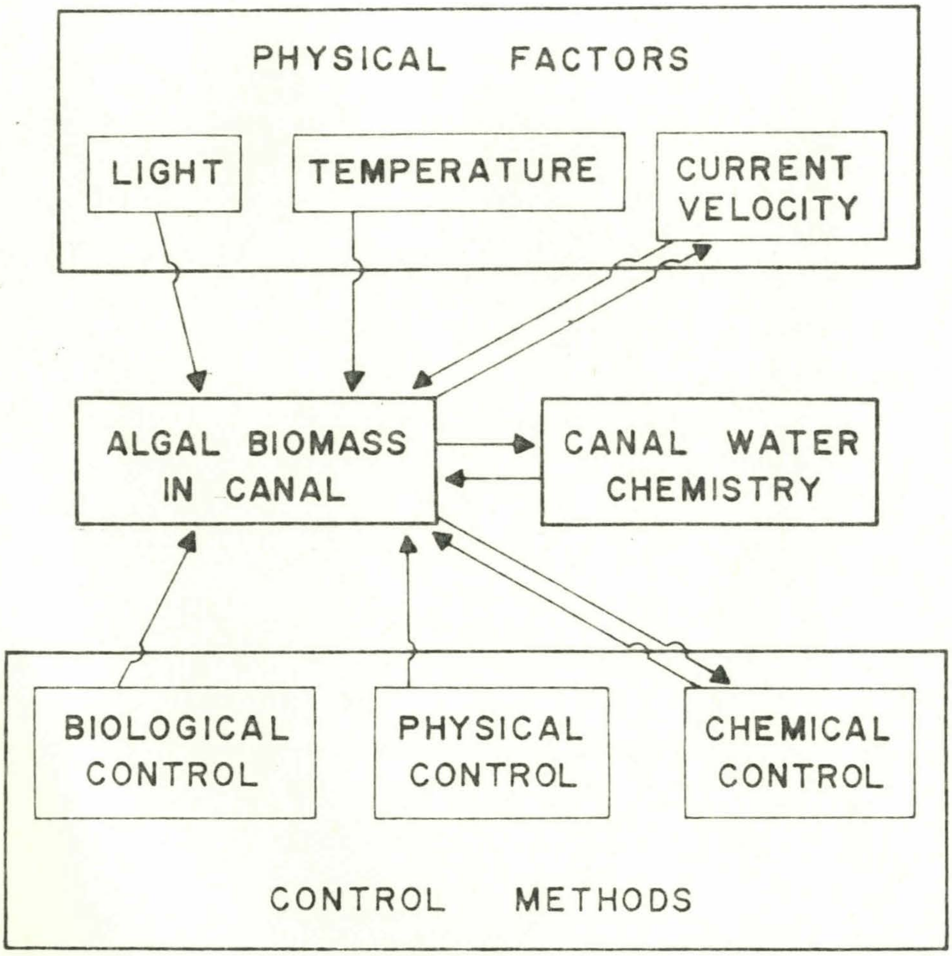

FIGURE 1: Interactive processes considered in the development of a control strategy for *Cladophora* in open concrete canals

Basically the algal biomass in the canal was considered a function of the physical factors light, temperature and current velocity as well as the water chemistry of the canal water. The potential control strategies that could be considered to reduce Cladophora biomass consisted of physical control such as mechanical harvesting or manipulation of physical factors such as light, temperature and current velocity; chemical control by means of algicides or alteration of water chemistry; biological control by means of, for instance, herbivorous fish.

In the development of a control strategy important considerations are that

(i) the chosen control method should be applicable while the canal remains fully operational;

(ii) the chosen method should not pose a threat to the uses to which the canal water is put such as coding water, irrigation water, livestock water and to a lesser extent wash and drinking water;

(iii) the chosen control method should be successful on a cost benefit ratio;

(iv) the chosen control method should be both successful and require minimum manpower inputs for operation.

5. COMPARISON BETWEEN THE OCCURRENCE OF CLADOPHORA IN THE THREE DIFFERENT SYSTEMS (HARTBEESPOORT, ROODEPLAAT AND GROOTDRAAI)

Cladophora is a threadlike green alga and occurs in these supply canals attached to the canal wall in an apparent definite zone submerged beneath the water surface. Our experience with the control of this alga is based on work done on the canals below Hartbeespoort, Roodeplaat and more recently Grootdraai Dams.

Both Hartbeespoort and Roodeplaat Dams receive large quantities of sewage effluents and are nutrient rich systems. The continuous flow of nutrient water down the canal results in *Cladophora* developing to lengths of some 30 m. Although Grootdraai Dam does not receive sewage effluents and the canal water therefore has much lower nutrient concentrations, the continuous flow of water results in *Cladophora* attaining strand lengths of up to 21 m.

In the Hartbeespoort and Grootdraai systems the *Cladophora* growth occurs in a distinct zone on the canal sidewall. This zone which in all three instances have an upper limit of some 0,5 m below the water surface extending down the wall for a further 0,5 m in the vertical plane along the canal wall. The occurrence of *Cladophora* in this band-like configuration is suspected to be a function of small fluctuations in surface water level coupled to light attenuation with depth. In Roodeplaat Dam the canal is much shallower and the *Cladophora* occurs virtually throughout the under-water area of the canal.

The water in both Hartbeespoort and Roodeplaat canals are very clear whereas the water in Grootdraai canal is turbid. The Cladophora in Grootdraai Dam appears to be able to grow under much lower light intensities than in Hartbeespoort Dam. The light climate in micro-Einsteins per second in the open canal sections of Grootdraai, Hartbeespoort Dams, single and double layer shaded section of Hartbeespoort Dam is shown in Table 1.

TABLE 1: Light climate under various conditions in Hartbeespoort and Grootdraai canals

Depth (m)	Light intensities in μE^{-s}			
	Hartbeespoort Dam			Grootdraai Dam
	Open canal	Single layer shade	Double layer shade	Open canal
0,02	1 150	500	150	750
0,1	–	–	–	550
0,2	–	–	–	450
0,3	–	–	–	400
0,5	850	310	70	100
0,75	750	210	60	30
1,25	500	120	30	10

There is a drastic difference between the light climate of the three respective sections in Hartbeespoort Dam. Some 1 150 μE^{-s} was recorded immediately below the surface in the open water whereas only 150 μE^{-s} was measured at the similar depth under the double layer shaded section. A similar situation was recorded at the bottom of the canal at depth 1,25 m. In the open canal in Hartbeespoort Dam Cladophora occurs in a narrow band between depths 0,5 and 0,8 m on the side walls. Very little algal growth occurs on the bottom of the canal. The corresponding light ranged between 730 and 850 μE^{-s}. Under the single layer shaded section the odd tuft of Cladophora was noted while under the double layer shaded section no Cladophora growth occurred at all. This is not surprising if one considers that the measured light maxima of 500 and 150 μE^{-s} respectively are both lower than the bottom of the light range where Cladophora still grows well in the case of Hartbeespoort Dam.

In the case of Grootdraai Dam the Cladophora occurs in a narrow band between some 0,12 and 0,75 m below the water surface. Corresponding light climate ranges in this instance between 500 and 30 μE^{-s}. Under bridges in Grootdraai canal where Cladophora does not grow due to shading the light intensities measured were also below 30 μE^{-s}. From the above data it is thus clear that Cladophora in Grootdraai canal occurs under a much lower light climate than in Hartbeespoort canals. The reason for this is not known and needs further investigation.

The occurrence of Cladophora in Hartbeespoort and Roodeplaat Dams over the annual cycle is cyclic: Cladophora starts to develop in these canals during August each year when water temperature reach approximately 12 to 13°C. Growth in Roodeplaat canal continues throughout the summer season until growth is terminated by the decrease of temperatures below 13°C with the onset of the winter season. The growth of Cladophora in Hartbeespoort canals is terminated mostly during the middle of the summer season by repeated light attenuation caused by extensive rain events washing sediment into the canal. These turbid conditions lasting for about three days coincide with the die-off of Cladophora.

Observations on the seasonality of occurrence of Cladophora in Grootdraai canal has not been made but there is no reason to believe that it will be any different to the situation at Hartbeespoort Dam which is typical of the worldwide situation.

It may be stressed at this part that the green scum (blue-green Microcystis algae) observed in Grootdraai Dam bears no relation to the Cladophora observed in the canals.

5.1 Development of Cladophora in Grootdraai canals during the summer of 1982

The first inspection of Cladophora in the canals were performed at the beginning of September 1982. The whole length of the canal of about 35 km was inspected by means of a three pronged grappling hook. This meant amongst other difficulties, such as dangerous muddy roads immediately alongside the canal, the open and closing of about

80 locked gates. During this inspection only very small tufts and small attached algal mats were found for the whole length of the canal occurring in a band 0,1 to 0,6 m below the water surface.

During the beginning of January 1982 it was decided by Division of Operations to dry the Grootfontein forebay and some 3 km of canal upstream to inspect the situation of algal material clogging trash-racks. This is made possible by reduction in flow and operation of a system of weir boards whereby the water level in the canal may be manipulated. This presented the first opportunity whereby an under-water inspection of the algal biomass in the canal could be inspected in detail.

A startling discovery was that in the first 12 km of open canal the algal biomass consisted of the same small tufts and small attached algal mats as observed during September 1982. Within 12 km to 14 km downstream from the beginning of the canal the Cladophora exhibited a transition from a short woolly structure to a strandlength of some 2 m. At 25 km the strandlength that increased to between 4 m and 11 m depending on the magnetic concentration of the canal. Immediately above Grootfontein forebay strandlength had increased to between 14 m and 21 m. The band of biomass was still limited between 0,4 and 1,0 m below the water surface on the sloping side-walls of the canal.

Another underwater inspection was carried out some three weeks after the mentioned flow reduction. No algal biomass could be found in the section immediately above the Grootfontein forebay upstream to the first weirboard. Upstream of the weirboard the algal biomass was also reduced to odd tufts. This observation is confirmed by the fact that no algae were removed from the trash-racks at Grootfontein forebay at the time.

The last underwater inspection of the summer was carried out at the end of March 1983. During this inspection still very little algal biomass could be found in the canal. Again the observation is substantiated by the observation that virtually no algae were removed from the trashracks. These observations are discussed in a cause/effect relationship under paragraph 6.3.

6. CLADOPHORA CONTROL OPTIONS FOR GROOTDRAAI CANALS

The available control options for Cladophora management at Grootdraai canals consist of either chemical, physical and biological control or a combination of the three.

6.1 Chemical control

Successful chemical control of Cladophora has been applied at Hartbeespoort Dam canals by lowering the pH of the canal water to pH 6,0 by addition of concentrated commercial sulphuric acid and simultaneous dosage of copper sulphate to a final concentration of 0,5 mg/ℓ for a period of eight hours. One such dosing lasts for a period of approximately six weeks.

Chemical control could be applied at Grootdraai canals but concern has been expressed about the influence of copper in solution on the corrosion protection of the piping and pumps. Uncertainties that exist on chemical control at Grootdraai are whether the sediment in the water even at low pH would allow the copper to remain in solution; whether the plug of dosed water could be run to waste and the supply interrupted for about 10 hours; and the amount of acid needed to lower the pH to about pH 6,0. A controlled short-term experiment similar to that employed at Hartbeespoort Dam could render valuable information on the success rate of a chemical control strategy.

6.2 Biological control

Biological control refers to the control of Cladophora by means of herbivorous fish. These systems are attractive, although difficult to implement, because they are not labour intensive once implemented and they have the lowest cost benefit ratio of all the control methods. The experience thus far at Grootdraai Dam is not one of success and there are a number of reasons for this.

The decision for a biological control of <u>Cladophora</u> in Grootdraai canals came at a stage when there was already abundant algal growth. This form of control had furthermore never been tried before in South Africa. The summer season of 1982/83 was thus seen as an experimental phase during which we would get to know the system and carry out some initial work with maintaining fish in the canal by means of various barriers.

6.2.1 Design of the experimental area of biological control

Three fish species were considered initially namely the common carp (<u>Cyprinus carpio</u>), the grass carp (<u>Ctenopharyngodon idella</u>) and the red-breasted kurper (<u>Tilapia sparrmanii</u>). Of these species the grass carp is difficult to obtain in large numbers, the red-breasted kurper is small and therefore difficult to contain by means of barriers. The common carp is the most easily obtainable in large numbers and because of its size easily contained by barriers. It may be argued that carp is not a herbivorous fish. The senior author has, however, observed common carp in canals overseas feeding on the biota which occur amongst the <u>Cladophora</u> and on the canal wall, in the process dislocating the algae from the canal wall. It was therefore decided to use only common carp in the initial experimental stages. These were to be netted in Grootdraai Dam and trasported to the experimental section in the canal. Once experience had been gained with common carp additional introductions of grass carp would also be made.

The selection of the experimental section of the canal was important. It had to seal off an area with algae but not so much that the barrier would block continuously. There was no opportunity to make an underwater inspection of the canal. Furthermore, it was expected that the algae would not have developed fully due to temperature effects. Selection of the experimental section was thus based on our experience with Hartbeespoort and Roodeplaat canals. In the latter the Cladophora start developing 2 km downstream from the beginning of the open canal and are well developed some 5 km downstream. A similar situation was assumed to occur at Grootdraai Dam and the barrier was installed some 7 km downstream from the beginning of the open end of the canal. The barrier was graciously constructed by Division of Operations at Grootdraai Dam.

Stocking of the experimental section with common carp commenced during September 1982. Carp densities in Grootdraai Dam were very low and the catch per unit effort of 100 m seine net was 2,3 fish per net haul. This is extremely low if compared with a similar excersize on Bloemhof Dam where the catch per unit effort was 25 fish per net haul. Whereas it was aimed to stock the experimental section with 400 fish only 90 fish could be obtained under the circumstances.

Immediately after stocking the mesh barrier became blocked with plastic bags, short strands of algae and other debris. This resulted in the water overtopping the barrier by some 0,2 mm. Fish introduced close to the barrier were observed to escape downstream over the barrier and were lost from the experimental area. When the barrier was constructed the available mesh used had longitudinal gaps of 50 by 15 mm as opposed to a design opening of 80 by 80 mm. The situation was greatly improved by enlarging the gaps to 50 by 55 mm longitudinal section by means of hand-operated side-cutter. This necessitated removal of the screen from the water for a period of about three hours, thereby rendering the barrier non-effective. It is unknown whether the introduced fish escaped downstream during this period.

6.2.2 Fate of fish and effectiveness of control on Cladophora

Inspection of the effectiveness of control of the fish on the algal biomass was performed at the beginning of January 1983. I stated previously the Cladophora did not develop well in the experimental section of the canal. Biomass consisted of a thin algal film on a sediment-laden cake which floated when dislodged. The majority of the material sampled during the biomass determinations consisted of this sediment, a material that would not be controlled by fish. This "biomass" as determined above and below the barrier of the experimental section was similar.

During March 1983 the experimental section was netted to see whether any fish were still present. This netting operation was done in a downstream direction. The screen barrier was blocked by debris at this stage and water was overtopping the upper edge of the barrier by about 0,2 m. When the net had moved to within

100 m upstream of the barrier close observation for any fish going over the top was kept. As the net moved down to the screen two carp were observed to cross over the barrier.

6.2.3 Use of alternative barriers

It was also suggested that the authors investigate the use of electrical barriers to maintain fish in the canal. These systems have been developed for shark control in marine systems. It was found that no definite design criteria existed for the fish species envisaged and the freshwater environment. The costs quoted by the National Physical Research Laboratory of the CSIR for building the electrodes, supervising the installation and getting that barrier operative would amount to R48 000. This price was not acceptable to Operations Division. The authors also agree that it is prohibitively expensive and negotiations are currently under way to see whether a drastic reduction in price can be effected.

6.3 Physical control

The only physical control method actively performed at Grootdraai canals was the erection of bar screens immediately before Grootfontein forebay as well as the pump intakes. Cladophora caught in these screens were then manually removed by labourers. No clear facts on the amount of material removed could be obtained but situations arose where the pumping rate was affected due to inadequate removal rate.

Some other physical manipulations such as alteration of current velocity, light climate and dessication of algae were inadvertently performed due to pumping operation. Observations made of changes in the biomass of Cladophora that could probably be related to these alterations in physical factors, merit further investigation.

7. DISCUSSION

The boundary conditions within which a control strategy for the overabundant development of Cladophora at Grootdraai must be developed had been changed often by Operations Division during the past summer. Boundary conditions for control have still not been finalised by Operations Division. For lack of this the following boundary conditions were formulated for future research on the project by the research team at the Hydrological Research Institute.

(i) A control strategy will be sought within the options of biological, physical and chemical control methods or a combination thereof;

(ii) the selection of an alternative will be based on a cost benefit basis;

(iii) it is assumed that pump rate can be altered within reason of that of demand;

(iv) the proposed control strategy, once implemented, should also be less labour intensive than the current removal operation at Grootfontein pump station.

(v) Operations Division will have no "fish farming type activities" expected from them.

Observations at Grootdraai during the past summer season have yielded information on Cladophora control within the boundary conditions as spelled out, that hold great promise in formulating our future action in regard to the problem. These will be discussed under the various control options.

7.1 Biological control

Based on previous experience and the most recent advances overseas the research team is still of the opinion that the most cost effective long-term solution to the problem will be by means of limnobiological control making use of fish. Past experience has shown that keeping fish in sections of the canal by means of physical barriers are very difficult due to clogging of screens and an adversion to make staff available to clean these screens. Experience has also shown that fish are not as easily available as originally expected. The design and timing of the experiment due to unforseen circumstances was such that no information could be gathered on the effectiveness of fish against Cladophora in Grootdraai canals.

We have no idea where the other 88 introduced carp went (remember 2 of the 90 were seen crossing the barrier). We have firm reason to believe that they are still in the canal. This statement is based on observations made by Mr. Moll at Grootfontein since the time of introduction of carp on all dead fish taken from the forebay. These consisted mainly of moggel (Labeo umbratus) but no dead carp were taken out. These moggel (some of them quite large) were not introduced and must thus have come through the pump. This fact is borne out by some having injury marks on their bodies. We expect all moggel to die in the canal though as they are known not to be able to tolerate any continuous current.

Our efforts and experience on Grootdraai during the past summer have, however, given us valuable insight into the problem. After analysis of the data we are convinced that the information gained has eliminated a number of uncertainties and that we now actually have a much better basis from which to perfect a biological control strategy for the problem than at the beginning of summer 1982/83.

7.1.1 Uncertainties related to using fish as bio-control at Grootdraai canals

Certain uncertainties exist about the procedure of using fish as bio-control at Grootdraai canals. These are mainly the following, not in their order of importance:

(i) What stocking density is needed for adequate control of Cladophora;

(ii) what is the rate of consumption of the Cladophora by the fish;

(iii) are oxygen levels adequate at all times to prevent fishkills;

(iv) what will the fish feed on in winter when Cladophora has died off;

(v) will fish need supplementary feeding in winter;

(vi) will fish breed in the canal;

(vii) how will fish cope with the continuous current;

(viii) what will happen to fish if the canal is drained completely;

(ix) what about commercial exploitation;

(x) how will fish be maintained in the canal;

(xi) will fish all move downstream, upstream or upstream and downstream in equal amounts;

(xii) how will fish negotiate weirboards during upstream movement.

7.1.2 Biological control workplan for summer 1983/84

In order for biological control to be effective the controlling agent (fish in this instance) must be present in adequate numbers for control before the agent to be controlled are present in overwhelming numbers (Cladophora in this instance).

As we expect Cladophora to start developing again in the canal when canal water temperatures reach about 13°C fish must be introduced by the middle of September. We envisage to go large scale and introduce enough fish to control Cladophora over at least the nuisance length which consists of the last 28 km of the canal. This length of canal corresponds roughly to 30 ha of wetted canal area and an area of 5 ha with Cladophora attached to it, slight fluctuations in canal depth taken into account. A stocking density of a minimum of 75 fish/ha wetted canal area is aimed at. Stocking will start in June 1983 and commence until the desired stocking density is achieved.

The stocking pattern will be to start with the section of the canal from Grootfontein forebay upstream to the first weirboard. Stocking of this section will proceed until the desired stocking density has been achieved. Once this has been achieved the section from the last weirboard to the second last weirboard from the forebay will be checked for fish by means of netting before this section will be stocked to the desired density. This process will be repeated until the 28 km of canal is stocked. Observations here should provide answers to uncertainty on how fish will negotiate weirboards in an upstream fashion. To find out whether fish move mainly up or downstream it is necessary to check the bottom section on occasion to see whether the fish numbers increase here or not. If change in numbers do occur we will have to check other sections as well.

Fish will be maintained in the canal by the existing double grid barriers currently in operation in the forebay at Grootfontein. These are adequate to prevent carp from passing through. They have to be maintained in any case and would not exert any more maintenance effort on behalf of Operations Division manpower.

On the question of stocking density and consumption rate only regular monitoring of the effect of the fish on the <u>Cladophora</u> biomass will supply us with this information.

Oxygen levels have been regularly monitored in the canal during the past summer and have always been above 6,0 mg/ℓ, even at night in the section of the canal with the densist algal growth. It is thus not anticipated that fishkills will occur due to deoxygenation.

On the matter of obtaining enough fish to stock, a few factors have changed in our favour. Both Vaal and Grootdraai Dams have had their levels severely drawn down. Our experience has shown us that under these circumstances the fish biomass is concentrated on an area basis and therefore should our catch per unit effort increase. Past experience have shown that we have no problem in maintaining dense populations of fish (40 carp/black garbage can) alive with no ill effects for a period of four hours. It furthermore apppears as if we will be able to obtain red breasted kurper and grass carp in some quantities from Provincial fisheries.

On the other uncertainties it can only be said that additional feeding of carp and red breasted kurper is not seen as necessary during winter but grass carp may need some form of additional feeding. Carp and red breasted kurper will breed in the canal but grass carp will not. All three species have been shown to be able to cope well with the current velocities present in Grootdraai canals. The fingerlings may have difficulty when the fish breed. There are, however, quiet areas immediately upstream of weirboards. On the subject of commercial harvesting it can be said that everything related to the bio-control system in Israel National Water carrier is financed by money generated by the commercial exploitation of the fish.

Finally, as fish are known not to be able to survive out of the water environment it is expected that they would die if the canal is totally drained. If the canal has to be drained it may be possible to save the fish by netting and temporarily holding them in small farm dams from where they may be restocted.

7.2 Control by means of alteration of physical factors

Observations made during changes in pumping rate has given us reason to believe that the possibility exists to control the growth of Cladophora by exploitation of the fact that certain physical factors are related to pumping rate. These factors are dessication, light climate and current velocity.

7.2.1 Dessication

It was observed during lowering of the water level at the section of the canal from the last weirboard to the forebay for a period of eight hours by 1,2 m that the Cladophora was exposed. As previously mentioned strands of 21 m were measured. During biomass determinations some three weeks later it was found that no Chladophora was left on the canal wall. During the last inspection some $2\frac{1}{2}$ months after the dessication period still no Cladophora could be found. This treatment is a possibility that can be very effective provided that structural problems with the concrete lining of the canal do not arise.

7.2.2 Alteration of current velocity and light climate

At the time when the water level was dropped at the bottom section of the canal the pump rate was drastically reduced. This resulted in the current velocity also being reduced in the whole length of the canal. Water levels above the last weirboard dropped only by about 0,2 m. At the time the algal biomass was similar to that below the weirboard. On inspection some three weeks later only small tufts or very short strands of Cladophora were observed. This situation existed along the whole length of the canal. At the last inspection some 2½ months after the dessication and pump rate reduction still only small amounts of Cladophora could be found on the canal walls. These observations were borne out by the fact that no algae were removed from the bar screens at Grootfontein pump station during the inspection period.

Either one of two or both factors may be involved in this observation. These factors are current velocity and light climate. Current velocity is important in nutrient supply. In systems with low nutrient concentrations the developed biomass is often a function of the rate of nutrient supply. Grootdraai canals is such a system. If the rate of nutrient supply is suddenly drastically lowered as it would with lowered current velocity the algal biomass may be reduced because of die-off due to nutrient limitation. At the same time a drop in current velocity would result in a lowering of water level. A lowering of water level would mean a corresponding displacement of the underwater light climate.

The depth range over which the Cladophora occurs stretches from depth 0,4 to 1,0 m from the surface. If it means that this growth range is solely a function of light climate then it would mean that with a lowering of water level for a depth of 0,2 m the top 0,2 m of the growth band would receive too much light and could probably be damaged. This would, however, mean that 0,4 m of the growth band occurring between original depths 0,6 to 1,0 m should have remained. This was not the case as observed at Grootdraai canals. If Cladophora is prone to light shock, something which would occur during rapid changes in light climate, then the whole growth band would be affected by a drop in water level.

A combination of the factors, current velocity and light climate may also be responsible for the observed disappearance of Cladophora. Under the "normal" current velocity the strands of Cladophora are observed to move in a wavelike fashion. Under the reduced current velocity this wavelike motion is greatly diminished. The strands of Cladophora move less and the selfshading effect of the Cladophora upon itself is greatly enhanced bringing us back to the concept of light shock as previously mentioned. The question remains thus "Did Cladophora disappear from the canal when the current velocity and water level dropped due to nutrient limitation or alteration of light climate or a combination of both"?

Our observations up to date does not resolve this question. If selfshading is the factor that limits the depth of underwater growth of Cladophora it should be relatively simple to determine this by experimental design. If however, this is not the case then it is going to be considerably more difficult to separate the influences of current velocity and light climate from each other. This would mean that the "normal" water level must be maintained while current velocity is reduced.

The disappearance of Cladophora from Grootdraai canals after the lowering of current velocity and level reduction holds up till now probably the most promise as Cladophora control measure at Grootdraai. Provision should be made in the operating procedure for lowering of the pump rate for periods of eight hours, say once a month.

7.2 Chemical control

Chemical control of Cladophora was perfected at Hartbeespoort canals. This was the first time in the world that pH reduction with commercial sulphuric acid coupled with copper as algicide had been employed in an irrigation canal. The technique proved to be successful with the added benefit of remaining fully operational.

The situation at Grootdraai is different in that fear is expressed for the action of copper on the corrosion protection of pipes and pumps. Uncertainties exist on the behalf of the researchers as to the following:

(i) Will we be able to reduce the pH successfully at a flow of 8 m^3/s as to the maximum flow treated at Hartbeespoort had been 3,2 m^3/s;

(ii) for what distance of canal will we be able to reduce pH with one dosing station at Grootdraai;

(iii) what would the influence of the sediment-laden water be on copper solubility and pH reduction;

(iv) what would the definite influence of copper (in solution as well as at pH 8,0) be on corrosion protection.

Many of these problems can be resolved if Operations Division can finance a dosing experiment at Grootdraai, preferably when there are algae present. The effects of pH reduction are not expected to extend beyond 30 km (24 as experienced at Hartbeespoort) and at this distance copper will disappear from solution and be bound onto the sediments.

8. GENERAL

There is firm belief that a solution to the problem can be found provided enough manpower and co-operation can be generated.

Adequate manpower can be supplied by the Hydrological Research Institute. Co-operation should mainly come from Operations Division

(i) on the real extent of the problem of the weed,

(ii) manpower to trek nets at Grootdraai,

(iii) information as required on pumping rates, tripping of pumps and the possibilities of fluctuating pump rates,

(iv) co-operation from Sasol and Escom on the effect of copper under various circumstances in aqueous solution on corrosion protection of exposed equipment.

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