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ASSESSMENT OF AQUATIC WEED PROBLEMS AND THEIR ECONOMIC SIGNIFICANCE IN GHANA

Report On

ASSESSMENT OF AQUATIC WEED PROBLEMS AND THEIR ECONOMIC SIGNIFICANCE IN GHANA

Prepared For

U.S. Agency for International Development

and

Ghana Water and Sewage Corporation

By

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INTERNATIONAL PLANT PROTECTION CENTER

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INTRODUCTION

The two reservoirs of highest priority in Ghana are the Weija and the Barekese, the main drinking water supplies for the capital city Accra (pop. 740,000) and the nation's second largest city Kumasi (pop. 345,000), respectively.

Weija Reservoir

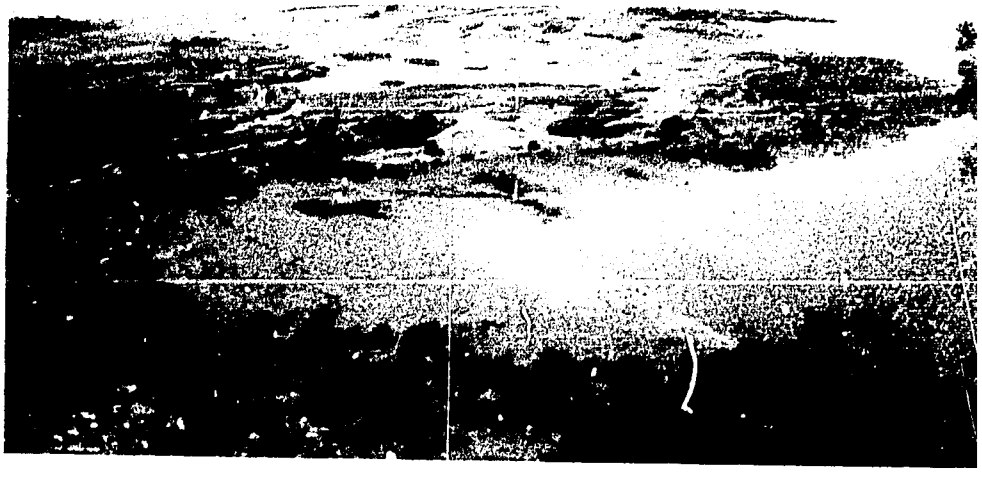
Weija Reservoir, fed by the Densu River and impounded in December 1974, is close to Accra in an area near the shore (Fig. 1) just north of the Winneba-Accra highway (Fig. 2). The twice-yearly peaks in discharge of this river correspond with the twice-yearly peaks in local rainfall (Fig. 3), with maximum discharge occurring in June. This maximum discharge is reflected in the yearly water level rise during impoundment (Fig. 4). At present, the dam is undergoing testing at close to the maximum level, 14.1 m (47 ft). This has resulted in a maximum inundation of 50 to 57 km^2 (14,000 acres) of surrounding land (Fig. 5).

Prior to construction of the new dam, a small natural lake and a dam which impounded water to a level of 8.1 m (27 ft) existed on the same site. This earlier dam created a weed-choked reservoir of 32 km^2 (8,000 acres) until its failure in 1968. It is not clear why this dam failed, but it seems to be a case of dam heightening with subsequent weakening of the original structure. The additional weight of flood water and weeds against the spillway contributed to its failure. The new dam is structurally superior and is equipped with rotary spillway gates (Fig. 6). It is an earth-filled dam with a compacted clay core; thus it cannot be overtopped.

Barekese Reservoir

The Barekese Reservoir, just north of Kumasi, is in the Ofin River Basin. Its dam was closed in February 1970 and the reservoir filled by May of that year. It is a narrow, elongated reservoir (Fig. 7) with a total area of 6.4 km^2 (1,600 acres). The Ofin River delivers a very

high discharge (4 times that of the Densu River at Weija), the maximum occurring just prior to maximum rainfall (Fig. 8). The dam encompasses a concrete spillway comprising 14 air-regulated siphons and an open central weir. The siphon intakes are kept clear of floating debris and weeds by screen bars and the floating material passes over the central weir. There is the possibility of large masses of floating material choking the siphons if the screen bars become clogged. This would cause more stress than the design allows, threatening the stability of the dam (Fiakpornu, 1973).



Floating islands of *Pistia* near Weija Dam.

Floating islands of *Pistia* near Barekese Dam.

ASSESSMENT OF AQUATIC WEED PROBLEMS

The local vegetation in the Weija area which was inundated by the reservoir was Guinea savannah, the typical vegetation of the Accra plains (de Graft-Johnson, 1977). No forest or trees were involved with the exception of occasional Borasus palms. In the earlier reservoir (pre-1968) and the natural lake, many aquatic weeds were present. These weeds were often bound together by the entwining roots of *Ficus congensis* and *Typha domingensis*, which grew into a mat 0.6 m (2 ft) in thickness. After impoundment in December 1974, the water surfaces remained relatively clear with much of the aquatic weed material relegated to the vicinity of the previous natural lake and the western edge of the new reservoir (GWSC, 1978). During the second quarter of 1976, the water level increased (Fig. 4) and a prolific weed growth followed. By the end of June 1976, it was estimated that about half the water surface was covered with floating weed masses. The general pattern appeared to be a rapid growth of the floating water lettuce *(Pistia)* followed in succession by invasions of grasses *(Echinochloa* and *Leersia)*, sedges *(Pycreus, Cyperus, Scirpus)*, ferns *(Cyclosorus)* and other herbs *(Alternanthera* and *Polygonum)*. The next-to-last stage was invasion by shrubs *(Mimosa)* and small trees *(Ficus)* or by the emergent bulrush *(Typha)*. The mats formed (referred to as sudd) were capable of supporting men.

In 1977 a weed survey was carried out by the Institute of Aquatic Biology (de Graft-Johnson, 1977). A list of all aquatic weeds from four sites surveyed is included in Appendix 1. On the basis of this survey it is possible to see some differences in composition of the sudd (Table 1). The most obvious change is a reduction in number of species farther away from the dam.

There are a number of other aquatic weeds in the reservoir *(Ceratophyllum demersum, Nymphaea lotus, Utricularia inflexa, Azolla africana,* and *Salvinia nymphellula)*, but they are of less concern at present than the sudd species. Later, after sudd clearance, the other weed species

may have to be controlled depending on future use of the reservoirs.

Table 1. Composition of the sudd on Weija Reservoir (de Graft-Johnson, 1977).

East - Weija	South - Machigeni	West - Domiabra	North - Ashalaja
Alternanthera sessilis	*Typha domingensis*	*Alternanthera sessilis*	*Alternanthera sessilis*
Cyclosorus striatus	*Leersia hexandra*	*Pistia stratiotes*	*Panicum maximum*
Eichinochloa pyramidalis	*Echinochloa pyramidalis*	*Polygonum senegalense*	*Paspalum orbiculare*
Ipomoea aquatica	*Ficus congensis*		
Pistia stratiotes	*Scirpus cubensis*		
Polygonum senegalense			
Scirpus cubensis			

No detailed report was available on the weeds of Barekese Reservoir, but from our observations, they did not appear to differ much from those at Weija. In fact, many of the species in Appendix 1 were seen near the barrier at Barekese.

Weed Growth

In both reservoirs, the question arises as to what caused this rapid weed growth, In earlier and much larger schemes such as Volta Lake, the initial weed growth consisted of a floating mat of *Pistia* which was later colonized by the sedge *Scirpus cubensis* (Okali and Hall, 1974a). This sudd did not survive the build-up of large waves on the lake. Today Volta Lake is not considered to have major weed problems in the open water (Opuku, 1976; Gaudet, 1978). However, in the sheltered bays and river deltas there is still a rapid growth of *Pistia* each year during flood seasons. This is thought to be due to an annual flush of nutrients (especially nitrogen, phosphorus and sulphur) washed in by surface run-off (Okali and Hall, 1974b).

The same process is at work at both Weija and Barekese. Here, nutrients come into the reservoirs at a high level. Chemical analysis of the Weija input (Densu River) and the Barekese input (Ofin River) shows

an average of 0.753 and 0.657 mg/liter of total nitrogen (1-year average for the Densu and 6-year average for the Ofin (Appendices 2 and 3). Using average discharges of 6 and 28 $m^3 \cdot s^{-1}$, we calculated a daily input of 0.4 to 1.6 tons of nitrogen. Based on average standing crop of aquatic weeds in the tropics (Gaudet, 1973), this would support the growth of 15 to 60 tons (dry weight) of weed per day. One estimate at Weija (GWSC, 1978) places one acre of weed at 500 yd^3 wet weight, or about 350 metric tons fresh weight, which is approximately 21 metric tons dry weight. Thus, the nitrogen input into either of the reservoirs could potentially support a growth of one acre of weed per day. Obviously not all of the nitrogen would be used for weed growth; much of it would pass directly through the reservoirs during periods of spilling. The point is that the daily nutrient flux is high enough to support good growth.

One result of this nutrient flux is the remarkable condition of the local *Pistia* plants. Neither of the USAID consultants assigned to this project has ever seen *Pistia* growing as well as it does in the two reservoirs. There it reaches a deep green, healthy aspect with no visible signs of insect injury. In fact, it resembles lettuce or cabbage grown under the best of hothouse conditions. The exceptional growth of *Pistia* must be the result of nutrient availability. A similar conclusion has already been reached by Okali and Hall (1974b) in regard to *Pistia* at the deltas of rivers entering Volta Lake.

The second obvious reason for such good weed growth is the slowing of the annual floods which normally scour Ghanian rivers, preventing weed growth (Hall and Polpe, 1968). This suggests that in new reservoirs now being built, for example the Kpong Reservoir on the Volta River, care must be taken to allow for aquatic weed control.

Effects of Aquatic Weeds

The rapid build-up of weed masses in both reservoirs could threaten both dams with collapse as happened at Weija in 1968. The new Weija Dam is an earth-filled, 20-million-Cedi project that cannot be overtopped because of the loss of lives, property, major highway and bridge, and water supply to Accra. The Barekese Dam, although less expensive and not earth-filled, could still be damaged, especially at the siphon portion of the spillway, resulting in an enormous expense to the Ghana Government.

Aside from the potential physical damage, a large loss in water quality has already occurred in both reservoirs. Water quality at Barekese has been well documented (Fiakpornu, 1973; Amuzu, 1975) and will serve to illustrate the problem in general.

A. Origin of the Problem. The excessive growth of weeds in Barekese since 1970 has brought about anaerobic conditions (oxygen depletion), lower pH and a higher organic content in the water. Such conditions result in higher levels of dissolved iron. The decaying remains of vegetation impart an intense dark brown color and a pungent odor which are repugnant to the consumer. These conditions necessitate a water treatment scheme as follows:

B. Water Treatment.

1. Iron. The high iron content of the raw water in 1972 (5.2 mg/liter) required potassium permanganate treatment. Later pretreatment with lime was attempted (to change the pH, and hence iron solubility) but this interfered with flocculation. Eventually the iron content dropped (1.6 mg/liter) and it is no longer considered a problem.

2. Odor and low oxygen. Aeration is carried out on the raw water (dissolved oxygen range 0.0 to 1.4 mg/liter), improving water quality before it passes to the flocculators.

3. Suspended solids and organic matter. Alum is added (80 mg/liter) as the aerated water is passed to the counter-rotary clariflocculators where flocculation and sedimentation occur. Rapid gravity filtration follows.

4. Biological and pH. Filtration is followed by chlorine disinfection and pH adjustment with lime.

5. Color. Color is reduced, but not eliminated, by the above sequence.

C. Cost. This complicated scheme of water treatment as a result of aquatic weed growth has resulted in an increased cost of water to the consumer. Although it is not possible to say exactly what portion of the increased expenses are caused by the weeds, we can at least estimate the over-all increase. For example, we could use water from the Volta River at Kpong as a standard for raw water. This type of water costs ¢0.09 per 1000 gallons to treat before delivery to the consumer. On the other hand, water from Weija and Barekese costs ¢0.14 and ¢0.22 per 1000 gallons, respectively. Accra takes 11×10^6 gal/day from Weija, while Kumasi takes

10.5×10^6 gal/day from Barekese. This results in an excess cost of ¢200,000 and ¢498,000, respectively, or a total loss of ¢700,000 per year. Even after treatment, complaints are received about Weija water from Accra residents.

Succession of sedge grass on *Pistia*, Weija Dam.

Succession of grasses and other plants on *Pistia*, Barekese Dam.

WEED CONTROL

Chemical

Only two attempts have been made to control the aquatic weeds using herbicides, both conducted at Barekese Reservoir. In May 1970, an aerial application of Gramoxone-S was carried out without much success. The tall trees along the edge of this reservoir did not allow the plane to fly low enough to prevent loss of herbicide to the atmosphere. When another aerial application was made one year later much of the weed material succumbed. Consequently, a fish kill occurred 3 days after application. No follow-up was done, and subsequently the weeds grew back. Many of the sedges and grasses were unaffected. Residues were monitored and all tests proved negative except for a single detection of a minute trace of the herbicide (Fiakpornu, 1973).

Mechanical, Spillage

At Barekese weeds can be spilled over the central weir almost on a year-round basis. The amount of weeds that can be spilled is limited because the downstream channel is quickly filled by weed masses, resulting in local flooding. At Weija, weed spilling can only be done when the level is between 8.7 and 14.1 m (29 to 47 ft). Weed spilling is restricted to the one gate equipped with stoplogs (Fig. 6); the other gates cannot be used as they spill from below the water surface. Other problems at Weija interfere with weed spillage. For example, sudd islands cannot even be spilled over the gate equipped with stoplogs, because the spillway may become clogged completely. Previously, when 0.5 acres of weed was spilled it accumulated under the highway bridge downstream (Fig. 2, "The Bridge") and took 5 hours to clear. In general, spilling at Weija must be done cautiously as there is always the danger that fast spilling will put too much pressure on the weed barrier, which could give way with disastrous results.

Mechanical, Barrier

In order to keep the area clear immediately in front of the Weija

Dam, two 1.5 inch cables supported on floats were positioned across the narrow sector of the reservoir. This is at best a temporary measure effective only as long as excessive flooding or excessive spillage does not occur; then pressure on the barrier would be dangerous. At Barekese a smaller floating cable (0.75 in) has already given way because of chafing on the concrete anchoring piers.

Mechanical, Removal

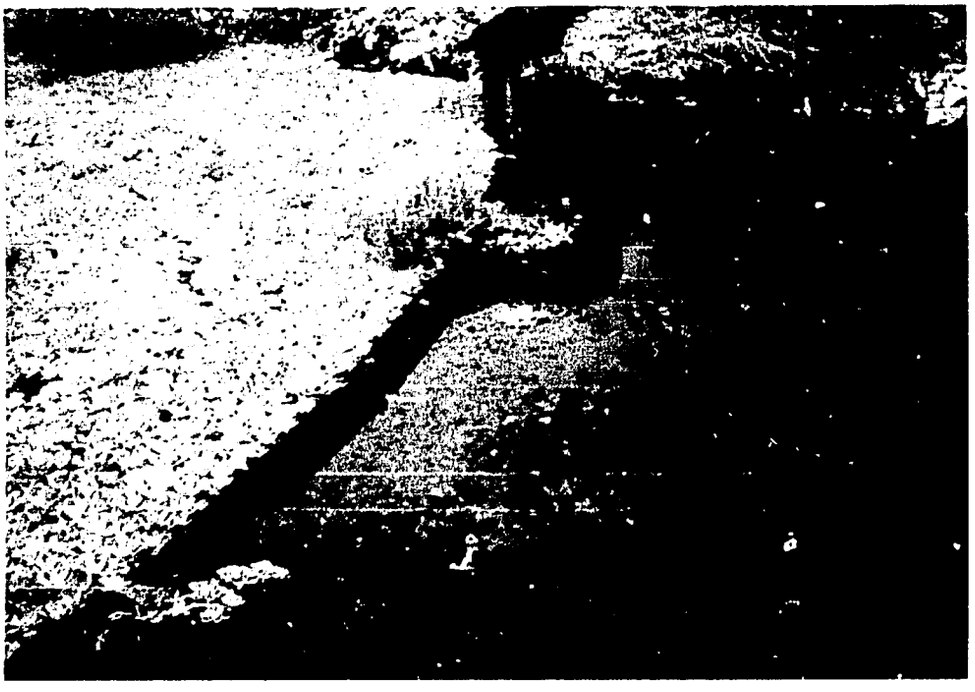
At Barekese one gang of workers removes weeds manually. They work in the upper northern section of the reservoir until the dry season in December while the weeds are compacted above the barrier. Later, southerly winds push the weeds downlake close to the dam. The labor force then shifts to the reservoir close to the dam from December to March. In March the wind changes, driving the weed mass back up the reservoir. This active work program is still not making an appreciable dent in the present weed mass. Also, it is thought (Fiakpornu, 1973) that a more efficient weed removal scheme would result in large quantities of dead rotting organic matter on the reservoir banks, causing a definite health hazard.

At Weija a more ambitious weed removal trial was carried out. There it was estimated that at least one acre (500 yds^3) must be removed daily to keep pace with the growth rate. During the trial a dragline attached to a tipper was used to haul floating vegetation close to shore where a clamshell or manual labor was used to remove it.

Biological Control

No biocontrol trials have been attempted. The fish fauna at Barekese (Appendix 4) is notably deficient in plant feeders. At Weija the weeds are at such an advanced stage of sudd formation that it is doubtful that plant-eating fish, were any present, could effect any natural control.

Floating islands of *Pistia*, Barekese Dam.



Retainer cables restraining *Pistia* growth, Weija Dam.

RECOMMENDED CONTROL PROGRAM

Immediate Alternatives

A. Chemical. Weed masses at both reservoirs could be controlled more efficiently using herbicides other than Gramoxone-S, which is more effective on submerged weeds. More efficient herbicides on sudd islands would be 2,4-D Amine for broadleaved floating weeds and Dalapon for sedges and grasses. Both of these herbicides have been suggested for use in the Kpong Reservoir in Ghana (Opoku, personal communication). They are available locally and are relatively non-toxic (Table 2). Gramoxone-S (or paraquat) would be effective against *Pistia* only.

Table 2. Herbicides for use in control of aquatic weeds (Opoku, pers. comm.)

Chemical Name	Application Rate*	Use and Limitations
2,4-D Amine (amine salt of 2,4-dichlorophynoxy acetic acid)	2-4 lb/acre after dilution in 100 gal water	Do not use treated water immediately. Do not apply near sensitive crops. Does not harm fish.
Paraquat (1,1 dimethyl-4,4 dipyridinium (Also, Gramoxone-S	1-1.5 qt/acre after dilution in 50 gal water	Controls *Pistia*. Do not use treated water immediately. Does not harm fish.
Dalapon (2,2-dichlor-proprionic acid	15-20 lb/acre after dilution 100 gal water	Controls grasses and sedges floating or rooted. Add wetting agent. Spray before plants mature. Does not harm fish.

* Refers to active ingredient

A mixture of the three herbicides is much more effective than Gramoxone-S alone. The cost of herbicide control varies considerably depending on application. A light airplane was used in the previous aerial spraying, but a helicopter is a better vehicle for application. In this report the cost of using such aircraft is not considered since we assume it may be possible to borrow a helicopter from the military or police and outfit it

for spray runs. Use of a single herbicide such as 2,4-D Amine, which costs ¢12 per pound in Ghana, would cost ¢23 to ¢47 per 100 gal mixture per acre. Added to this would be the local cost of hand labor (¢5 per day) and equipment rental. A gang of 36 workers over one year would cost ¢54,000. A conservative estimate for clearing weeds is ¢380,000 in Weija alone and in both reservoirs, ¢480,000. The cost would vary depending on the number of boats, motors and other equipment used.

B. Mechanical. The estimated cost of the dragline is ¢2,000/acre (de Graft-Johnson, 1977). Coupling the dragline with an extra tipper to haul the weeds away and using a clamshell to load the weed from shallow water into the tipper would result in a yearly cost of ¢750,000 just to keep pace with the weed growth in Weija alone. The recent report on the weed problem at Weija (GWSC, 1978) estimated that 3000 equipment days would be needed to clear the reservoir using a simple technique, costing a minimum of ¢6,000,000. If the weeds covered one-half of the reservoir, or 7,000 acres, removal by the more elaborate dragline method mentioned above would cost ¢14,000,000. In other words, the cost of weed clearance would lie somewhere between ¢6 and ¢14 million. Barekese, a smaller reservoir (1,400 acres to be cleared), would cost less to clear, but would still be expensive at ¢2,800,000.

Procedures

Based on past aquatic weed control efforts on the reservoirs and the alternatives discussed above, we suggest the following program of action.

A. Training. The Reservoir Maintenance Officer has undergone a training course in aquatic weed control at the Aquatic Weed Program, International Plant Protection Center, University of Florida. His training syllabus included: principles of aquatic weed management; chemical control; mechanical control; biological control; and herbicide residue analysis. During the period of training the GWSC should carry out a "holding action" on both reservoirs as outlined in our Interim Report.

B. Preparation. The Reservoir Maintenance Officer should immediately institute a program of monitoring both reservoirs which will continue during and after the clearing operation. The monitoring program should include the following:

1. Aerial infra-red photography of each reservoir directly after the 1978 flood period;
2. Daily environmental data such as wind speed and direction, reservoir levels, discharge, rainfall in the basin and sedimentation;
3. Water quality data such as phytoplankton species and density, full chemical and physical analyses, nutrients and herbicide residues (monthly except during weed control, when daily monitoring is necessary);
4. Periodic monitoring of emergency equipment to determine condition of the barrier, boats, spray equipment, motors, hand tools, life saving equipment and availability of tippers.

Some monitoring equipment is already available in the GWSC, but additional equipment especially useful for this purpose is listed in Appendix 5.

C. Mobilization. Consultants should be secured for the duration of the weed control program. We recommend Mr. A.K. Opoku of the Volta River Authority and Mr. K. de Graft-Johnson of the Institute of Aquatic Biology. The local consultants along with the Reservoir Maintenance Officer, a long-term consultant from World Bank and a short-term consultant from USAID will constitute the Weed Team.

All weed clearance equipment should be assembled, checked and serviced. Several basic items have been suggested by Mr. Opoku's work on Volta Lake (Appendix 6). On the basis of his experience it is suggested that initially two eight-man mobile crews be assembled for use at Barekese. One crew will be permanently stationed at Barekese while the other will be the nucleus of a larger task force at Weija. In addition to the two mobile crews, the existing 20-man shore crew should be used. Each crew should be composed of six laborers, one coxswain and one supervisor. All crew members must be able to swim and will be equipped with life belts at all times.

Arrangements must be made to use a helicopter for a minimum of eight separate spray applications, each application requiring 2 days use (one day for fitting spray rig and preparation and one day for the actual run). A spray rig which can be fitted to a helicopter must be located.

Finally, stocks of herbicides, wetting agents and spare parts for the spray rig must be assembled well in advance. An adequate supply of fuel and oil for all boats, helicopters and local transport must be provided.

D. Testing. Several herbicide mixtures should be tried at Weija, including Gramoxone-S + 2,4-D Amine; 2,4-D Amine + Dalapon; and 2,4-D Amine + Dalapon + Gramoxone-S. All mixtures should be spot tested with and without wetting agents (dilute liquid detergent or molasses). Carrying agents, if available, should also be used in the spot tests (for example, polyethylene glycol), depending on manufacturer's recommendation. Each combination should be spot tested using a hand sprayer and the results should be scored as ++, + or -, depending on whether the control is very good, fair or negative. Extensive trials or elaborate statistical analyses are not necessary since all three herbicides have been extensively tested previously by many workers. The manufacturers should be contacted to determine the best mixture for aerial application and, if possible, a representative should be present during the actual mixing and leading of the tanks.

If possible, a dry run of the helicopter with spray unit fitted should be done at the Barekese Reservoir. This will allow the pilot to familiarize himself with the terrain. A temporary landing pad must be marked out near the reservoir where the herbicides can be mixed and loaded early in the morning. (Caution: Spray applications in Africa should be done in the early morning to avoid mid-day and afternoon thermal wind currents. Otherwise a loss of herbicide mixture will result in poor application and drift.) Adequate water with drainage into a noncritical area must be supplied in order to flush and wash equipment. On the testing day all mobile and shore crews should participate in order to fully test all boats, radios and communication with area offices.

E. Action Program. The action program should begin during the start of the flood season at Barekese. There are several reasons for this:

1. In March and April the weed mass is compacted behind the barrier because of the change in wind direction;
2. Flood waters will bring a high discharge through the reservoir in April, washing out residues and resulting in maximum dilution;
3. The high rate of water movement will result in maximum aeration and maximum wash-out of decomposing weed matter.

Initial application will be confined to a center strip following the old river bed to open up a central "freeway" and allow the mobile crews to come into the weed mass. The day after the aerial application the mobile crews should begin near the barrier with a follow-up spray. On

the third day after the spray the crews should be able to penetrate further into the mass and begin work along the freeway, cutting up and towing out sudd islands. The cut portions will be brought to shore where the shore crew will haul them out for disposal. The shore crew will also carry out a similar follow-up operation along shore. Sudd islands will be cut with chain saws followed by long-handled straight spades, cutlasses, etc.

After 2 weeks the second application should be made, this time along both edges of the freeway. A helicopter is the only suitable aircraft for this, as the tall trees right at the edge of the reservoir restrict maneuverability. Directly following this last application both mobile crews will begin a second follow-up operation. At this point the weed mass should have been reduced to manageable size and one mobile crew can be transferred to Weija. At Weija the Weed Team and the experienced mobile crew will form the nucleus for an operation similar to that at Barekese, but on a larger scale. The mobile crew members should be dispersed into six or eight new mobile crews, and the spray technique, herbicide mixture, crew operations, etc. should be modified based on the experience gained at Barekese.

In both reservoirs provision should be made to alert fishermen and water consumers of the impending weed control program. Potable water in both areas may have an objectionable, muddy taste or a phenolic smell following each aerial application. Also, it may be necessary to cut off the supply for short periods of time if residues exceed certain levels. However, the basic idea behind this program is not to apply heavy doses of herbicide on any one occasion, but to apply herbicides that are known to be relatively nontoxic during periods of maximum dilution.

F. Assessment. Infra-red photographic coverage will be very useful following the control program. The comparison of photographs will enable the Weed Team to quickly assess the remaining weed cover. All consultants in the team should tour both reservoirs during the program to advise the Reservoir Management Officer on the progress of weed control. Expecially important is identification of any weed species showing resistance to the control measure.

G. Management. Management of the weeds should begin at Barekese after the second follow-up operation. Management will consist of a concerted effort to cut and tow out every remaining sudd island. When the wind shifts in December, all workers (one mobile crew and the shore crew)

should be mobilized at Barekese to collect the small floating masses of *Pistia*. The smaller masses can be fished out using the wire nets or towed to the spillway for spilling. After March of the second year, Barekese Reservoir should be mostly free of weed and management will be easier. The Regional Manager should carry out monthly checks and report on the weed situation. The mobile crew should be sent to chase down any reported weed infestation and the shore crew should be used along the banks.

At Weija, management will be possible only after considerable time, and it will be greatly assisted by the monitoring program of the Reservoir Management Officer. He should be able to predict the general pattern of weed movement based on his monthly summary of reservoir conditions. After the Barekese operation he should begin producing a weed situation report for Weija each month. With time and experience this report could be refined so as to predict where and when weed masses will be present. His mobile crews can then cut and tow sudd, spray *Pistia* mats, spill weed, etc., with some degree of accuracy.

H. Long-term Recommendations.

1. The nutrient input into the reservoirs, which is a large contributing factor to the present weed problem, will also be responsible for algal blooms after weed clearance. Thus, a long-term solution should be found to curb nutrient influx at both Weija and Barekese. This could take the form of a better system of local drains and sewers to ensure that all run-offs carrying pollutants be channeled through sewage plants.

Studies on specific weed problems such as the work of Okali and Hall (1974a) should be encouraged at the universities in Legon and Kumasi. The Institute of Aquatic Biology should be encouraged to follow weed succession in the sudd, algal blooms after weed removal, and local surveys of the aquatic weed flora and weed density in all reservoirs in Ghana.

2. A Biological Control program should be initiated through the Commonwealth Institute of Biological Control Laboratory in Kumasi. Ghana has an agreement with CIBC. It will be necessary to station a senior scientist at the laboratory to supervise the needed research.

By the time the weed situation is at a management level biological control agents should be available for release. CIBC has screened,

evaluated and released the grasshopper *Paulinia acuminata* for the control of *Pistia* in Africa. Other insects are in the evaluation stage including *Samea multiplicalis* from the West Indies and a species from Southeast Asia. Both are highly mobile moths with the caterpillar or larvae the effective stage in feeding on *Pistia*.

Biological control agents require time to become established and develop populations capable of having an impact on aquatic weed infestations. If biotic agents become established a delay of 2 to 4 years can be expected before significant management of weed infestations can be accomplished.

The prospects of controlling *Pistia* with fish or manatees are poor and do not warrant consideration. Certain fish species are excellent for submerged weed species, however, they have little preference for floating species.

Commitments

The GWSC has much equipment and resources that could be used during the weed control program, but it is obvious that these are not sufficient. The importance of potable water supply to the people of Ghana and the protection of their multi-million Cedi dams will not be dwelt on here. It should be stressed, however, that any money spent on the weed control program will be balanced by money saved in improved water quality. The annual loss of ¢700,000 because of water treatment would easily cover the cost of the above program. The GWSC will not be able to fund the cost of the program directly, and in this instance the need for assistance of international agencies is most pressing. The World Bank has shown a strong interest in working with GWSC and USAID in developing a long-range program. Indications are that a consultant can be furnished for 1 to 2 years and essential equipment can be purchased by the World Bank.

Timetable

If the weed control program is to be undertaken, we would suggest the following estimated timetable:

March 1979	Preparation Stage: infra-red photography of both Weija and Barekese Reservoirs;
April 1979	Mobilization Stage: equipment check-out, herbicide stockpile, helicopter and consultant alert, assembly of mobile and shore crews;

May 1979	Testing Stage: helicopter dry run, herbicide spot tests:
July 1979	Control Stage I - Barekese: July 1 - first aerial application July 2 - first follow-up operation July 15 - second aerial application July 17 - second follow-up operation
August 1979	Control Stage II - Weija: August 1 - first aerial application August 3 - first follow-up operation August 15 - second aerial application August 18 - second follow-up operation August 29 - third aerial application (subsequent applications will be based on immediate progress)
February 1980	Assessment Stage: second infra-red photography of both reservoirs, weed team tour of reservoirs, Regional Manager's monthly reports from Barekese;
April 1980	Management Stage: monthly weed situation reports from the Reservoir Management Officer and assessment reports by the Weed Team are evaluated prior to next flood season.

LITERATURE CITED

Amuzu, A.T. 1975. Water treatment practices at the Barekese water utility in Ghana. J. Amer. Water Works Assoc.

Attionu, R. 1970. Eco-physiological studies on *Pistia stratiotes* L. with special reference to its occurrence on Volta Lake. M.S. Thesis, Univ. of Ghana.

de Graft-Johnson, K.A.A. 1977. Some studies on the weeds of the Densu Reservoir. Institute of Aquatic Biol. Rpt. IAB76.

Fempong, E. and B. Nijjhar. 1973. Some preliminary observations on the fauna and flora of Barekese Lake, Ghana. Bull. de l'I.F.A.N. Ser. A. 35:67-78.

Fiakpornu, F.K. 1973. Barekese Dam - Water quality problems. Ghana Water and Sewage Corporation.

Gaudet, J. 1973. The normal role of vegetation in water. p. 24-37. In: Aquatic Vegetation and Its Use and Control. UNESCO, Paris.

Gaudet, J. 1978. Aquatic weeds of man-made lakes. Internat. Weed Sci. Conf., Internat. Instit. of Trop. Agric. Ibadan, Nigeria.

Ghana Water and Sewage Corporation. 1978. Notes on the aquatic vegetation - Weija.

Hall, J. and W. Pople. 1968. Recent vegetational changes in the lower Volta River. Ghana J. Sci. 8:24-29.

Okali, D.U.U. and J. Hall. 1974a. Colonization of *Pistia stratiotes* mats by *Scirpus cubensis* on the Volta Lake. Ghana J. Agric. Sci. 7:31-36.

Okali, D.U.U. and J. Hall. 1974b. Die-back of *Pistia stratiotes* on Volta Lake, Ghana. Nature. 248:452-453.

Opoku, A.K. 1976. The development of aquatic weeds. Conf. Volta Lake and National Develop., Volta River Authority.

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Kiéré
Houndé
Koumbia
Diébougou
Poura
Sideradougou
Gaoua
Tolkaboua
Kampti
Batié
Lankio
Téhini
Varalé
Bouna
Bania
Koutouba
Parhadi
Banda Nkwanta
Saleye
Bondoukou
Goméré
Sampa
Wenchi
Berekum
Sunyani
Dormaa Ahenkro
Agnibilékrou
Goaso
Bechem
Kumasi
Bibiani
Bekwai
Lake Bosumtwi
Mpraeso
Antubia
Awaso
Obuasi
Enchi
Dunkwa
Oda
Kade
Akwatia
Twifu Praso
Fosc
Aboisso
Boinso
Swedru
Prestea
Half Assini
Esiama
Axim
Sekondi
Takoradi
Cape Three Points
Cape Coast
Saltpond
Apam
Winneba (Simpa)
Accra
Teshi
Tema
Nsawam
Nyakrom
Ada
Keta
Cape St. Paul
Lomé
Porto Seguro
Aného
Tsévié
Athiémé
Palimé
Nuatja
Abomé
Jasikan
Atakpamé
Kpandu
Ho
Akosombo
Koforidua
Dzodze
Akuse
Kpandae
Salaga
Bimbila
Yeji
Kintampo
Dawadawa
Damongo
Chama
Yapei (Tamale Port)
Larabanga
Sawla
Bole
Seripe
Wasipe
Tuna
Daboya
Ga
Bantala
Wa
Yala
Fian
Lawra
Han
Tumu
Nako
Navrongo
Bolgatanga
Gambaga
Walewale
Chereponi
Karaga
Savelugu
Tamale
Yendi
Demon
Lama-Kara
Bassari
Laganya
Sokodé
Kandé
Mt. Kora
Savalc
Kantankpari
Waso
Ejura
Mampong
Honoe
Nuatja
Dam
Tarkwa
Prah
Black Volta
White Volta
Kulpawn
Manga
Blanche
Dayku
Lake Volta
Afram
Mono
Ogou
Oti
Kumoé
Komoé
Bia
Tano
Ofin
Adiéké
Lagune Aby
Grand Bassam
Port Bouet
Canal de Vridi
Alépé
Bingerville
Gold Coast
1886
1070
579
2340
28
68
10
150
1825
2018
2313
1194
1520
1942
2415
2585
2556
2682
2864
2989
3018+

Figure 1.

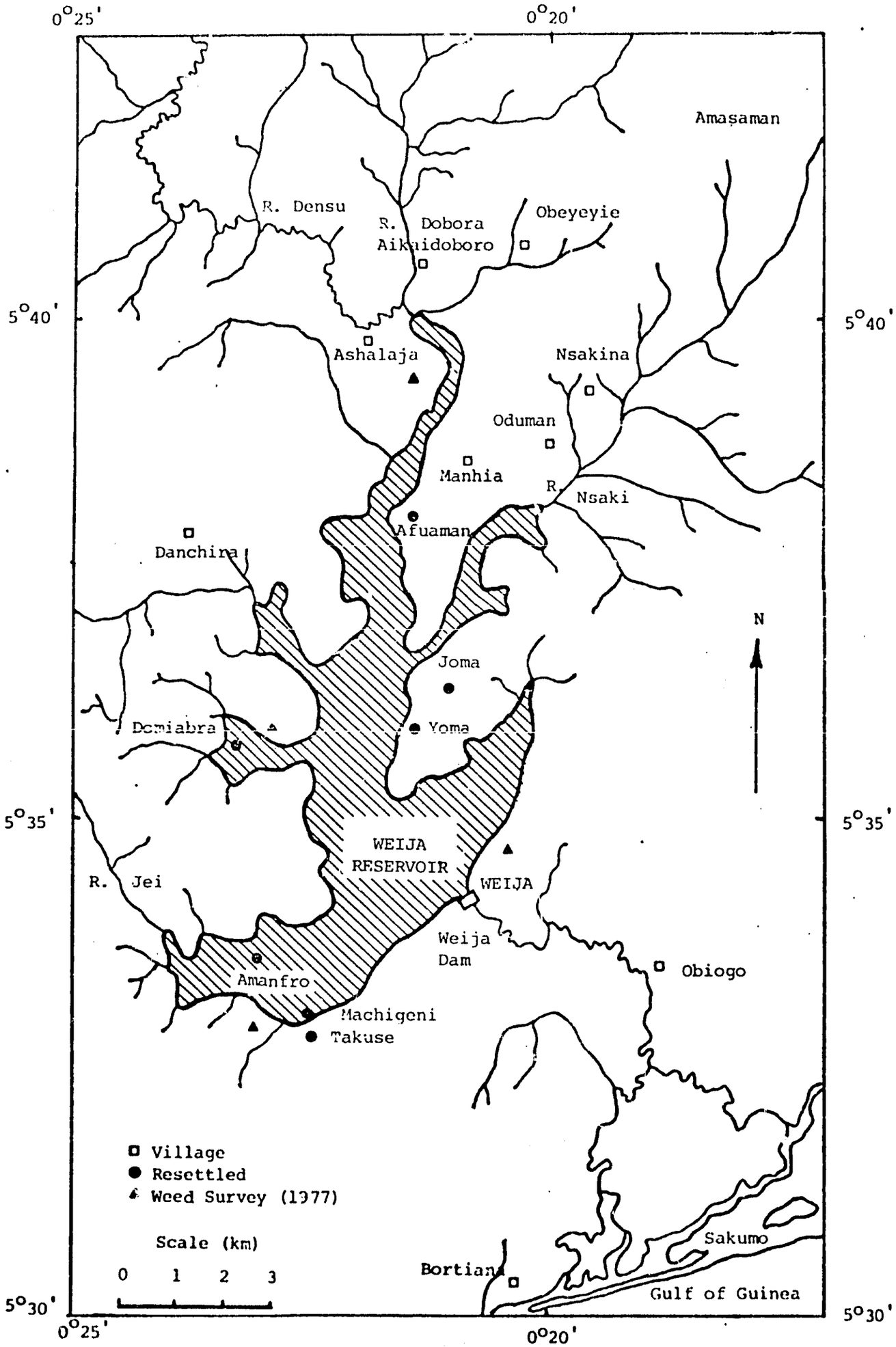

0°25'
0°20'
5°40'
5°35'
5°30'
Amasaman
R. Densu
R. Dobora
Aikaidoboro
Obeyeyie
Ashalaja
Nsakina
Oduman
Manhia
R. Nsaki
Afuaman
Danchina
N
Joma
Domiabra
Yoma
WEIJA
RESERVOIR
R. Jei
WEIJA
Weija
Dam
Obiogo
Amanfro
Machigeni
Takuse
Village
Resettled
Weed Survey (1977)
Scale (km)
0 1 2 3
Sakumo
Bortiana
Gulf of Guinea

Figure 2.

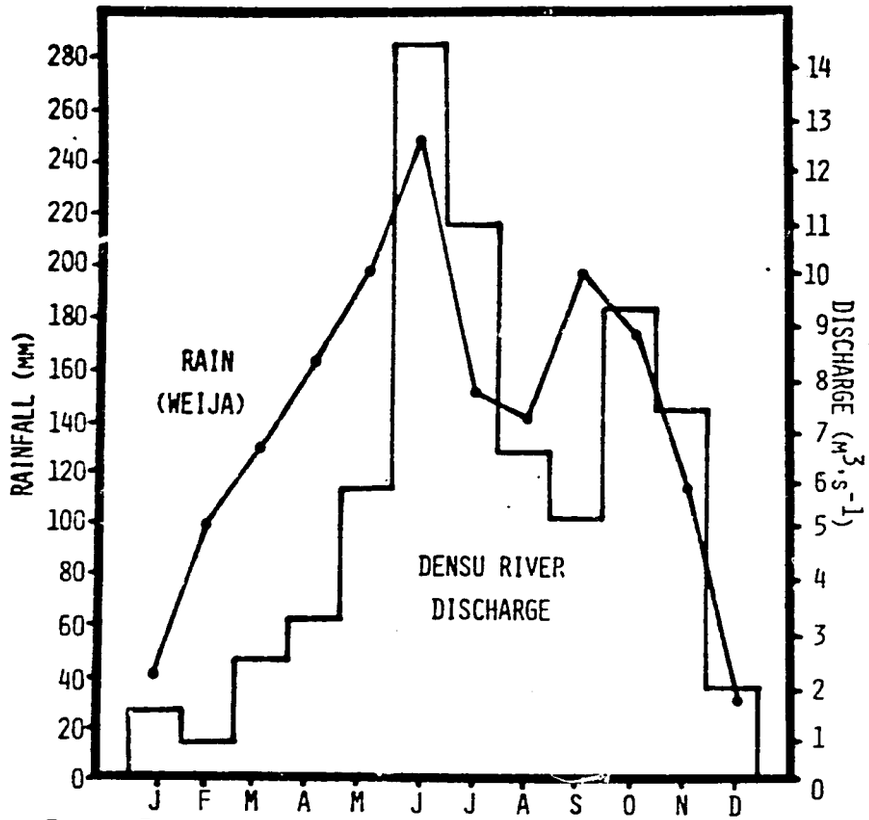


FIGURE 3.

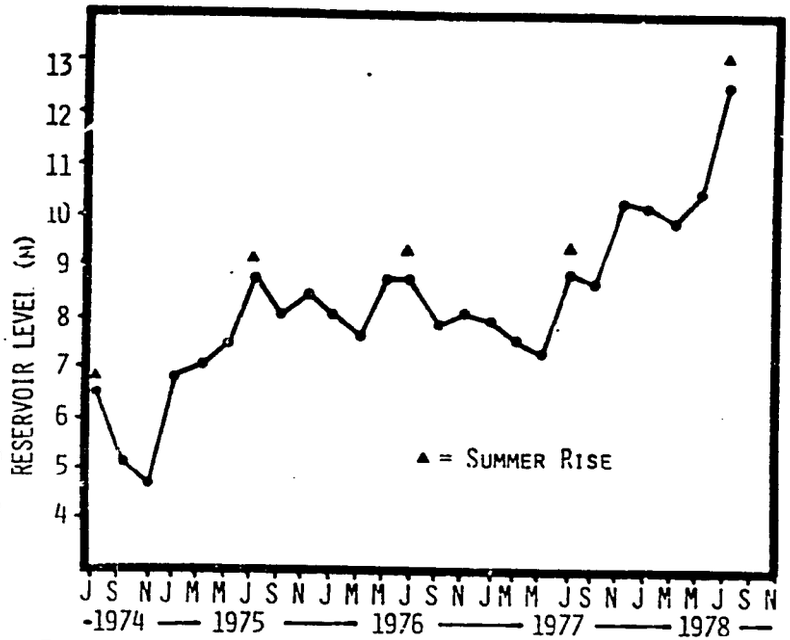


FIGURE 4.

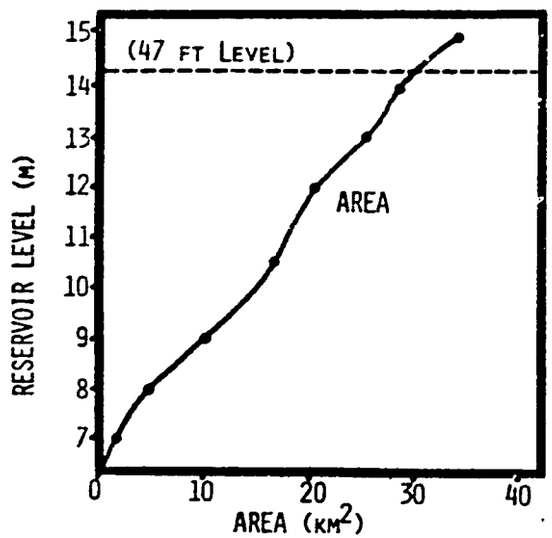


FIGURE 5.

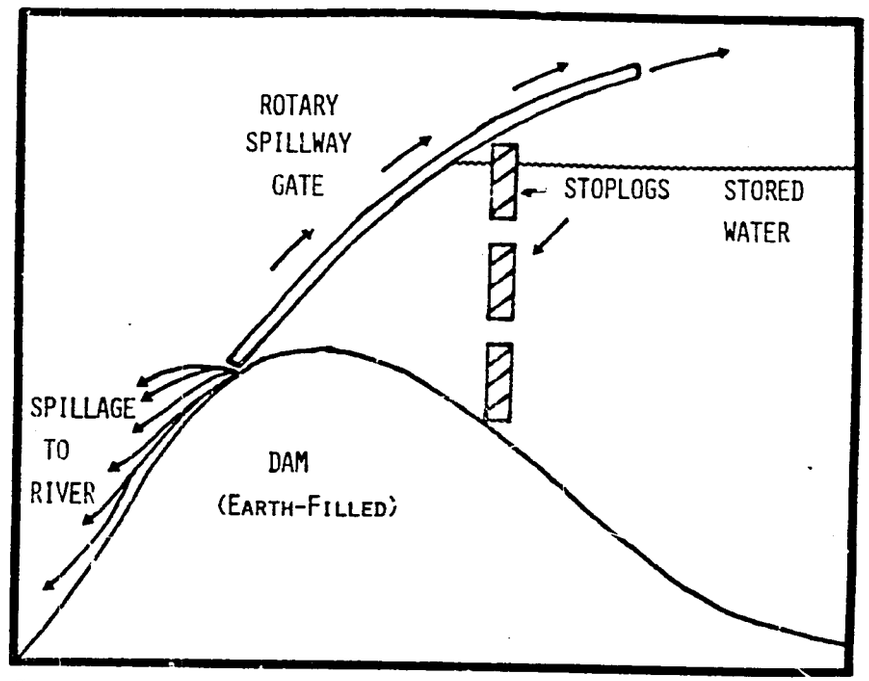
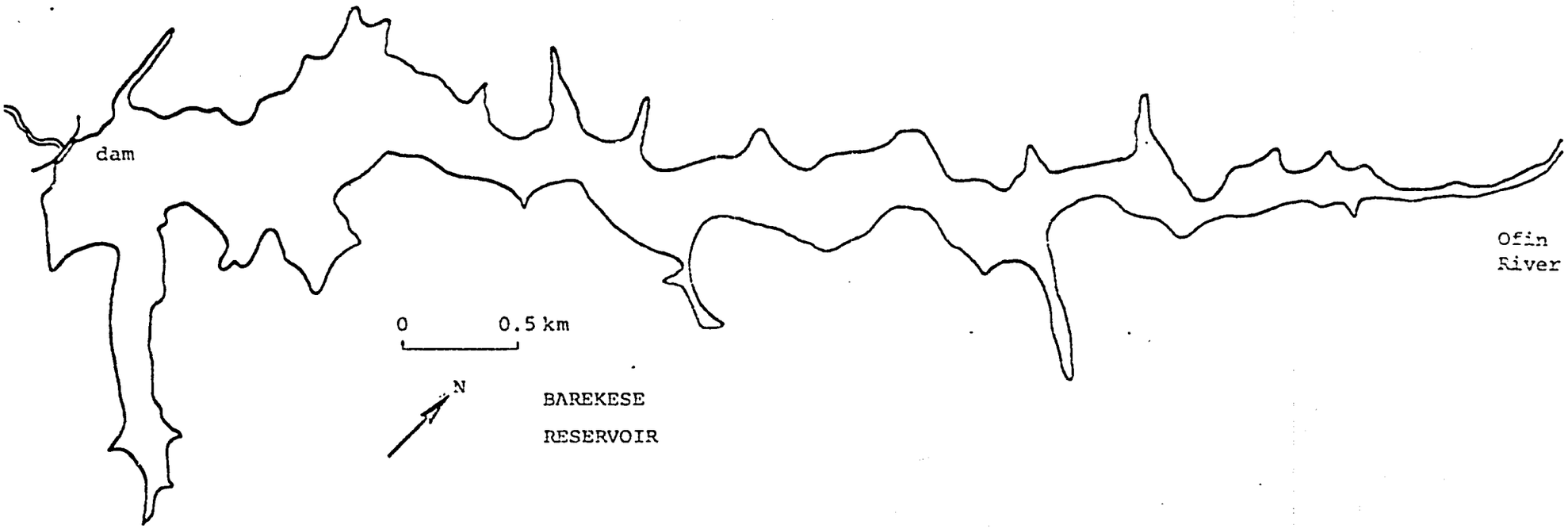


FIGURE 6.


dam
Ofin
River
0
0.5 km
N
BAREKESE
RESERVOIR

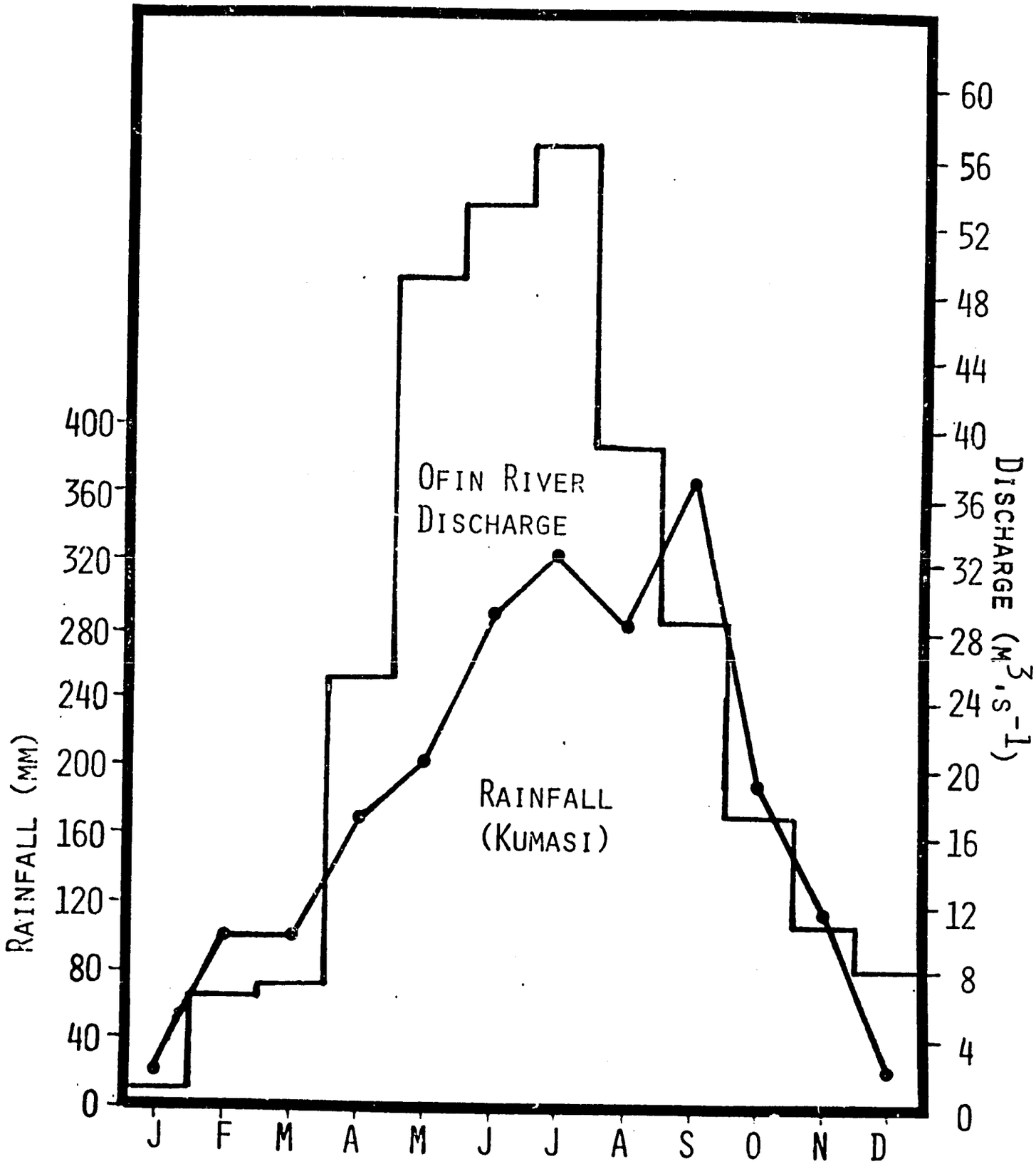

OFIN RIVER
DISCHARGE
RAINFALL
(KUMASI)
RAINFALL (MM)
DISCHARGE ($M^3.S^{-1}$)
0
40
80
120
160
200
240
280
320
360
400
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
J
F
M
A
M
J
J
A
S
O
N
D

FIGURE 8.

APPENDIX

Table 1.

Aquatic Weed Survey of 1977 (de Graft-Johnson, 1977). Four sites listed are shown in Figure 2.

Species	Weija	Machigeni	Domiabra	Ashalaja
Alternanthera sessilis	*	*	*	*
Amaranthus hybridus	*	-	-	-
Andropogon sp.	-	-	-	*
Azolla africana	*	*	-	-
Ceratophyllum demersum	*	*	-	-
Chloris barbata	*	-	-	-
Commelina sp.	-	-	-	*
Cyclosorus striatus	-	*	*	-
Cyperus articulatus	-	*	-	-
Cyperus distans	*	*	-	*
Cyperus haspan	*	*	-	-
Echinochloa pyramidalis	*	*	*	-
Ficus congensis	*	*	-	-
Fimbristylis dichotoma	*	-	-	*
Fuirena umbellata	-	*	-	-
Ipomoea aquatica	*	*	-	-
Leersia hexandra	-	*	-	-
Lemna paucicostata	*	*	-	-
Leptochloa caerulescens	-	*	-	-
Ludwigia leptocarpa	*	-	-	-
Ludwigia stolonifera	*	*	*	-
Mikania cordata	-	-	*	-
Mimosa pigra	*	*	-	-
Neptunia oleracea	*	*	-	-
Nymphaea lotus	*	*	-	-
Panicum maximum	*	-	*	*
Paspalum orbiculare	*	-	*	*
Paspalum polystachyos	*	-	*	*
Pistia stratiotes	*	*	*	-
Polygonum senegalense	*	*	*	-
Salvinia nymphellula	-	*	-	-
Scirpus cubensis	*	*	-	-
Spirodella polyrhiza	*	*	-	-
Torulinium odoratum	-	*	-	-
Typha domingensis	*	*	-	-
Utricularia inflexa	-	*	-	-
Wolfia arrhiza	*	*	-	-

* indicates presence of species
\- indicates absence of species

Table 2.
Water Analysis of the Densu River (March, 1976 - February, 1977)

	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
pH	6.9	6.9	6.9	6.9	6.7	6.9	6.9	6.9	7.0	6.9	6.7	6.9
Apparent Color	80.0	115.0	116.0	85.0	100.0	55.0	45.0	70.0	55.0	90.0	65.0	55.0
True Color	50.0	60.0	92.0	55.0	95.0	40.0	35.0	48.0	45.0	65.0	55.0	40.0
Odor	M	O	SM	SM	O	O	SM	SM	O	SM	SM	SM
Taste	-	unobj	unobj	unobj	accep	accep	accep	unobj	accep	accep	unobj	unobj
Solids												
Total	366.0	322.0	380.0	301.0	335.0	287.0	332.0	212.0	327.0	270.0	292.0	287.0
Suspended	19.0	11.0	24.0	11.0	17.0	26.0	11.0	10.0	18.0	22.0	19.0	17.0
Nitrogen												
Nitrate	trace	0.28	1.20	0.55	0.36	0.45	0.38	0.32	0.26	0.32	0.27	-
Nitrite	trace	trace	0.03	trace	trace	nil	trace	nil	trace	nil	trace	nil
Ammonia	0.52	0.22	0.42	0.36	0.46	0.36	0.32	0.58	0.32	0.42	0.36	0.30
O_2 abs. in 3hr	5.24	4.12	3.60	4.52	12.16	5.56	5.36	6.80	5.62	7.92	7.48	6.24
Carbon Dioxide	15.0	16.0	32.0	32.0	40.0	27.60	18.0	16.0	19.0	23.0	19.0	16.0
Alkalinity												
Phenolphthalein	nil	nil	nil	nil	nil	nil	-	nil	nil	nil	nil	nil
Total	138.0	148.0	104.0	116.0	85.0	108.0	130.0	122.0	108.0	91.0	118.0	132.0
Hardness												
Permanent	nil	nil	8.0	nil	nil	2.0	nil	4.0	10.0	8.0	nil	nil
Temporary	137.0	130.0	104.0	105.0	74.0	108.0	125.0	122.0	108.0	91.0	105.0	122.0
Total	137.0	130.0	112.0	105.0	74.0	110.0	125.0	126.0	118.0	99.0	105.0	122.0
Calcium	65.0	63.0	69.0	98.0	55.0	105.0	83.0	96.0	24.0	24.0	56.0	47.0
Magnesium	72.0	67.0	43.0	7.0	19.0	5.0	42.0	30.0	94.0	75.0	49.0	75.0
Sulphate	8.8	7.28	7.89	15.62	14.36	13.33	7.41	6.27	8.89	7.89	8.89	10.70
Chloride	80.0	66.0	73.0	62.0	27.0	58.0	61.0	65.0	34.0	24.0	64.0	60.0
Carbonate	82.8	88.80	42.40	69.0	51.0	64.80	78.0	73.20	64.80	54.60	70.80	79.2
Silica	20.5	19.0	17.50	15.0	15.50	18.50	17.0	4.50	14.0	22.0	12.0	8.0
Iron in Soln.	0.20	0.05	0.15	0.05	0.10	0.10	0.10	trace	0.15	0.30	0.25	0.10
Total Iron	0.60	0.15	0.40	0.20	0.30	0.30	0.20	0.30	0.30	0.45	0.40	0.20
Manganese	nil	nil	0.56	0.50	0.24	0.30	nil	trace	nil	nil	trace	nil
Conductivity (K20)	496	480	590	450	290	405	490	490	390	290	390	390

M - musty
O - odorless
SM - slightly musty

Table 3.
Water Analysis of the Ofin River from 1970-76. Chemical examination expressed in milligrams per liter.

Parameters	Minimum	Maximum	Average
pH	6.3	7.5	6.7
Color (Hazen)	60	250	104.5
Alkalinity	4	70	19.4
Free Carbon Dioxide	0.03	28.35	10.18
Chloride	0.38	11.0	4.35
Ammonical Nitrogen	Nil	0.524	0.078
Albuminoid Nitrogen	Nil	0.38	0.104
Nitrous Nitrogen	Nil	0.12	0.006
Nitric Nitrogen	0.15	3.0	0.469
Oxygen Absorbed (3 hrs)	0.52	30.24	6.23
Impurity Factor	Nil	5.6	3.20
Temporary Hardness	2.0	50.0	17.8
Permanent Hardness	Nil	51.0	19.2
Total Hardness	19.0	65.0	34.5
Suspended Solids	Nil	71.0	16.0
Silica (SiOs) in solution	Nil	36.0	15.8
Iron in solution	Nil	2.1	0.73
Total Iron	0.30	4.5	1.55
Manganese	Nil	0.4	0.02
Calcium	4.8	12.8	7.6
Magnesium	0.49	17.0	3.33
Carbonate	1.2	42.0	11.8
Sulphate	1.98	228	52.6
Magnesium Hardness	2.0	43.0	
Total Dissolved Solids	69	309	133

Table 4.
Fish fauna of the Barekese Reservoir (Fempong and Nijjhar, 1973).

Name
Alestes imberi
Alestes nurse
Aplocheilichtyhys schinoetzi
Barbus parablabes
Barbus sublineatus
Barbus trispilus
Chromidotilapia guntheri
Chrysichthys nirgodigitatus
Eutropius mentalis
Hemichromis bimaculatus
Hemichromis fasciatus
Hepsetus odoe
Heterobranchus isopterus
Labeo senegalensis
Mastacembelus nigromarginatus
Micralestes brevianalis
Micralestes occidentalis
Ophiocephalus obscurus
Synodontis eupterus
Synodontis obesus
Tilapia busumana
Tilapia pelmatilapia

Table 5.
Monitoring equipment.

Equipment
Hach portable water testing kit
Yellow Springs polarographic oxygen meter
Yellow Springs conductivity meter and cell
Depth sounder (for sedimentation and profile study of bottom)
Hallicrafter communication system (for contact during emergency and during weed control program)

Table 6.
Weed control equipment in addition to present GWSC equipment.

Quantity	Equipment
2	aluminum boats, 14 ft (minimum)
4	outboard motors (25 hp, short shaft)
24	cutlasses
24	rakes
24	life jackets
24	wheel barrows
4	life rings
12	wire nets (for picking up floating weed; made locally)
24	long-handled straight spades (for cutting islands)
4	portable chain saws
8	portable spray units
2	compressor-operated spray units (for mounting on boats)
1	large wooden boat (16 - 20 ft) with inboard deisel motor (Possible to use the present boat at Weija, but it must be overhauled and re-fitted)
4 - 8	drums (50 gal) for mixing herbicide solutions