Aquatic Weeds & their Management

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I. INTRODUCTION

1.1 Global Irrigated Area

Of the world's total geographical land area of 13045 mha,1450.8 mha of arable land area is under permanent crops, sustaining a population of 6 billion people. The world's total irrigated area was 249.5 m ha in 1997 (FAO 2000) which is 17.2%of total arable land. It is this land which provides sustained and assured productivity of crops and employs high input returns. The continentwise spread of irrigated area indicates that Asia has the maximum irrigated area followed by Europe and Africa. (Table 1).

Table 1. Continentwise distribution of area under arable and permanent crops, and Irrigated Area

Continent	Area under arable & Permanent crops (APC) (m ha)	Irrigated area (m ha)	Percentage of irrigated land w.r.t. APC
World	**1450838**	**249549**	**17.2**
Africa	185916	12439	6.7
N.C.America	271533	30118	11.1
South America	105224	9664	9.2
Asia	472514	159073	33.6
Europe	135365	16534	12.2
Oceania	52210	2428	4.6

Source: FAO yearbook Vol. 49, 1995.

In the African continent, there is wide variability amongst countries as regard the percentage area irrigated to total arable area. For e.g. Egypt has 100%, Sudan 15%, Morocco 13.5% and South Africa 9.6% of the total arable land under irrigation.

In North-Central America, U.S.A has the maximum arable area but irrigated area constitutes only 11.4% of the area and Mexico has 24.6% arable area under irrigation.

In the South American Continent, Peru has 41% area under irrigation followed by Chile (29.7%), Argentina (6.2%), and Brazil (6%).

The Asian continent has 33.6% of area under irrigation of which Pakistan has 80.2% followed by South Korean Rep. (64.9%), Japan (62.8%), China (51.5%), Iraq (44.3%), Iran (40%), and India (28.2%).

In Europe, Romania has 31.2% of arable land under irrigation followed by Italy (25%), Bulgaria (18.9) and Spain (18.1%). In Oceania, Australia has 4.5% of the total arable area under irrigation.

Every year, efforts are being made to increase the area under irrigation with the sole purpose of increasing productivity of the land. The area under irrigation and corresponding water availability has increased globally over the past 20 years with the building of storages, tanks and channels for irrigation and fish production.

1.2 Damages caused by aquatic weeds

Aquatic weeds are those unabated plants which grow and complete their life cycle in water and cause harm to aquatic environment directly and to related eco-environment relatively. Water is one of most important natural resource and in fact basis of all life forms on this planet. Therefore, appropriate management of water from source to its utilization is necessary to sustain the normal function of life. It is one important part of natural resource management. The presence of excessive aquatic vegetation influences the management of water in natural waterways, man made canals and reservoirs which amounts to millions of kilometres/ square kilometers of such water bodies around the world. The area under small tanks and ponds is equally important due to the establishment of many small irrigation schemes and watershed management projects all over the world. For example, India has 1.9 m ha under water in reservoirs and 1.2 m ha under irrigation canals. The area under village ponds and tanks is nearly 2.2 m ha.

Aquatic weeds often reduce the effectiveness of water bodies for fish production. Aquatic weeds can assimilate large quantities of nutrients from the water reducing their availability for planktonic algae. They may also cause reduction in oxygen levels and present gaseous exchange with water resulting in adverse fish production. Although excessive weed growth may provide protective cover in water for small fish growth it may also interfere with fish harvesting.

Dense growth of aquatic weeds may provide ideal habitat for the development of mosquitoes causing malaria, encephality filarasis. These weeds may also serve as vectors for disease causing organisms and can greatly reduce the aesthetic value of water bodies from a recreational point of view.

Aquatic weeds have been found to severely reduce the flow capacity of irrigation canals thereby reducing the availability of water to the farmers field. Aquatic weeds may also damage pumps and turbines in super thermal power stations and hydroelectric power stations influencing electric production and increasing the cost of maintenance of power stations. Many aquatic plants are desirable since they may play temporarily a beneficial role in reducing agricultural, domestic and industrial pollution. Many aquatic weeds may play a useful role of providing continuous supply of phytoplanktons and help fish production. Some of the harmful effects of aquatic weeds are listed in Box 1.

BOX 1

Harmful Effects of Weeds

- Reduces water storage capacity in reservoirs, tanks, ponds
- Impedes flow and amount of water in canals & drainage systems
- Reduces fish production
- Interfere with navigation and aesthetic value
- Promote habitat for mosquitoes

Aquatic weeds (emergent, floating and submerged) interfere with the static and flow water system. They cause tremendous loss of water from water bodies like lakes and dams through evapo-transpiration. In flowing water system, aquatic weeds impede the flow of water in irrigation canals and drainage channels thereby increasing evaporation damage structures in canals and dams, clog gates, siphons, valves, bridge piers, pump etc. Impediment in flow of water may result in localised floods in neighboring areas. India has the largest canal network in the world where the velocity of flowing water is reduced by about 30 - 40 percent due to the presence of aquatic weeds.

Floating and deep rooted submerged weeds interfere with navigation. Water hyacinth and Alligator weed grow profusely and create dense mats which prevent the movement of boats and at times even large ships.

Village ponds and tanks get infested with floating and submerged weeds which results in reducing the capacity of the water storage and therefore effecting efficient irrigation.

Therefore, considering the losses caused, it is essential to keep aquatic weeds under control in water bodies, flow water systems, ponds and tanks so that these systems can be utilized to best of their efficiency.

Mechanical methods are being practiced at present as use of chemicals is very much restricted due to the difficulty in control on water use for different purposes. Use of bio-agents for weed control is under experimental dissemination and needs further research and refinement in technology for control of aquatic weeds. Within the next two decades bio-agents will be one of the major methods of controlling aquatic weeds, especially the floating ones. Research is also necessary for studying the various factors influencing the aquatic environment and the resultant vegetation. Researchers are envisaging to establish an integrated approach to aquatic weed control using a mix of mechanical and biocidal techniques to control aquatic weeds under specific situations.

1.3 Classification of aquatic weeds

Aquatic weeds are classified according to various habitats which form their eco-environment and become conducive for their growth, reproduction and dissemination.

1.3.1 Emergent weeds

These weeds grow in shallow waters and situations existing near the water bodies where water recedes and rises with the seasons or regular releases from a large water body or reservoir. Most of such situations are of permanent in nature where minimum and maximum water levels are consistent. Such situations includes banks of canals, rivers, periphery of water bodies which are mostly in earthen dams, and partly in masonry dams, drainage ditches and water ponds near villages. These weeds may be called semi-aquatic but more appropriately referred to as emergent aquatic weeds. Some examples of the emergent weeds are given below:

Botanical Name	**Common Name**	**Family**
Typha angustata	Cattail narrowleaved	Typhaceae
T. latifolia	Cattail common	Typhaceae
T. orientalis	Cattail	Typhaceae
Phragmites communis Trin.	Common reed	Poaceae
P karka	Common reed	Poaceae
P australis	Common reed	Poaceae
Pontederia cordata L	Pickrel weed	Pontedericeae
Commelina benghalensis L	Watergrass	Commelinaceae
Alisma plantago	Water cattail	Alismataceae
Cyperus difformis L	Umbrella plant	Cyperaceae
Ipomea carnea Jacq.	Besharam	Convolvulaceae

There are situations where vast areas of land- remain inundated with water for long periods of time, and may only dry out in severe drought conditions. Such lands are known as marshes or swampy areas. They support a different type of vegetation which may include plants/weeds that are capable of growing under both flooded and saturated conditions. These may include annuals to large trees. Some of these amphibious species are given below:

Temporary water situations

Botanical Name	**Common Name**	**Family**
Alternanthera philoxeroides(Mart)Griseb	Alligator weed	Amarantheceae
Marsilea minuta L.	Pepper west	Marsileaceae
Meteranthera limosa (SW) Wild	Mud plantain	Pontederaceae
Monochoria vaginalis Presi.	Carpet weed	Pontedereceae
Panicum perpurascens Raddi.	Paragrass	Poaceae
Paspalum fluitans Kunth	Water paspalum	Poaceae

Clay substratum situation

Botanical Name	Common Name	Family
Fimbristylis miliacea Vahl	Hoorah grass	Cyperaceae

Floating mat situation

Botanical Name	Common Name	Family
Ipomea aquatica fersk	Floating morning glory	Convolvulaceae
Hydrocotyle umbellata L.	Water pennywort	Hydrocolylaceae
Jussiaea repens L	Water primrose	Onagraceae
Ludwigia parviflora	Water purslane	Onagraceae
Trapa bispinosa Roxb.	Water chestnut	Trapaceae

1.3.2 **Floating weeds**

These are plants which grow and complete their life cycle in water. They vary in size from single cell (algae) and may grow up to large vascular plants. In case of drying of water bodies most of them give their seeds and other vegetative reproductive organs in base ground lands. These weeds are observed in the surface of the large, deep and shallow depths of water bodies; deep continuous flowing canals; continuously flowing rivers large ponds tanks etc. Some of the weeds in this ecosystem freely float and move long distances, while some of them do float on the water surface but anchor down to soil at the bottom of the water body. These weed species make loss of water through evapotranspiration in addition to impediment caused in flow of water. Therefore, these weeds can be classified in two sub groups viz. a) Free floating and b) Rooted floating weeds. Examples of common weeds under each sub group are given below:

a) Free floating weeds

Botanical Name	Common Name	Family
Eichhornia crassipes (Mart) Solens	Water hyacinth	Pontederiaceae
Salvinia auriculata (Mitch) Syn.	Water fern	Salviniaceae
S molesta	Water fern	Salviniaceae
S natans	Water fern	Salviniaceae
Pistia stratiotes L	Water lettuce	Araceae
Lemna minor	Duck weed	Lemnaceae
Spirodela polyrhiza(L) Schlcid	Giant duck weed	Lemnaceae
Azolla imbricata waxai	Water velvet	Salviniaceae
A pinnata	Water velvet	Salviniaceae
Polygonum amphibium L	Water smart weed	Polygoneaceae

b) Rooted floating weeds

Botanical Name	Common Name	Family
Sagittaria guayanensis HBK	Arrowhead	Alismataceae
Ipomea hederacea	Nilkalmi	Convolvulaceae
Nelumbo nucifera G	Lotus	Nymphaceae
Nymphaea alba L	White water lily	Nymphaceae
Nuphar lutea L	Yellow water lily	------do---------
Zannichellia palustris L	Horned pond weed	Zannichelliaceae

Fig.1. Water hyacinth (Eichhornia crassipes), a free floating weed

Fig.2. Water hyacinth (Eichhornia crassipes) infestation in irrigation canal

Fig.3. Vallisneria, a submerged aquatic weed

Fig.4. Hydrilla verticillata, a submerged aquatic weed

Fig.5. Infestation of Typha latifolia, an emersed weed

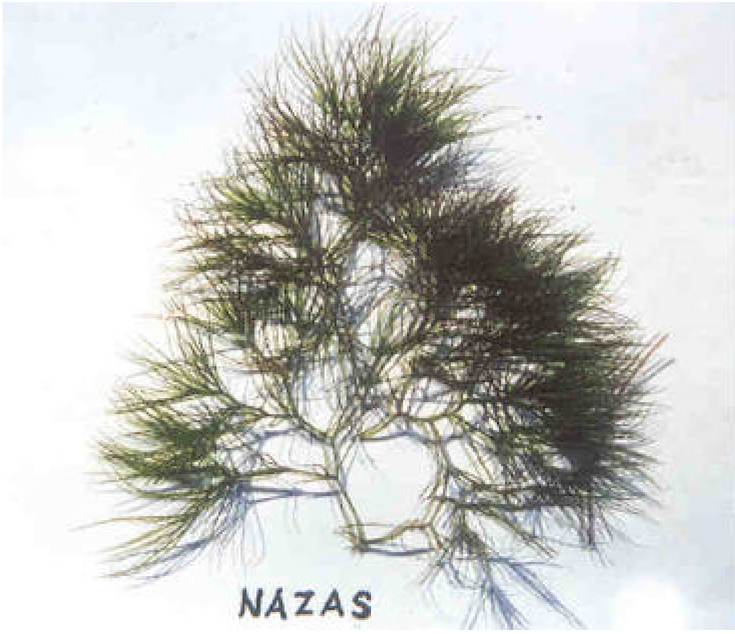

Fig.6. Najas, a submerged aquatic weed

1.3.3 Submerged weeds

Weed species belonging to this group germinate/ sprout, grow and reproduce beneath the water surface. Their roots and, reproductive organs remain in the soil at the bottom of the water body. These weeds damage the maximum, because they are not visible on the surface and impede the flow of water varying upon the degree of their intensity and growth. Most of these weeds are found in shallow and medium deep water bodies and continuous flowing canals and drainage ditches.

The ecosystem provides situations which allows the growth of algae, filamentous algae, higher algae in shallow water situations and under deep water situations, and thus submerged weeds may be further categorized as a) shallow water submerged weeds, and b) deep water submerged weeds. Commonly occurring weeds in these categories are as follows:

a) Shallow water submerged weeds

Algae

Botanical Name	Common Name	Family
Anabaena spp.	Blue green algae	Nostocaceae
Cladophora spp	Cottonmat type algae	Cladophoraceae
Pithophora spp.	Wet wool type algae	Chloraphyaceae
Spirogyra spp.	Slimy green algae	Chloraphyaceae
Chara zeylanica	Musk grass	Characeae
Nitella hyalina	Stone wort	Characeae

Higher plants

Botanical Name	Common Name	Family
Najas minor All.	Naiad	Najadaceae
Vallisneria spiralis	Eel weed	Najadaceae
Potamogeton crispus	Curly leaf pond weed	Potamogetonaceae

P. natans L	Broadleaved pond weed	----------do----------
P. pusillus L.	Small pond weed	---------do-----------
P. nodosus		---------do----------
P. pectinatus		---------do---------

b) Deep water rooted submerged weeds

Botanical Name	Common Name	Family
Myriophyllum spicatum L.	Eurasion water milfoil	Holorhagaceae
Hydrilla verticillata Royle	Hydrilla	Hydrocharitaceae
Elodea canadensis	Elodea	--------do-----------
Utricularia flexuosa Vahl.	Bladderwort	Lentibulariaceae

II. A GLOBAL SCENARIO OF WEED DISTRIBUTION

The global scenario of aquatic weeds includes wide populations of aquatic vegetation in different aquatic ecosystem broadly based on type of eco-environment i.e., lakes, dams, ponds, tanks, canals of various categories, which are adversely effected by aquatic vegetation. The major aquatic weeds of the world are listed in Box 2. An attempt has been made to group weeds countrywise based on agro-ecological system as per table 2.

BOX 2

Major aquatic weeds of the world

Eichhornia crassipes	Water hyacinth
Typha spp.	Cattail
Ipomea carnea	Besharam
Hydrilla verticillata	Hydrilla
Salvinia spp.	Water fern
Alternenthera pheloxeroides	Alligator weed
Monochoria vaginallis	Carpet weed
Sagittaria spp.	Arrowhead
Potamogeton spp.	Pond weed
Pistia stratiotes	Water lettuce

Table 2. Distribution of aquatic weeds in different regions of the world

Region/ Country	Important Weeds	Affected/Infested areas
South east Asia Malaysia, Indonesia, Philippines, Thailand	*Eichhornia crassipes; Salvinia molesta; S.auriculata; Lemna perpusilla; Pistia stratiotes; Chara spp.; Hydra spp.; Elodea canadensis; Myriophyllum aquaticum; Vallisnaria gigantia; V.spirallis; Alternanthera rossefolia; Cubomba carolina; Hydrilla verticillata; Appimosa pigra; Ceratophyllum plemersum; Scirpus grassus; Polygonum barbatum; Phragmites karka; Hunguana malgyana; Alternanthera philoxeroides; Ludwigia adscendens.*	*Eichhornia crassipes* dominates in canals, rivers and man-made lakes; influence fishing, power generation, navigation, recreation, waste disposal and flood control.
Sri-Lanka	*E.crassipes; Salvinia molesta; Panicum repens; Salvinia auriculata; Pistia stratiotes; Typha spp.; Limnocharis flava.*	Water-bodies, canals and drainage ditches.
Bangladesh, Myanmar	*E.crassipes; Typha spp.; Hydrilla verticillata.*	Damaging rice fields and inland water fisheries programs.

India		
Peninsular India (Kerala, Tamil Nadu, Karnataka, Andhra Pradesh).	*E.crassipes; Typha latifolia; Cyperus spp.; Chara spp.; H.verticillata; Nymphaea spp.; Nelumbo lutea; Nymphoides spp; Vallisnaria americana; Potamogeton spp.; Najas spp.; Ipomea aquatica; S.molesta.*	Lakes and tanks growing fishes, causing floods, damage irrigation and drainage systems.
Eastern India (Assam, Orissa, West Bengal).	*E.crassipes; H.verticillata; S.molesta; Trapa bispinosa; Azolla pinnata; Ceratophyllum spp.; Ipomea aquatica; Pistia spp.; Nymphaea spp.; Nelumbo spp.; Lemna minor; Scirpus spp.; Chara spp.; Nitella spp.; Sagittaria spp.; Monochoria vaginalis; Marsilia quadrifolia; Najas spp.; Ipomea carnea.*	Fisheries, ponds and tanks water works, deep water rice infestation and in lakes.
Central and Western India (Maharashtra, Rajasthan, Gujarat and Madhya Pradesh	*Typha latifolia; Phragmites karka; E. crassipes; Potamogeton crispus; P.nodosus; Hydrilla verticillata; Vallisnaria americana; V.spirallis; Ipomea carnea; I. aquatica; Nymphoides spp.; Chara spp.;* Green algae.	Water storage reservoirs for city water supply system, fisheries development, irrigation canals and drainage system.
Northern India (Punjab, Uttar Pradesh, Bihar, Haryana).	*Typha angustata; T.latifolia; Phragmites karka; Cyperus aquatica; E.crassipes; Potamogeton crispus; P. zosterifolius; P.perfoliatus; P.nodosus; P.pectinatus; Hydrilla verticillata; Vallisnaria americana; V.spirallis; Najas spp.; Chara spp.; Ceratophyllum spp.; Nymphaea spp.; Myriophyllum spicatum; Spirogyra spp.; Ipomea carnea;* green algae.	Damaging irrigation canals, and drainage system, ponds, lakes, fisheries areas and rivers.
Jammu and Kashmir.	*Nymphoides peltatum; Polygonum amphibium; Nelumbo nucifera; Nymphaea spp.; Trapa natans; Lemna gibba; L.minor; L.trisuleha; Spirodela polyrhiza; Salvinia natans; Potamogeton spp.*	Natural water bodies for storage, aquatic sports and aesthetic value
Australia	*Typha spp.; Phragmites sp.; Sagittaria graminea; Juncus spp.; Elodea canadensis; Potamogeton ochereatus; P.crispus; Vallisnaria spirallis; E.crassipes; Salvinia auriculata; Alternanthera philoxeroides; Eleocharis spp.; Myriophyllum spp.;Nymphaea spp, Azolla spp.; Salix spp.*	Water bodies, irrigation canals and drainage ditches.
New Zealand	*Ceratophyllum demersum; Potamogeton crispus; Hydrilla verticillata; Lagarosiphon major; Elodea canadensis; E.gariadensis; Nitella hookeri; Chara fibrosa; Hydrodictyon reticulatum; Sagittaria natans; Spatinna townsendii; S.alternifolia.*	Damages hydro-electric power generation, navigation, drainage and irrigation systems.

Africa Egypt	 *Potamogeton pectinatus; P.crispus; E.crassipes.*	 Lakes, navigation, irrigation canals.
Zimbabwe, Kenya, Tanzania, Uganda.	*E.crassipes; Salvinia molesta; Pistia stratiotes; Scirpus spp.; Alternanthera philoxeroides; Ludwigia spp.; Polygonum barbatum.*	Lakes, canals, irrigation and drainage system.
South Africa.	*E.crassipes; Pistia stratiotes; Salvinia molesta.*	Water reservoirs.
South America Argentina, Brazil.	 *Hydrilla verticillata; Potamogeton illionoinsis; P.stratiotes; E.crassipes; Salvinia spp.*	 Water flow problems in irrigation canals and navigation.
Europe Spain, France, Germany, Switzerland.	 *Beaucoup d'erreurs native species : Potamogeton pectinatus, P.fluitans; P.lucens; P.natans; Myriophyllum spicatum ; Lemna sp., M.;*	 Irrigation canals, rivers, water reservoirs, lake Constance, Rhine river.
England Portugal	*Ranunculus fluitans, R.penicillatus, Ceratophyllum demersum;;* green algae. *exotic species : Myriophyllum brasiliense; Elodea canadensis, E.nuttallii, Ludwigia grandiflora, L. peploides, Lagarosiphon major, Egeria densa.*	
Norway	*Juncus bulbosus; Myriophyllum alterniflorum; Potamogeton spp.; Elodea canadensis.*	Water reservoir, lakes.
Netherland	*Hydrocotyle ranunculoides, Potamogeton illionoinsis; P.stratiotes; pas possible*	Water bodies, shallow water areas, Eutrophied areas.
USA and Mexico Mexico	 *Typha domingensis, Scirpus spp.; Cyperus spp.; Phragmites spp.; Potamogeton pectinatus; Hydrilla verticillata; E.crassipes; Eleocharis spp.; Pistia stratiotes; Salvinia spp.*	 Lakes and irrigation distributaries.
USA	*E.crassipes; Hydrilla verticillata; Najas flavilis; Ceratophyllum demersum; Utricularia biflora; Potamogeton crispus; P.pectinatus; P.gramineous; Myriophyllum sibiricum; M.spicatum; Alternanthera philoxeroides.*	Water reservoirs, canals, supply canals, flood rivers, problems in navigation and recreational activities; problem is more in south-eastern states and California.

III. AQUATIC FLORA IN SOME COUNTRIES

3.1 South and South East Asia

India

There are large number of weed species which emerge according to various habitat. These include shallow and deep reservoirs, canals with earthen and lined embankments and drainage systems with lined and unlined bunds. Some dominant weeds of the aquatic environment of India are shown in Box 3.

In a case study, it has been observed that, most canals carry enough silt in the flowing water which does not allow photosynthetic activity in the submerged aquatics to take place. Further, the weed seeds or their vegetative parts get buried under the silt. The Bhakra canal water is practically free from silt because of sedimentation in Govind Sagar. The little amount of silt which goes to the canals settles in the main canal bed and the water flowing in the distributaries and minor canals where the water depth is below is below 10 ft is completely free from silt. The weed seeds carried by water from the hills germinate and get established within a short period of time. The roots of these aquatic weeds penetrate quite deep and increase seepage losses. Certain, Algae produces poisonous substances which are harmful to birds, fish and animals.

BOX 3

Important weeds of the aquatic environment of India

Emergent	*Typha angustata*	*Polygonum glabrum*
	Paspalum distichum	*Eclipta prostrata*
	Scirpus maritimus	*Ipomea carnea*
	Phragmites karka	*Polygonum glabrum*
Floating	*Eichhornia crassipes*	*Salvinia molesta*
	Lemna polyrhiza	*Nymphaea stellata*
	N. nauchali	*Nelumbo nucifera*
	Jussiaea repens	*Ipomea aquatica*
	Azolla pinnata	
Submerged	*Hydrilla verticillata*	*Vallisneria spirallis*
	Potamogeton pectinatus	*P. crispus*
	P. perfoliatus	*Myriophyllum spicatum*
	Zanichellia palustris	Ceratophyllum demersum

Malaysia

After 10 years of field surveys on various water bodies ranging from stagnant water, ponds, pools and man made lakes to flowing waters such as rivers, streams and canals, there is a clear evidence of four problematic weeds in Malaysia. These are *Eichhornia crassipes, Salvinia molesta, Lemna purpusilla* and *Pistia stratiotes.* Among these, *E.crassipes* and *S.molesta* are widely distributed throughout Malaysia. *E.crassipes* generally dominates canals, rivers and has also spread in man made lakes. Favourable tropical climate and conducive environmental factors help to trigger massive weed growth. High phosphates of 0.1 mg/l help in productivity (Mashnor-Mansor et al,1966).

Japan

The aquatic vegetation in Japan consisted of *Egeria densa, Elodea nuttillii, Eichhornia crassipes*, *Trapa japonica* (Oki & Bay Peterson, 1992)

Philippines

Cubomba carolina, Elodea canadensis, Myriophyllum aquaticum, Vallisneria gigentia, V. spiralis and *Alternenthera rossefolia* are among the aquatic weeds found in Philippines, Malaysia, Indonesia and Thailand (Revilla et al,1990).

The impact of dynamic inter-relationships between resource components (fishing, power generation, Navigation, recreation, waste disposal and flood control) on Laguna-de Bay was monitored with *Hydrilla verticillata* as indicator species to monitor the outcome of lake management policies (Bravo, 1990).

Indonesia

The most common aquatic plants of Rawa Pening Lake included 4 submerged and rooted species, 6 emergent and 10 floating species. Some of the important weed species included *E.crassipes*, *Hydrilla verticillata*, *Salvinia molesta* and *Mimosa pigra* (Tjotropcdirdjo,1990). In addition, *Hanguana malayana* and *Phragmites karka* have been observed in open waters in Indonesia. At Irian Jaya in Sentani Lake, presence of 89 aquatic weed species were identified. The most common of which were *E.crassipes Hydrilla verticillata, Ceratophyllum demersum, Salvinia molesta, Scirpus grossus* and *Panicum repens* (Sukrawa,1990). *Polygonum barbatum* biomass was 11.57 kg/m^2 and RGR 1.23 percent/day and ET was 45.31 m^3/ha/day (9 times higher than weed free area) in Rian Kanan reservoir(Hisbi,1990).

Sri Lanka

E. crassipes, Salvinia molesta, S. accicenlata, Potamogeton stratiotes and *Panicum repens* are important aquatic weeds in Sri Lanka (Solangarachichi and Dushyanta,1994; Chandrasena,1990).

Thailand

E. crassipes Pistia stratoites, Ludwigia adscendens, Alternenthera philoxeroides, Mimosa pigra, Salvinia cuculata and *Hydrilla verticillata* are important aquatic weeds in Thailand and have been put to biological control using various bio-agents (Napompeth,1990).

Bangladesh

Most of the weeds common to India have also been observed in Bangladesh.

3.2 **Australia and New Zealand**

Emergent weed problems in supply channels are generally limited *Typha spp., Phragmites spp., Sagittaria, graminea* and *Juncus spp.* Recent times has seen the emergence of *S.graminea* as a serious flow impediment. *Elodea canadensis, Potamogeton ocheratus, P.crispus* and *Vallisneria spirallis* are the more common submerged weeds. *Typha spp., Myriophyllum spp., sagittaria spp*. and *Juncus spp.* and a range of grasses are some of the emergent weeds found in nutrient enriched drainage waters (Krake, 1999).

Ceratophyllum demersum, Potamogeton crispus, Hydrilla verticillata, Lagarosiphon major, Elodea canadensis, Egeria densis, Nitella hookeri, and the algae *Chara fibrosa, Hydrodictyon reticulatum* have been observed in New Zealand (Wells & Clayton, 1993).

Alligator weed (*Alternenthera philoxeroides*) is well established in northern North Island of New Zealand and has the potential of spread to further south (Stewart et al.,1995).

3.3 Africa

Egypt

In design of earthen canal, Manning's roughness coefficient is assumed between 0 to 0.25. Field monitoring showed that more than 40% of the canals are infested with submerged weeds (*Potamogeton pectinatus, P.nodosus and P.crispus*). A numerical procedure for design of canal with submerged weeds has been worked out. The procedure is based on the Manning’s formula considering factors such as vegetation density and different types of distribution of submerged weeds along the canal cross section. The numerical solution is an iteration process within the capabilities of scientific pocket calculator. (Bakery, 1992).

Congo - Zaire

Eichhornia crassipes has caused problems in Zaire river(Congo) since its appearance in 1954. The plant reproduce rapidly and huge bulk of vegetation makes travel through water difficult (Ledver, 1995, Charlier, 1995).

Zimbabwe

Water hyacinth has been a major aquatic weed in Zimbabwe. The potential range of floating water weeds particularly *Salvinia molesta, Pistia stratiotes* and *Eichhornia crassipes* are also important weeds of Kenya, Tanzania and Uganda. The information is based on a case study in Northern Lake Victoria and also studies done in different lakes in Uganda(Taylor et al.,1991;Twongo et al, 1991). *Salvinia molesta* have been observed as very important weed at Tangwe in north western Zimbabwe where different methods of its control were evaluated(Chikwenhere and Keswani, 1997).

Kenya

The distribution and abundance of aquatic flora of lake Naivasho was shown to be constrained by two ecosystem level processes, 1) the natural and unpredictable fluctuations of water levels in the lake which results in the drawdown zone of several vertical meters, and 2) the consequence of herbivory by several alien species linked with the competition between rooted aquatic plants and phytoplankton (Harper, 1992)

South Africa

Eichhornia crassipes is the most important aquatic weed of South Africa. *Pistia stratoites* is another weed along with *Salvinia molesta* are particularly troublesome in regions with subtropical climate (Cilliers, 1991).

3.4 Europe

The hydrophyte *Myriophyllum heterophyllum* was observed in irrigation canals in Spain. The plant was abundant down to a depth of 80 cm. Other species found in canals included *Chara vulgaris var. longebracteate, Nitella tenuissima, Ricciocanpos natans, Potamogeton fluitans, Nymphaea alba, Utricularia australis and Ceratophyllum demersum.* (Cirujano et al., 1997).

Two new aquatic weeds *Callitriche obtusanula* and *Elodea muttalli* have been observed in weakly mineralized eutrophic streams in Haute-Moder catchment (Chiebaut and Muller, 1995).

The effect of liming in lakes in S and SW Norway help in the growth of *Juncus bulbosus* .The other acid intolerant species observed were *Myrophyllum alterniflorum* and *Potamogeton spp.* (Brandrud and

Poclops, 1995). *Phragmites australis,* an important lake side weed have been observed in Lake Constance-Untersee (SW Germany/Switzerland) (Ostendop, 1995). The submerged aquatic macrophyte, *Elodea canadensis* is reported as new to West Norway (Rorslett, 1995).

Fifty eight algal and cynobacterial taxa were observed from 47 samples out of 56 samples taken from Spain, France and Netherlands. The majority of taxa were Bacillariophyta (44.8%) and green algae (34.9%) in composition in tap waters (Sabatu, 1995).

Myrophyllum aquaticum and *Paspalum paspelodes* (*P. distichum*) were the most frequently occurring toxic species were highly invasive and were threat to pestiegere river system (Ferreira et al.,1995).

Potamogeton pectinatus and *P. lucens* infestations were observed in Lake Madine (Peltre et al ., 1995). A field study was conducted to study the productivity of six dominant submerged aquaphyte (*Potamogeton lucens, P.natans, Myrophyllum spicatum, Ceratophyllum demersum,* and *Lageosepho major* (Airo and Seonfietti, 1995).

Hydrocotyl ranunculoides (Greater water pennywort) is an aquatic weed of potential economic importance in Western and Central Netherlands. The incidence of the weed in the two important outbreak areas was investigated and it was found that this plant will not pose lasting threat to the native recreational flora (Bau and Holverda, 1996).

Crassula helmsii an amphibious species originating from temperate Australia and New Zealand was recorded for the first time in 1995 in the native reserve near Breda, Netherlands. It was suggest that it should be destroyed to prevent its becoming an invasive weed (Brouwer *et. al*..1996)

In Netherlands, due to eutrophication, many aquatic macrophytes have strongly declined , while at present their former habitats are *Chara chluzo* by non-rooting species such as *Lemna spp*., *Spirodela polyrhiza* and *Azolla filliculoides*. The alkaline nature and high sulphate contents of the river Rhine water which is allowed in large parts of peaty lowlands of the Netherlands is suggested to be responsible for this internal eutrophication, which appears to be caused by increased mineralization of organic material in semi-aquatic and aquatic habitats(Smolder *et al*. 1994).

Phyto-sociological surveys of the *Potamogeton coloratus* in 19 flowing waters of South Central Europe (France, South Germany and Central Switzerland) showed that this community maintains well defined florastic composition in flowing waters, but total destruction takes place by even a slight eutrophication (Buchwold et. al. 1994).

Lemna minuta was observed during boom bust cycle of the weed in Vauxhall lake near Canterbury in U.K. High intensity invasion lead to fish mortality and decrease in invertiberate diversity, due to invasive nature of *Lemma* spp. (Bramley et al. 1995).

3.5 **North and South America**

The wide extension of lake Cuitzeo, Michoacan, Mexico, its shallowness and its numerous springs gave rise to great diversity of habitats which have allowed the development of different aquatic and sub-aquatic life forms. There is extensive florastic richness, represented by 40 families, 70 genera and 92 species of which 25 are strictly aquatic, 30 sub-aquatic and remaining water tolerant species. The dominating communities are the attached emergent hydrophytes represented by the genera *Typha, Scirpus, Cyperus, Eleocharis* and *Phragmites*. The attached submerged hydrophytes. *Potamogeton pectinatus* covers more than half of the eastern part of lake. It was found associated with an alga (*Chara caneseens*). The long draught periods, high evaporation and high mineral concentration in water and sediments are some of the limiting factors of the growth of aquatic vegetation in almost the whole lake (Rojas and Novelo, 1995).

Mexico's National Water Commission (CNA) transferred 2.6 m ha. of irrigated land to 340 Water Users Associations from 1990 to 1994. The CNA started the programme of training WACA managers for the management of irrigation drift. Weed control was one of the major objectives .the most prominent plants are water hyacinth and *Hydrilla verticillata* for which bioagents were successfully used (Rendon et al. 1996).

Typha domingensis was observed in brackish as well as in water in coastal desert marsh in Colarado river delta in Mexico (Glenn et al. 1995).

Among the submerged weeds, early leaf pond weed *(Potamogeton crispus*), pond weed *(P. pectinatus*), Elodea (*Elodea canadensis)*, *Chara* spp. and Eurasion water milfoil (*Myrophyllum spicatum)* have observed major submerged aquatic weeds in California (Pine et al.1990 & 1991, Speneu et al 1989). A filamentous alga *Cladophore spp*. has also been observed.

In Atlanta, the most problematic water weeds include *Hydrilla verticillata*, *Myrophyllum spicatum, Ceratophyllum demersum , Utricularia biflora* and *Najas fluoilis* (Santha et al. 1994). Florida, Lake Wingra was found to contain *P. crispus, M.sibiricum, P. pretinatus* where population of *M. spicatum* was decreasing (Charudattan et al . 1994) .

Potamogeton pectinatus, P. gramineus in Solano canal (California), *H.verticillata* in Potomac river (Virginia) and *P.nodosus* from Big Main Canal in Madera county and from supply Canal in Butta county (both in California) were observed (Spencer et al. 1994).

Hydrilla verticillata has become an important aquatic weed of irrigation canals in Costa Rica causing slowness in waterflow resulting in flooding of adjacent roads (Rojas and Aguaro, 1996) .

Potamogeton illinoensis was a major weed of irrigation canals in Viedma (Argentina). Its mechanical removal could not give discernible effects because of fast regrowth from rhizomotons system which assists in its rapid multiplication (Armellina et al. 1996).

IV. ECOLOGICAL PROBLEMS RELATED TO AQUATIC ENVIRONMENT

Ecologically, aquatic vegetation can be broadly grouped as Algae and Hydrophytes.

4.1 **Algae**

The fresh and saline water exposed to sunlight provide ideal ecological environment to algal growth. Majority of them are purely aquatic in nature and adapt to live in ponds, lakes, streams, swimming pools and oceans. Fresh water algae is grouped as planktonic and filamentous in nature.

Planktonic algae may color the water as green, yellow, red, and black. They may physically look as scums or water bloom. Physiologically they use solar energy to convert it into food, remove CO_2 from water during photosynthesis (in day) and produce Oxygen as by product. During dark hours (in night) they release CO_2 in H_2O through respiration and consume O_2. Some of the algae maintain balance in natural aquatic environments as they produce O_2 and provide food for most of the fish and other aquatic animals. Although, under normal conditions algae are beneficial, their over population may be undesirable for domestic and commercial water uses. Excessive phytoplanktonic booms may result to zooplanktonic developments which may deplete water of Oxygen and lead to eutrification which may prove destructive to fish and other aquatic wild life. Dense growth of planktonic algae will create shade, thus reducing light to the bottom of water body which may prevent germination of seeds, growth of rooted submerged weeds and may result in destabilization of aquatic environment. Generally, they do not disturb irrigation systems, but may spoil the places of recreation value like swimming due to bad odours and scum created on water surface. Some of them may prove toxic to fish, birds and domestic animals. The filamentous algae consists of thread like structures or filaments made of single cells attached end to end.

They do not have roots or stems etc. and grow in cool and warm waters. They cause immense nuisance in irrigation system. The important genera include *Chara, Nitella, Spirogyra, Hydrodictyon, Cladophera Pithophera etc.*

The filamentous and planktonic algae produce undesirable odours and spoils the taste of drinking water, interferes with domestic and industrial usage, clog the filters of the water treatment plants. They also provide a coating to cooling towers and condensers. The filamentous algae clogs the weirs and lining of the canals thereby interferes with the irrigation system. It may also adversely influence the fish production.

4.2 **Hydrophytes**

These plants grow fully or partly submerged in water. There are more than 100 families that represents vascular plants. These plants are structurally different from meso or xerophytes. They have less developed protective and conductive tissues. They have extensive arrangement for buoyancy and aeration, particularly in ground tissue of petiole and leaf mesophyll and cortex of stem and root. Buoyancy is provided by aerenchymatous tissues which may be either schizogenous or lysigenous or both. These plants can be classified as emergent, floating or submerged weeds.

4.2.1 **Emergent weeds**

Most of the weeds are of emergent nature which can grow under saturated and emerged soil - water condition. They grow in soil from saturated moisture on the banks of canals, depression in river shore line and canals into water upto depth of one meter. These weeds may vary in growth according to its habitat. Plants belong to grassy, broad-leaved, shrubs categories. These plants are also found in marshy habitats from saturated to shallow sub-mergence, low lying stretches of lands which remain for a fixed time under water.

These weeds have been observed on the bank of irrigation canals and drainage ditches. They have been observed in seepage areas of canals, depressions containing water along canals, rivers flowing with slow velocity, earthen embankments of water reservoirs, tanks and shallow depths of water reservoirs.

Most of these weeds have been observed in and around water-bodies in tropical and sub-tropical parts of the world as, the ecological environments of these regions are highly congenial for growth, reproduction and dissemination of these weeds.

The important genera to which most of the weed species belongs are *Typha, Polygonum*, *Phragmites, Alternanthra, Scirpus, Ipomea, Tamarix, Cephalanthus, Populus, Juncus, Cyperus, Monocharia* etc.

Some of the important weed species observed are *Typha angustata, T.latifolia, Ipomea carnea, Phragmites karka, Monocharia vaginallis.*

4.2.2 **Floating weeds**

Many aquatic plants have leaves floating on water surface either singly or in groups. They have true roots, leaves and flowering parts above the water surface. Some of them are free floating while the roots of few are anchored in mud in the bottom of water body. These plants rise and fall with the level of water in the water body. They flower very rapidly and some of them are the most troublesome aquatic weed of the world. Free floating weeds belong to the genera *Eichhornia, Pistia, Lemna, Salvinia, Nymphea, Brasenia spirodella* etc.

Eichhornia crassipes, Salvinia molesta, Pistia stratoites are some of the most problematic weeds in the tropical and subtropical regions of the world.

Surface weeds has a category where plants are rooted in the mud below the water body and leaves are at or above the water surface. These plants grow in situations where free water (moisture) is available at ground level to a depth which nears half the depth of normal aquatic plant species. The plants may be broad leafed or narrow like grasses. The leaves do not rise and fall with increase and decrease in water levels as in case of anchored floating weeds. Some of these weeds belong to genera *Nuphar*, *Nelumbo, Jussiaea, Myriophyllum, Sparganum, Pontederia, Sagittaria, Rorippa, Lythum, Epilobium* etc.

Various ecological parameters influence the growth, reproduction and dissemination of the weeds. Variability in the depth of water, the nutrient content in the water, contamination of water with industrial pollutants like metallic ions greatly influence the growth of these weeds. The source of contamination in flow water system like rivers and canals and silting in case of anchored surface weeds greatly influence weed species and their growth. Velocity of water in rivers and canals greatly influence the growth and stability of these weeds. Greater presence of free floating weeds have been observed in rivers and canals which have a slow water velocity.

4.2.3 **Submerged weeds**

There are mostly vascular plants that produces most of its vegetation under the water surface. Most of these plants emerge from seeds and propagules and have true roots, stems and leaves. Abundance of these weeds is dependent on the depth and turbidity of water and physical characteristics at the bottom of the water surface. A depth of 3.5 to 4.0 m. in clear water is the reasonable limit of submerged weeds. They are capable of absorbing nutrients through leaves, stems and roots. Severe competition exists with planktonic alga for nutrients and results in decreased production.

The submersed weeds belong to the genera :- *Potamogeton, Elodea, Myriophyllum*, *Ceratophyllum, Utricularia, Ranunculus, Heteranthera, Alisma?, Zanichellia* etc.

Some of the important problem weeds include *Hydrilla verticillata*, *Potamogeton nodosus, P.pectinatus* (major problem in Chambal and Bhakra Nangal Command canals in India).

4.3 **Effect of aquatic weeds on environment**

Aquatic weeds create number of environmental problems.

Aquatic weeds create situations which are ideal for mosquito growth. The mosquitoes are sheltered and protected from their predators by aquatic weed roots and leafy growth and are responsible for the spread of Malaria, Yellow fever, river blindness and encephalitis. Snails are able to multiply, playing a crucial role in the life-cycle of blood and liver flukes(parasitic worms) as they shelter, and find sustenance among the root zones. Schistosomiasis and fuscioliasis diseases spread as the floating weed carry the snails to new locations. People living close to these areas complain of mosquito problems.

Fish production is greatly affected by the presence of floating and submerged aquatic weeds. Isolated weed beds may be tolerated, providing shelter and shade for fish, but when the growth becomes thick and covers entire water body, it can be lethal for fish growth. Fish may suffocate from a lack of oxygen and may cause death. When floating and submerged aquatic weeds become extremely dense, many fish species are unable to exist in such environments and vanish. For example, fishes production in Harike lake in Punjab is decreasing and is a matter of concern to all.

The decomposition of huge amounts of biological mass creates condition where CO_2 and carbon monoxide are produced and released to the atmosphere. The decomposition period is much less than decomposition of other vegetation on land. The decomposition creates emissions of foul smells which are unpleasant to public convenience. Mosquitoes and other parasites grow in these situations and affect the life of those living in close proximity.

Water bodies which are places of recreational and aesthetic use are badly affected by unwanted growth of aquatic weeds. They hinder the movement of boats and effect other aquatic activities. The decomposition of weed material consists of silicious material and other insoluble salts which settle on the bottom of the water body. Dense weed growth slows the flow of water in rivers, canals and drainage ditches allowing silt to settle out and be deposited on the bed of the water body. This increase in silt deposition raises the bed level and finally affects the life of lakes, dams, tanks etc. and requires expenditure to be increased for frequent desilting through dredging.

Aquatic weeds also affect quality of water. These weeds cause taste and odour problems and also increases biological oxygen demand because of organic loading. They increase the organic matter content of water which may affect the strength of the concrete structures when used as curing and mixing water. It is due to the organic matter that combines with cement to reduce bond strength and may cause large amount of air entrained in concrete.

Aquatic weeds impede the free flow of water which may contribute to increased seepage and may cause rises in water-tables in the adjoining areas. It may lead to water logging. This may also create saline or alkaline conditions in the soil and also give rise to many other land weeds.

Submerged and floating weeds propagate at a tremendous rate. *Eichhornia crassipes* needs a special mention in this category. A pair of these plants can multiply up to about four thousand times in one season. A canal or drain surface normally gets covered and clogged in one season, from just a few germinating or introduced plants. . The surface floating weeds get interwoven and form dense mats that move downstream. . Often these moving mats pack up against bridges and structures creating enormous pressure that sometimes results in serious damage being caused. An example of this sort of damage was observed on Kasur Nala near Taran-Taaran in India.

Over time if left unchecked the weed mats become so dense that people and animals can walk on them, although at the risk of injury or drowning.

V. MANAGEMENT OF AQUATIC WEEDS

Considering the losses caused by aquatic weeds, their management is of utmost importance to improve the availability of water from the source to its end users. This does not only improve availability but also the conveyance efficiency. Irrigation and drainage systems provide favorable conditions for the growth of aquatic weeds which interfere with the storage and delivery systems of irrigation water, maintenance of canals, drains, barrages, lakes, ponds etc. These systems often get choked with the weeds and cause environmental pollution. On low lying areas, adjoining irrigation and drainage channels, soil salinity and alkalinity problems do arise.

Management of aquatic weeds consists of two approaches viz. preventive and control of existing infestation.

1. Preventive approaches
2. Control

Type of aquatic weeds flora and their intensity influence the damage caused by them. The habitat and the type of aquatic weed flora influences the technique of weed control. In broader sense, weed "control" means keeping the weeds at a level where they do not cause economic damage. Aquatic weed can be brought under control to manageable limits by various methods. Broadly, these methods can be grouped under four groups: -

(1) Physical or Mechanical methods
(2) Biological methods
(3) Chemical methods, and
(4) Cultural and physiological methods

There is rarely a situation when weeds can be 'eradicated' but often can be 'prevented' from infesting other areas. Prevention can be useful for a certain weed species or may include a group of aquatic weeds in a given aquatic environment. Once prevention fails the next step is to eradicate it, i.e., treating them in a way that they do not emerge again.

5.1 PREVENTIVE APPROACHES

Quarantines are legislative tools that may be used to mitigate the effect of weeds. Quarantine is defined as the restriction imposed by duly constituted authorities whereby the production, movement or existence of plants, plant products, animals, animal products, any other article or material or the normal activity of persons is brought under regulation in order that introduction or spread of a pest may be prevented or restricted. If a pest has already been introduced and established in a small area, a quarantine is necessary so that it may be controlled or eradicated or dissemination stopped in newer areas, thereby reducing the losses that would other wise occur through damage done by pest (Sand, 1987).

The success of preventive weed management programs varies with weed species, its biology, means of dissemination and the amount of effort needed to be applied. Preventive weed programs usually require community action through enactment and enforcement of appropriate laws and regulations (Day, 1972). It was found that the irrigation water in Nebraska was the significant source of weed seeds (Aldrich, 1984). In India, irrigation canals appear to be a potential source for spreading water hyacinth (Sushil Kumar and Bhan, 1994). Recently preventive weed management approach has been reviewed and discussed by Walker (1995). When prevention and eradication fail to give desired results under aquatic environment, the only alternative left is to keep aquatic weeds under manageable limits so that water use efficiency with respect of water storage in reservoirs and transportation through canals is not reduced. Management of aquatic weeds in water reservoirs, canals, drainage systems, ponds etc. consists of following systems approach of aquatic weed management i.e., following prevention, eradication and control techniques based on the habitat and type of weed flora present in a given situation. These situations may result in serious reduction in water flow in irrigation and drainage systems which may result in flooding, salinity and alkalinity. Under specific situations it may adversely influence navigation and operation of turbines in hydro electric projects.

Case Study:

In a case study of Punjab (India) which has one of the oldest and intensified canal system. There are thousands of kilometers of seepage come anti-flood drain, large numbers of village ponds and barrages like Harike (area 41 sq.km), Shah nehar, Nangal etc. Approximately 75% of the total area is infested with water hyacinth. Nearly 60% of the seepage come anti-flood drains are also infested with water hyacinth. About 10% of this area is infested with emergent weeds such as *Typha* and *Phragmites*,. *Ipomea carnea* is also present around the periphery in dense stands. Due to release of silt free, low turbidity water from dams and reservoirs in canals, the weed flora is different. The majority of these weeds belong to submerged group. Most of these weeds are in main canals where water velocity is very fast but in secondary and tertiary canals where velocity is low *Hydrilla, Chara*, *Potamogeton* have been observed in huge volumes. An example is the site near Shahpur Barrage (Punjab, India) where weed, though not visible on surface, constantly breaks off and lodges on barriers specifically installed to trap the dislodged weed. The weeds are removed with the help of motorized weed removers or manually removed by workers with poles and hooks. Inspite of this, weeds still enter the turbines, fouling the turbine blades, resulting in the power house having to be shut down to remove the weeds.

5.2. CONTROL METHODS

5.2.1 **Physical or mechanical control methods**

a) **Mechanical Control of aquatic weeds**:

Mechanical control of aquatic weeds primarily consists of removing the weeds of any group physically from the water body. It may also involve any physical power which may directly or indirectly inhibit the growth and development of aquatic weeds. This could be done manually by hand, using hand tools or machine power. It may also consist of altering the environment or creating conditions/situations which may inhibit or do not permit growth and development of weeds.

The advantages of mechanical methods include- utilization of available manpower resources, environmental friendly and target specific, yields immediate results, non selective (under specific situations) and provides fewer chances of permitting ecological shifts in aquatic flora. Mechanical methods often reduce massive nutrient load of eutropic water bodies, helping indirectly in diminishing the future weed population. Harvested weeds may have various utilities such as feed, manure, energy source etc. and most importantly mechanical methods can be exercised in any localized area of water bodies.

The limitations include limited effectiveness as in some cases aquatic weed regrow up from their rootstocks, rhizomes and the like; physical removal especially with machines may help spreading weeds to new areas; and sometimes removal of aquatic weeds may deplete water bodies of their nutrients limiting growth of plantation.

A vegetation survey of Pening Lake in 1989 revealed the presence of 4 submerged and rooted species, 6 emergent species and 10 floating species. The most common aquatic plant, which occupied 410 ha of the fluctuating lake area of 1760-2770 ha in 1988, was water hyacinth (*Eichhornia crassipes*), followed by *Hydrilla verticilatta, Salvinia molesta* and *Mimosa pigra*. Two potentially noxious weeds were recorded in the lake for the first time. Two trials were conducted in 1988 and 1989, during which 14 ha and 30.8 ha respectively of *E. crassipes* were manually removed from the lake and left to decompose on dryland (Tjitrosoedirdjo, 1991).

Controlling weeds in an aquatic environment is greatly complicated because of lack of ownership of waterbodies. Most of these are places of public interest. Often frequent approvals are needed from public health Dept., water surveyor, fish and other wildlife agencies before weed control works may be carried out. In many developing and under developed countries there is no control on water use. In many Asian countries a water body can be used for a number of purposes including bathing, drinking, stock watering and irrigation.

b) **Manual Cleaning**:

In areas sparsely infested, weeds can be removed by hand. This could apply to the removal of floating weeds like water hyacinth. Generally, this method is applied to emergent weeds eg. *Typha spp*., *Phragmites spp., Justicia spp*. (Willow), where men cut the vegetative growth with heavy knives and hooks. In shallow water the propagules, rhizomes and other underground reproductive organs can be removed.

c) **Cutting**:

This method consists of physically cutting the biomass over and under the water with the help of heavy knives, or mechanical weed cutters. In the case of *Typha*, it has been observed that if plants are cut under the water and remain submerged for more than a week to 10 days, control is possible

This may also hold good for *Phragmites, spp*. Also mechanical cutting of water hyacinth and other submersed aquatic weeds like *Chara spp*. Filamentous *algae*, *Potamogeton* spp. will give temporary relief from weed infestations A mechanical weed cutter is used to cut floating and submersed weed at 1-1.5 m depth in water reservoirs. It consists of sharp cutter bar and operates from a boat. The harvested weeds are collected and water is squeezed from them to hasten dehydration and desiccation.

d) **Chaining**:

Chaining consists of a heavy iron dragchain attached between two tractors, which is dragged down a densely weed infested ditch or medium canal. The chain tears the rooted weeds and loosen them from the bottom. This method has been found effective where there is dominance of emergent and submersed weeds. The practice of chaining should be followed when new shoots of weed are around 30-50cm above water level. Dragging the chain up and down the stream may be effective in dislodging most of the weeds. For effective weed control the practice should be repeated at frequent intervals if found successful. One of the limitations of this method is that ditches need to have uniform width, accessible from both the sides with tractors and free from trees and other such obstructions. The debris thus collected at the end should be removed to avoid reinfestation by plant proagules further downstream

e) **Water weed cutters and harvesters**:

In high discharge canals and very large water bodies weed cutters/harvesters are used to control rooted submerged weeds.

i) Under water cutters: These are normally attached to a motorboat. The equipment consists of sharp and strong cutter bars with heavy reciprocating blades, sliding against a fixed blade.
ii) Harvesters: Machine that cut and picks up the weeds from water body and convey these to shore simultaneously.

Under water weed cutters were employed at Kota (India) to clear Chambal canal from aquatic weeds (Gupta, 1973). At the Central Institute of Fisheries Technology (CIFT), a portable machine gadget has been developed which can clear both floating and submersed weeds at the rate of 1-1.5 ha area per day (Mukhopadhyay, 1995).

f) **Dredging**:

Dredging is one of the techniques by which the weed vegetation along with excess silt is removed from drains and ditches. A Dredger is a machine equipped with a forked bucket which can be opened and closed on command. The machine could operate from the ground or from a boat in water. Dredging is done in large water bodies, canals and drains. It is a common method of cleaning ditches but slow, time consuming and is a costly operation. Small lakes, water reservoirs etc. get silted if area surrounding them is under cultivation or surrounded by erodable lands with poor aforestation. When silts gets sedimented at bottom the water retention gets decreased and emergent weeds (*Typha, Scirpus* spp. etc.) establish. Such a situation demands the use of dredging facilities to remove silt and increase the water capacity of lakes. This also reduces the problem of emergent weeds.

Fig.7. Dredging essentially meant for desilting along shores also helps in removal of aquatic weed vegetation

g) **Mowing**

This process consists of cutting the weeds close to the ground with the help of manual or power operated mowing machines. Mowing is effective on tall growing plants. Repeated mowing not only prevents seed production of emergent weeds but may also starve the under ground parts which store carbohydrate reserves and provides energy to vegetative reproductive organs. The best time to mow is when carbohydrate reserves are low. For many species it is when the active growth phase is over and the time of flowering initiation starts. Repeated mowing hastens carbohydrate depletion and slow death of plants. Generally, this practice effectively controls emergent weeds on canals, water reservoirs etc banks. Where gradient in ditches is smooth and not too steep the under water cutters can be used to control emergent and submerged weeds. The effect of mowing is short lived. The operation needs to be done frequently to exhaust carbohydrate resources. Therefore this process does not give any effective control on long term basis. Pasturing is the economical and effective way in controlling marginal grasses, weeds etc. A good legume grass mixture if properly managed and grazed will give a lawn like appearance. A good sod shall also protect banks of canals, drains and dams against erosion Excessive movement of animals may destroy the banks and make water muddy and may also degrade the quality of the water.

h) Netting:

Scattered floating weeds can be skimmed out of small water bodies using nets usually made of 3 mesh coir ropes.

i) Barriers:

Bamboo or inflatable rubber boom fencing is used to restrain the drift of free floating aquatic weeds. The barriers are made to allow water to pass through them and to sustain the wave and wind action.

j) Checking weeds seeds through irrigation water:

Irrigation water often carries the seeds of aquatic weeds such as *Eichhornia crassipes, Pistia stratiotes* and *Salvinia molesta*. It is important to control weeds near and in reservoirs and irrigation canals to prevent them form shedding seeds into the water. Weed seeds can be collected by screens and removed from the source of supply. The screens should be made of woven plastic cloth of less then 1.0 mm mesh supported on rigid metal 1.5 cm screens. Allowing a square meter of screen for each 0.05 m^3 per second of water flow with the fine screen tightly stretched to encourage vibration and self cleaning as water falls on it.

Fig.8. Lining of canals helps in reducing weed vegetation (Yamuna Canal Haryana, India)

Fig.9. High velocity of water in flow water system discourages weed growth

Fig.10. Infestation of Algae and submerged aquatic weeds in Baigul Dam (U.P.), India

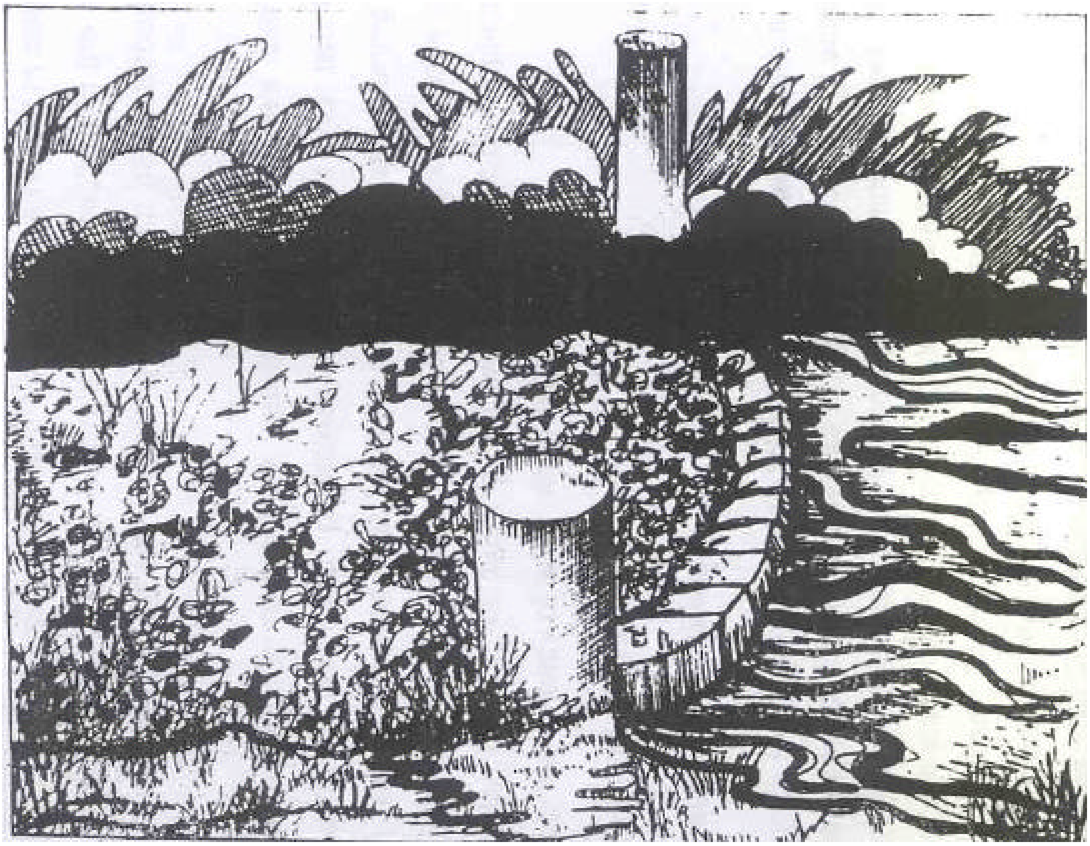

Fig.11. Collection of water hyacinth in flow water system

k) Burning/Fire/Heat treatment:

Aquatic weeds especially emergent bank weeds can also be brought under control with the help of fire. The general thermal death point of most of the weeds is in between 45-55^{0}C. Higher temperature treatment than this results in coagulation of cell protoplasm which inactivates the enzymic process resulting in the death of the plant. The heat treatment required for weed control is provided with the help of fire through flame throwers.

Burning may be used to control bank weeds in irrigation canals, ditches etc. Usually green plants are also given preliminary shearing and after two to three weeks vegetation may be dry enough to be successfully re-burnt. Burning can be combined with herbicides and mowing to increase its efficiency. Often mowing followed by burning or burning followed by herbicide application on regrowth will help the efficacy of each other treatment.

5.2.2 **Eco-physiological alterations:**

a) **Drying or water level manipulations:**

This method is a simple and effective way of controlling submerged weeds. Most of the aquatic weeds respond quickly to changes in water level. Control is achieved by either dehydration of the vegetation or by exposure to low temperatures. In tanks, fish ponds and canals emptying the water periodically to kill the weeds susceptible to desiccation is practiced. To kill submersed weeds in the canals of Bhakra Canal System in Haryana (India) (Malhotra, 1976) and in Chambal Command Area (India) in Rajasthan (Brezney, 1970) exposure to sun is given by draining the water and this practice prevents regrowth for nearly six months. Cutting of the aerial shoots of *Typha spp.* at flowering stage and keeping the stubble submerged under the water for four weeks controlled *Typha* (Singh, 1976). Under such cases, there may be disadvantages in lowering the water level as it may induce production of vegetative propagules or sexual reproduction. Therefore, in such cases, weeds should be removed quickly and the sediments should be dried completely.

Planting of trees on the banks of canals may create shade to reduce light intensity hence checking the weed growth. However care should be taken that trees or their appendages do not impede. water flow. Light intensity can also be checked by adding dyes to the water. This type of control is more effective in static water such as ponds or tanks where dye remain suspended for a longer time.

Drying or water level manipulation is generally practiced in flowing water system like irrigation canals, drainage ditches. In some cases where facilities exists, in tanks and ponds. During the process the water is removed and the base of the tanks, canals etc. is made dry by exposing the land to sun & air. This totally changes the ecoenvironment, which is very adverse to the eco-environment required for growth and development of submerged weeds. Frequent drying and wetting for several days may control the growth of roots and propagules in the bottom soil. This method is not effective for control of emergent weeds.

The Irrigation and Power Research Institute, Amritser (India) has developed a weed cutter operative from banks of the canals (Singh et.al. 1987). Thereafter, applied drying method i.e., plants were exposed to the sunlight for 7 days by affecting closure in canals. Following the exposure water was delivered for 2 weeks. Four such cycles were necessary. The weeds were disintegrated after the fourth cycle. This method has the limitation of alternate closure and operation of the canals.

b) **Light**:

Light is an essential component of the photosynthetic process, which is necessary for the growth and development of aquatic plants, especially submersed aquatic weeds. Growth of submerged aquatic plants in small tanks and ponds can be checked by reducing light penetration . Use of fiber glass screen is popular in some countries. Coloring chemicals have also been tried for intercepting solar radiation reaching the water.

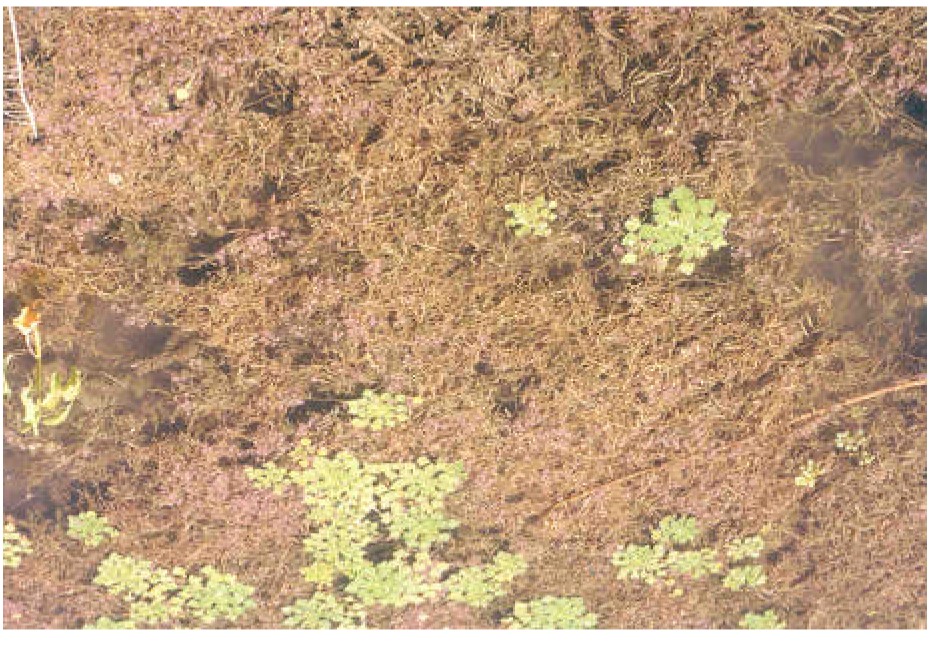

Fig.12. Clean water encourages growth of submerged weed vegetation in ponds, tanks and reservoirs

Ponds that are adequately fertilized develop millions of tiny plants which give the water a cloudy appearance (bloom). If this water is nearly 75 cm deep, submerged aquatic weeds have almost no chance to grow (KLINGMAN, 1961). This is due primarily to shading the submerged plants.

Fig.13. Covering the water surface with Azolla helps to check under water weed vegetation

Fig.14. Movement of turbid water reduces the growth of submerged aquatic weeds

A 8-8-8 or similar fertilizer is suggested at about 150 kg/ha. A light colored object should not be visible at around 50 cm below the surface. This practice should be followed where there is little loss of water from the pond. Some object to it as unclean water but that is not the case. The bloom induced by fertilizer application is not considered as bad for health.

The proper construction of a tank is very important for controlling pond weeds. Many rooted aquatic plants do not establish in deep water. Therefore tanks should generally be deeper than 1m. The slope, at the bank should not be more than 2m i.e. the angle of slope should be steep i.e. around 3:1 and this will help in reducing the area where infestations of *Typha, rushes* and *sedges* could establish. This may be dangerous for access but flatter separate slopes can be provided at one or two location in the pond for general access. In an experiment conducted at Irrigation and Power Research Institute of Amritser (India) in small plastic trough of 45cm dia meter and 22.5 cm height with silt added at base for little more than 7.5cm. The weeds were transplanted and allowed to stabilize. Nutrition was provided through well decomposed Farm Yard Manure. When new sprouts started emerging, the polyethylene film was used to cover troughs for 1,2,3,4,5 i.e. up to 15 days the leaves started falling after six days.

c) **Breaking of anchorage**:

Submerged aquatic weeds can only survive if there is optimum sunlight. In shallow water, optimum light may penetrate to the bed level allowing plants to anchor and take root at the base of the distributary, water course, shallow pond etc. In case of canals, barrages, tanks with deeper water levels, the light may not reach the bed level. Under such situation weeds may form anchorage on the inside banks of the irrigation system. In an experiment conducted at Nirwan Branch near Patiala (India). A canal was heavily infested with submerged weeds. Divers cleared the bed of weed. Thereafter a plough was lowered in the canal along with wooden floats which were connected with a tractor and pulled upstream of canal. However no weed could be brought out from the bed. It is important to check where the weeds are anchored and growing from so that they can be successfully managed. Alternatively side walls may be covered with colored polyethylene to exclude all light penetration and facilitate early decomposition of the plant materials.

Fig.15. Infestation of Typha latifolia on the banks of large pond in Avanti Bai Sagar Project (M.P.), India

Fig.16. Earthern bank large reservoirs having shallow depth near banks encourages the growth of submerged aquatic vegetation

Fig.17. Large scale infestation of Ipomea carnea in water tanks in Maharashtra, India

Fig.18. Large scale infestation of water hyacinth (Eichhornia crassipes) in drainage system in Haryana, India

d) **Sub-mergence**:

Typha is one of the most important emergent weed growing all along the unlined canals margins of the water bodies and shallow submersed area s along canals. Cutting *Typha* close to the ground followed by subsequent submergence or cutting *Typha* under the water provides effective control of this weed.

e) **Competitive displacement**:

The approach of replacing harmful vegetation by relatively less harmful and beneficial vegetation needs more research. Planting of Paragrass (*Brachiaria mutica*) in drainage ditches in the Chambal Irrigation Project eliminated *Typha angustata* after 10 to 12 months and yielded green fodder (Mehta and Sharma, 1975). Besides direct competition, growth is also suppressed by some plants by shading effect. For example, the growth of *Azolla* in rice fields effectively controls the growth of other weeds.

5.2.3 **Biological control of weeds**:

Biological management of aquatic weeds is a broad term for the exploitation of living organisms or their products to reduce or prevent the growth and reproduction of weeds. The organisms that are used for biological control are diverse e.g. insects, pathogens, nematodes, parastic and competing plants Biological control involves the deliberate use of organisms such as insects or fungi to control weeds. Biological control is more complex than chemical control because it requires (a) long term planning (b) multiple tactics and (c) manipulation of cropping system to interact with the environment.

Julien (1989) has attempted to work out the total releases made against weeds by biological agents. He found that after 13 releases of agents for classical control of weeds in the first decade of this century, the number of releases per decade increased nearly exponentially. The rate of effectiveness declined from 29% of all releases up to 1980 to 25% of all releases up to 1985. The various approaches of biological control are briefly discussed as below:

i) **Biocontrol agents**:

Owing to the increasing awareness about ill effects of herbicides and no control on use of water, lately emphasis is being given to research for non-chemical approaches. Biological control is considered to be one of the most safest approaches. Any plant feeding organism may be used to control aquatic weeds provided, it does not harm plants of economic value or create undesirable imbalances in the plant community. Some of the natural enemies have been considered for control of submersed, floating and emergent weeds.

ii) **Pathogens**:

Weeds can be controlled by pathogens like fungi, bacteria, virus and virus like agents. Among the class of pathogens, fungi has been used to a larger extent than bacterial, viral and nematode pathogens. In some cases, it has been possible to isolate, culture, formulate and disseminate fungal propagules as mycoherbicides. Several books and reviews detail the history, development prospects and technical aspects of the use of plant pathogens (Julien, 1992). Pathogens may have many advantages like (i) most pathogens of plants are fungi (ii) they are destructive (iii) they are widely prevalent (iv) most of them can be easily mass cultured, and, (v) they can be integrated into organized pest management systems. Most specificity is the fundamental feature. Pathogens with broad host range are unsuitable simply because they may attack the cultivated plants. Formulations of fungi applied as inundative inoculum in a manner similar to that of chemical herbicides have been termed "myco-herbicides". It involves mass-culturing, standardization, formulation and application of fungi inoculum to weeds. Already two mycoherbicides have been registered in USA for use as herbicides. They are De-Vine and Collego.

During surveys from 1992-94 in and around Jabalpur (India) in different months, two fungi viz. *Acromenium zonetum* & *Alternaria* spp. from infected leaves of water hyacinth were isolated (Kauraw and Bhan, 1994). A series of surveys were conducted throughout Haryana in 1988-92 to identify naturally occurring fungal pathogens of water hyacinth. Infection of water hyacinth leaves by *Fusarium chlamydosporum* was observed, characterized by small, punctuated leaf spots with ash colored centers, which become elliptical to irregular shaped structures. The infection of water hyacinth leaves at 1 months after inoculation with *F. chlamydosporum* ranged between 25 and 54%. Survey carried out during 1988-91 on *Eichhornia crassipes; Alternanthera pheloxeroides; A*.perngens; *Asteracantha longifolia; Convolvulus arvensis; Ranunculus sceleratus;* and *Typha angustata* yielded 18 fungal pathogens. New host records included *F. chlamydosporum*.

iii) **Use of aquatic mammals and rodents**:

Introduction of Manatee (*Trichechus inunguis*), and the rodent *Coypus* (*Myocastou coypus*) both known to feed on aquatic vegetation had earlier been suggested as possible biocontrol agents against aquatic weeds, but the slow reproductive rate of the former and the omnivorous feeding of the latter have discarded their trials.

iv) **Use of fish**:

Hickling (1965) has dealt in detail the use of fish in biological control of aquatic vegetation. Among the several species of herbivorus fishes which feed on aquatic weeds, the more important are ; *Tilapia melanoplaura; T. zilli; T nilotica;* and *Puntiase gonianatus*. Verigin (1963) tried *T. Zilli* in the cooling ponds of a power station in Moscow and found it to be a great consumer of weed *Vallisneria*, but this fish cannot survive below 55^{o}F. The Russians who consider fish as more valuable and more permanent agent for weed control than mechanical or chemical, are using the grass carp *Clenopharyngodon idella* and *Hypophthal michthys molitrix*. The former is said to be the more effective species. It feeds on a wide range of aquatic weeds such as (*Potamogeton*; *Lemna; Ceratophyllum; Elodea; Hydrocharis*; *Vallisneria*; and *Myriophyllum)*. The *C. idella* fish has been employed for weed control in China, Hungary and Japan and has shown promise in other regions. It feeds on a range of submerged and floating weeds, but prefers plants having soft tissues. Its rate of growth and development varies with the source of food. The white amur displays good performance in high and low temperatures and is not known to reproduce naturally outside its native water.

Fig.19. Grass carp (Ctenopharyngodon idella), voracious feeder of submerged aquatic weeds

Spencer (1994) used a computer program to simulate the growth of *Potamogeton pectinatus* and plant consumption by the herbivorous fish *Ctenopharyngodon idella* (triploid grass carp) under environmental conditions of Northern California Irrigation System. The program was executed using several initial fish densities ranging form 0 to 300 kg fish/ha. It was concluded that for temperature of 12-24^{o} C would require more fish (50 or 250 kg vegetated/ha). It is also concluded that *C. idella* may be an effective and economically feasible option for *P. petinatus* control in cool water irrigation systems.

Santha et.al. (1994) studied the control of the submersed weeds in water lily production ponds in Georgia USA, under enclosed condition. Complete control of *Hydrilla; Myriophyllum*; *Ceratophyllum, Utricularia* and *Najas* was observed at 1 and 2 fish (triploid grass carp) per enclosure. When weeds were controlled, there was some damage to water lilies in 2 of the enclosures.

In a study testing the preference of grass carp (triploid) on submersed aquatic weeds; Pine and Anderson, (1991) based on experimental value triploid grass carp preference was determined as *Potamogeton pectinatus* > *Chara* > *Myriophyllum spicatum*. A filamentous alga *Cladophora sp.* disappeared the area not surrounded by enclosure 9 months after fish introduction. The efficiency of controlling *Hydrilla verticillata* using grass carp was studied in three trials during 1993-94 in Costa Rica (Rojas and Aguero, 1996). 987 kg/ha of grass carp reduced *H. verticillata* biomass in nearly 62 m^3 with in 21 days. In another trial 1264 and 2042 kg/ha of the fish completely eliminated the weed after 30 days. In third case 1000 kg/ha of carp only reduced *H. verticillata* volume in 19 m^3 after 66 days. The ration of kg of carp initial volume of *H. verticillata* was more important than kg/ha of carp. When this was <0.02, the carp did not satisfactorily control *H. verticillata,* while ratio of >0.05 resulted in the significant reduction of the weed. The equilibrium point between weed regrowth and biomass consumed by the carp occurred at a ratio close to 0.03.

Jhingran (1968) reported grass carp to feed voraciously on *Hydrilla, Azolla, Nechamandra* and *Lemna spp*. In India. Ponds choked with *Hydrilla* have been cleared within a month by stocking 300 to 375 grass carps (weighing 78 to 173 kg per hectare.) White Amur is a poor breeder in the warm water, therefore, for weed control purposes it is bred artificially and released in the water when fingerling are 100g each. About 1500 fingerlings must be released per hectare area of water. Fry and fingerlings of the carp are being distributed to different states in India by Central Inland Fisheries Research Institute, Barrackpore, India. Some important fishes used to control aquatic weeds are given in Box 4.

v) **Use of Snails**:

Promising results have also been obtained utilizing snails *Pomade canaliculata Lamer*, against the aquatic weed, *Anachaares alensa* in Brazil and *Marisa cornuarietis* in Florida (Seaman and Porterfield, 1964). Good results have also been observed against aquatic weeds like *Ceratophyllum demersum, Najas guadalupensis* and *Potamogeton illinoensis* which were controlled completely. *Pistia stratoites* and *Alternanthera philoxeroides* were partially controlled while *Eichhornia crassipes* was not completely eaten but its growth and flowering were greatly retarded by root pruning action of the snail. The snail *Marisa cornuarietis* feeds on a number of aquatic plants and was considered to have weed control potential. However, its usefulness was limited because of its ability to feed on young rice plants and poor tolerance to water temperature below 10^{o}C. On the other hand, its ability to destroy the breeding sites of the snail vector of *bilharzia* may allow its introduction in non rice areas. *Pomacea australis*, a South American snail is also being considered for weed control.

vi) **Use of insects**:

Water hyacinth (*Eichhornia crassipes*) remains the world's most important aquatic weed. It is spreading at an alarming rate in Africa and Papua New Guinea and is a major problem in the Indian Subcontinent and South-East Asia. Successful biological control can significantly reduce this weed cover in 3 to 10 years after establishment of an agent and has achieved excellent control in number of countries. (Julien et.al., 1996). The use of curculionid *Neochetina bruchi* for controlling water hyacinth was investigated in Karnataka (India) in 1984. Between February and July, a total of 7 releases consisting of 1700 beetles was made into a 20 ha tank fully infested with water hyacinth. Releases were than confirmed to an area of about 1 ha and observations on establishment and dispersal of the beetle were made at 2 month interval. By March 1985, up to 5 adults were present per plant in the release area, and the insects had started dispersing to other parts of the tank. The beetle was present throughout the tank by Sept. 1985. By September 1987, about 90% control of water hyacinth had been achieved and the remaining plants were stunted with reduced vigor The curculionid coexists with *N. eichhorniae* which was also released in India from USA for biological control of this weed (Jayanth, 1988).

Over 7500 adults of *Neohydronmus affinis* were released in Florida between April 1987 and July 1988 for biological control of *Pistia stratiotes*. Periodic observations from June 1987 to Sept. 1988 indicated establishment and dispersal of bioagent. At some sites, *N. affinis* infested plants exhibited symptoms typical of plants in other countries where *N. affinis* has been used successfully to control this weed (Day et.al., 1990).

The potential of North American aquatic weevil *Euhrychiopsis lecontei* to serve as a bioagent for an exotic weed *Myriophyllum spicatum* which is currently found throughout USA and Southern provinces of Canada was evaluated. This weevil was found on *M. spicatum* in lakes where population of the exotic weed have declined. In both lakes there was 50% less *M. spicatum* biomass in enclosures with weevils than in enclosures without weevils. The results suggests that the North American insect may be suitable control agent for this introduced aquatic weed. (Sheldon and Creed, 1995).

Box 4 **Bioagents introduced in India for biological suppression of aquatic weeds (Singh, 1989)**			
Weeds and its origin	**Bioagents and its origin**	**Introduced and released in India**	**Present status in India and remarks**
Eichhornia crassipes (Mauritius) Solms, South America	*Neochetina bruchi* Hustache (Coleoptera, curculionidae)	1983	Ex. Argentina via USA. Released in Bangalore, Central India, North eastern India. Established very good control
	Neochetina eichhorneae Warner (Coleoptera, Warner (Coleoptera, Curculionidae).	1983	Ex. Argentina via USA. Released in Bangalore, Trichur, Hyderabad, Central and North eastern India. Established very good control.
	Orthogalumna terebrantis Wheelwork, (Acar: Galumindae)	1982	Ex. Argentina via USA. Released in Bangalore, Established.
Salvinia molesta D.S.Mitchell South America(Water fern, Salvinia) (Water fern, Salvinia)	*Cyrtobagous salviniae* Calder and Sand (Coleoptera: curculionidae)	1982	Ex. Brazil, via Australia. Released in Bangalore and Trichur. Established excellent control.
	Paulinia acuminata (De Geer) (Orthoptera: Acrididae)	1974	Ex. Trinidad. Established at one site. Establishment elsewhere uncertain because of predatory action of frogs and lycosid spiders.
Alternanthera philoxeroides(Mauritius) Grisebach	*Agasicles hygrophilla* Selman and Vogt.		Ex. South America via USA. Damages foliage.
Submerged aquatic weeds like *Hydrilla, Ceratophyllum Najas*	*Ctenopharyngodon idella* (Cuvier and Valenciennes) (Pisces : Cyprinidae) (Grass carp).	1959	Ex. China via Hong-kong, widely established and successful in fish ponds and tanks etc.
---------do-----------	*Osphronemus goramy* Lacepedes(Pisces: *Osphronemidae)*	From early 1800 to 1916	Ex. Java and Mauritius Well established in Tamil Nadu and successfully distributed to other areas.
--------do-----------	*Tilapia mossamabia* Peters (Pisces: *Cichlidae).*	1953	Ex. Africa, limited value in controlling soft leaf weeds in ponds, tanks etc.
-------do------------	*Hypophthalmichthys moitrix* (Cuvier and Valenciennes) (Pisces: *Cyprprinidae)* (Silver carp)	1959	Established but not very effective.

Fig.20.Visible impact of Neochetina infestation on water hyacinth in a water tank

Fig.21. Cytrobagous salviniae feeding on Salvinia molesta

Fig.22. Neochetina eichhorneae feeding on the leaf of water hyacinth

Fig.23. Neochetina bruchi feeding on the growing ponds of water hyacinth

Fig.24. Conductance of water through underground conveying system water source to tank saves from problem of aquatic weeds (Maharashtra State Electricity Board, Nagpur, India)

Investigations were undertaken on relative toxicity of 12 allelochemicals to nine aquatic weeds namely water hyacinth; *Pistia; Salvinia; Azolla; Spirodella; Lemna; Hydrilla, Ceratophyllum* and *Najas*. Allelochemicals tested included p-hydroxybenzoic acid, anisic acid, cinnamic acid, salicylic acid, coumeric acid, fumaric acid, tannic acid, gallic acid, chlorogenic acid, vanillic acid, caffic acid and ferulic acid 25, 50 and 100 ppm of allelochemical were wherever necessary dissolved in small quantity of acetone or ethanol directly prepared in distilled water. P-hydroxybenzoic acid was lethal to water hyacinth, P*istia, Salvinia, Azolla, Lemna, Spirodella*, *Hdrilla, Ceratophyllum* and *Najas* at 50 to 100 ppm. Anisic acid was lethal at 50 ppm to *Azolla*, *Spirodella* and *Lemna;* and at 100 ppm to *Hydrilla, Ceratophyllum* and *Najas*. The concentrations below lethal were usually inhibitary. Water hyacinth, *Salvinia* and *Pistia* were relatively more tolerant to phytotoxicity of the allelochemicals when compared with other floating and submersed weeds.

Over the last many years the erstwhile station of the Common wealth Institute of Biological Control had conducted surveys for natural enemies of several major and minor aquatic weeds. As a result of this survey, a number of insects, fungi, and other organisms associated with these weeds have been recorded, host specificity tests have been conducted and their actual and potential value as biocontrol agents evaluated (Sankaran et.al., 1966; Sankaran et.al. 1967).

vii) **Allelopathy**:

The concept that some plants may be allelopathic to certain weeds is receiving increased attention in the search for weed control strategies. A great deal of literature is available on the phenomenon of allelopathy which has been defined as “the direct or indirect harmful effect of one plant on another through the production of chemical compounds that escape Into the environment.”

Dry Casitta powder was added at the rate of 50g, 100, 150 and 200g/10 liters of water (0.5,1.0,1.5 and 2.0 percent respectively) and water hyacinth plants were grown in plastic tubs. All the treatments showed reduction in number of leaves and biomass in the treated tubs when compared with untreated ones. Casitta powder @ 1 to 2% w/v could completely kill the leaves and reduce the biomass two fold – (Kauraw and Bhan, 1994).

5.2.4 **Chemical methods of weed control**:

Aquatic weeds can be controlled effectively by use of herbicides. The time and method of herbicide application varies with the type of weed flora and the habitat in which the weeds are to be controlled. Control of aquatic weeds by herbicides is generally easier, quick and usually cheaper, when compared to mechanical methods. The use of herbicides has the disadvantage of being in water as residue and more especially in areas where there is no control on water use. Not all herbicides can be used for weed control in aquatic environment. A herbicide should have certain specifications for its use in different types of aquatic environments.

- It should have high degree of phytotoxicity to kill weeds fast.
- The chemical should degrade or dissipate from water immediately after the action on weeds.
- Technology should be available for their use in static or flow water systems.
- It should be environmentally safe for humans, fish and other aquatic fauna. Many herbicides are harmless to fish at concentrations required for control of weeds.

The use of herbicides may at times create problems of residues in the aquatic environment. However, many of the herbicides which can be used for aquatic weed control are relatively safe and free from toxins. Often the problem of aquatic weeds is so severe that it necessitates the use of herbicides which outweighs other considerations. There are many aquatic situations where herbicides can be of help in controlling aquatic weeds without coming in contact with water. For example, *Ipomea carnea*, a very common weed around the rim of the water reservoirs can be controlled by use of herbicides (2,4-D and glyphosate) in the month of April-June when water levels are very low and the application areas are several meters away from water. The other areas where herbicides can be effectively used, are where mechanical and other control measures are not very effective or feasible.

Most of the new herbicides are low in mammalian toxicity i.e. with reference to humans and other warm blooded animals. Many of the herbicides at recommended levels of application are harmless to fish and other beneficial aquatic fauna. Selective herbicides are also being used in managing weeds in the aquatic environment which will not hurt other flora and fauna which is necessary to maintain the birds and other aquatic species which generally thrive in these situation. Herbicides are applied to emersed (Cattail) and floating (water hyacinth) weeds through foliar application using spraying system in boats or other such carriers. Generally herbicides are applied in patches as spraying the whole weed growth may result in decaying of weeds which in turn may reduced oxygen levels in water thereby killing the fishes and other aquatic animals. In case of submersed weeds, the herbicides are added by adding dilute solutions of herbicides in water through main water system or introducing in patches through sprayers or injections.

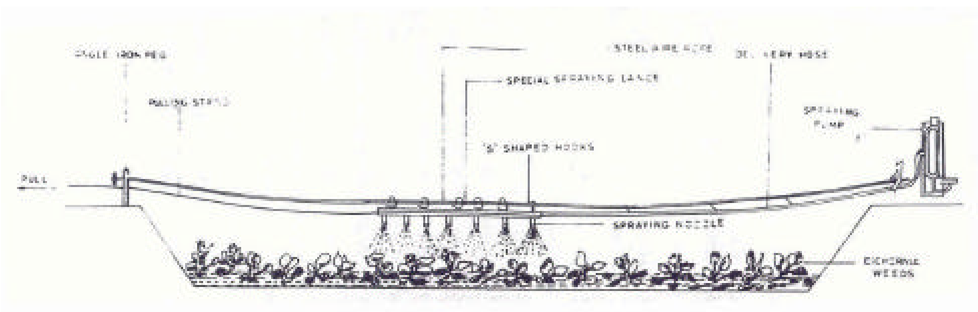

Fig.25. Special spraying arrangement for sites unmanageable from the banks

Some of the advantages of using herbicides are :

1. Herbicides are economical and fair in action thus save time.

2. The dead weed biomass sinks to the bottom of the water body avoiding loss of nutrients and biomass.

3. Herbicides kill even the roots and other deep rooted reproductive organs which generally can not be removed by mechanical means.

4. One or two applications of herbicides are sufficient while mechanical methods may need to be applied a number of times.

Application methodology:

Most herbicides are applied as high volume sprays by hand. Tractor and boat mounted sprayers are also used depending upon the location and weed species to be controlled. Boats are used in big reservoirs, tanks, lakes and large ponds where water is still and weeds are to be controlled belong to emerged and floating types. In the case of canals and drainage systems, tractor drawn sprayer can be used for spraying herbicides.

Application methods depend on the chemical properties of the herbicide and its formulation. Herbicides which diffuse in water quickly can be applied in a concentrated form while others must be diluted and then sprayed evenly over the surface to ensure uniform distribution. In the case of emerged and floating weeds the herbicides are applied as a normal post emergence spray when weeds are in active growth phase. In case of submerged weeds, herbicide application before the plants reach full maturity is advised preventing deoxygenation of water through the rapid breakdown of dying plant material resulting in harm to fish and fish populations.

Spray applications:

Surface area is the main consideration for emergent, floating and marginal weeds in reservoirs, ponds, tanks where water is stagnant. The quantity of herbicide can be determined as

$$\text{Quantity of herbicide (liters/ha)} = \frac{\text{Surface area (m}^2\text{) x Spray Vol./ha x herbicide concentration.(\%)}}{\text{10,000 x 100}}$$

For example: An area of 5000 m^2 to be treated with 0.1% Glyphosate at a spray volume of 500 L/ha, the quantity of glyphosate required will be :

$$\frac{5000 \times 500 \times 0.1}{10000 \times 100} = 2.5 \text{ l/ha}$$

Herbicide application to kill submerged weeds in static water bodies is calculated on the basis of total volume of water in the water body.

Example: The quantity of 2,4-D required for a lake of 10 ha with 2 m. depth of water is to be treated with 0.5 ppmw of 2,4-D, the quantity of herbicide required is :

$$\frac{10{,}0000 \times 2 \times 0.5}{10{,}000} = 10 \text{ Kg. 2,4-D}$$

Herbicide application to kill submerged weeds in flowing water system (canal, drainage channels etc.) is based on discharge, which can be determined as follows:

$$\text{Discharge (m}^3\text{/sec)} = \text{cross sectional area of the flow (m}^2\text{) x flow speed (m/s) x 0.9}$$

The discharge is used in determining the application injection rate of herbicide solution.
For example, if a canal has a discharge of 20 m^3/sec and it is to be treated with spray solution of 300 L in 60 minutes, the injection rate would be:

$$\frac{20 \times 300}{60} = 100 \text{ l/m}$$

There are number of herbicides which have been found to be effective in controlling aquatic vegetation. Herbicides are being used with restrictions in different countries depending upon the type of aquatic weed flora and control on water use by respective countries. In many situations herbicides are effective and can be preferred tools for managing noxious aquatic weed vegetation. There are specific problems where herbicides are to be used in developing or less developed countries of the world where there is no control on water use. Effect of these herbicides is also to be seen on other aquatic environmental factors which are associated with herbicide use. A single herbicide that controls weeds as well as being safe for all possible uses of the treated water is yet to come. However, there is now a large number of herbicides available keeping in mind the major weed problem, use of water system and the effect of chemicals on aquatic food chain down stream.

5.2.5 Commonly used herbicides for weed control

A brief description of some of the available and largely used herbicides is given below.

(i) **Algaecides**:

Copper sulfate specifically known as Copper sulfate pentahydrate is one of the most common and largely used chemicals for control of algal growth in aquatic system all over the world. It was first used in 1904. It controlled water bloom at 0.1 ppm, common sown algae at 1.0 ppm and *Chara* sp. at 5 ppm. *Pithophera* spp. are difficult to control (Gupta, 1987). It is one of the cheapest chemicals available and that is why it is used so widely as an algacide. It does not degrade in water hence, repeated applications may accumulate to toxic levels in the substrate of the water body. The safe limits are 2.3 – 12.0 ppm Cu in human drinking water and 100 ppm in animal drinking water, Chelates of Cu are used in hard water to avoid in-activation. It also reduces Cu toxicity to fish culture. In alkaline water having >100ppm $CaCo_3$, Cu gets precipitated as oxychloride to insoluble forms. In turbid water Cu gets adsorbed to suspended fine pentacles. Copper chloride is a Cu based algaecide made for use in irrigation water and stored recreational water. It is less harmful to fish and other crustaceans. It is less corrosive to sprayers. Satisfactory control of filamentous algae including *Cladophora; Spirogyra*, and *Ulothrix* has been obtained in large irrigation canals in Washington by applying $CuSo_4$ crystals. The concentration should be maintained at 1.00 ppm. The U.S. Public Health Service has ruled that water used for drinking shall not have over 7.5 ppm of $CuSO_4$ or 3 ppm of Cu The concentration of 1.0 ppm is safe for fish and applying to crops. Studies conducted in South Africa on problem blooms of micro-algae, Josaka; Bolton and Roux in Final Report observed that chemical applications give a rapid and seemingly effective result and require less labour for dosage. Although chemicals such as Diquat; Paraquat; Endothall; Roundup and Touchdown are registered for use in fresh water, by far the most common and comparatively in-expensive chemical used is copper sulphate. Some other chemicals have been proposed and used for algal control such as sodium arsenite, potassium permanganate bleaching powder. Some scientists have proposed heavy application of nitrogenous fertilizers to irrigation water.

Chemicals can be readily obtained and can be applied without immediate observation. Copper sulphate in not expensive. The application of chemicals could cause harm to animals and people who may use treated water. It must be borne in mind that most of all the chemicals will have only short term effects on the growth of algae. Algal growth will reoccur without regular application.

Many countries of Europe and UK are keeping extremely vigilant control on the use of all herbicides. The development of environmentally acceptable herbicides is very expensive and lacks impetus whilst a relatively in-expensive dosage of seemingly harmless chemicals continues.

The application of large amounts of nitrogenous fertilizers to irrigation water which appears to limit algal growth is interesting (Merezhko, 1991 (as reported by Joska et.al.). It is suggested that farmers would not need to fertilize crops as the suitable fertilizer was already present in the irrigation water. However, not all crops have similar fertilizer requirements and, according to irrigation method, there would be an increased number of salts in the soil and of course increased nutrients in natural water courses, in which the used canal water would flow. Salanization is already a problem in many parts of the world.

Copper sulphate should be applied to water which has a pH of approximately 6. However, most South African water tend to be alkaline with pH of 7. Thus the successful application of Copper Sulphate is carried out with a pre dosage of sulfuric acid which reduces pH of the water.

(ii) **Acrolein (acrylaldehyde)**

Acrolein has been found effective in controlling *Potamogeton spp*; *Elodea* and other submerged aquatic weeds and Snails. It is used on a large scale in many countries in flowing canals an drainage ditches., for quick control of aquatic vegetation. Being volatile, it evaporates from treated water with in short time of its application. It is effective at concentration varying from 4 -15 ppmv. Acrolein has pungent and foul smell. It is a non-selective, contact herbicide for control of submerged weeds. Canals require regular treatment as the Acrolein is not translocated to the root systems of the plants but merely chemically mows the plants off at bed level. It also kills snails and mosquitoes.

The herbicides may be introduced over a time period of 30 min to 4 hrs. in 3 cumsec to 8- 4.8 hours. in canals up to 56 cumsec. Dosages are to be adjusted with water temperature, weed intensity and speed of water flow in system.

Acrolein is injected in water directly from the cylinder container through an injecting system. It is toxic to fish. It is irritating to eyes and generally toxic to humans but can be applied without any problem when proper application equipment is used.

Egypt has 38000 km of canals and drains which are heavily infested with aquatic weeds. About 6000 km of channels are treated with herbicides mainly acrolein, ametryn, dalapon and glyphosate (Khattab and Gharably, 1988). In a case study results showed that velocity distribution through the water of a channel being injected by acrolein might effect seriously the performance of the herbicide. In kafr-Hakim a canal with uniform velocity, 100% of the submerged weeds were killed while this percentage was reduced to 60% in Abu Talab canal where 30% of the water cross-section was nearly a dead zone.

Temperature is also very important factor for both chemical injected for submerged weeds and for those applied to control ditchbank weeds. Results reveal that in Egypt (Khattab and El-Gharably, 1988) submerged weed *Potamogeton spp*. And *Ceratophyllum demersum* can be controlled at 5-12 ppm when water temperature is more than 15^0C, while these doses should be increased up to 50% if temperature is less than 15^0C.

Research and extensive field use during a period of 10 years with acrolein showed that this chemical is not toxic to irrigated crops at concentrations required to control submerged aquatic weeds (Timmons et.al., 1969, USDA 1963).

In Egypt, doses of 5-15 ppm of acrolein are used for control of submerged weeds and algae, and, no injury to crops has been reported by farmers. Acrolein has a very positive effect on *Potamogeton crispus*; *P. pectinatus; Ceratophyllum demersum*; Najas armata and algae. It has unsatisfactorily control of *P. nodosus* because of partly floated leaves in the Egyptian channels. The Ministry of Irrigation prohibits the use of water for human, livestock and irrigation for 48 hours after the acrolein injection in the channel.

Poor mixing of the herbicide may effect seriously its performance. Results show that the herbicide should be injected down stream of regulators, weirs or bridges. In canals with bed width of 15-30 m chemical should be injected in two points, while 3 points are needed for canals having bed width of 30-40m. It is not economic to treat canals of bed width more than 40m. In channels having larger discharge, mechanical or biocontrol system are recommended.??

It is worth stating here that it is not economic and not advisable to inject channels having discharge more than 2 million in m^3/day (23.1 m^3 /sec.) except in very special cases. In channels having large discharge mechanical or biological control is recommended (Khattab and Gharably, 1990)

Khattab and Gharably (1990) have developed a herbicide gravity feeder. During the operation of the new system, the herbicide drum is laid down on a variable height stand of maximum height one meter. The stand is made of steel and its height can be adjusted for the total head (H) from 1m to 6 m (Table 3). The total head is the distance between the water level in channel and the center line of the drum. (Fig. 26).

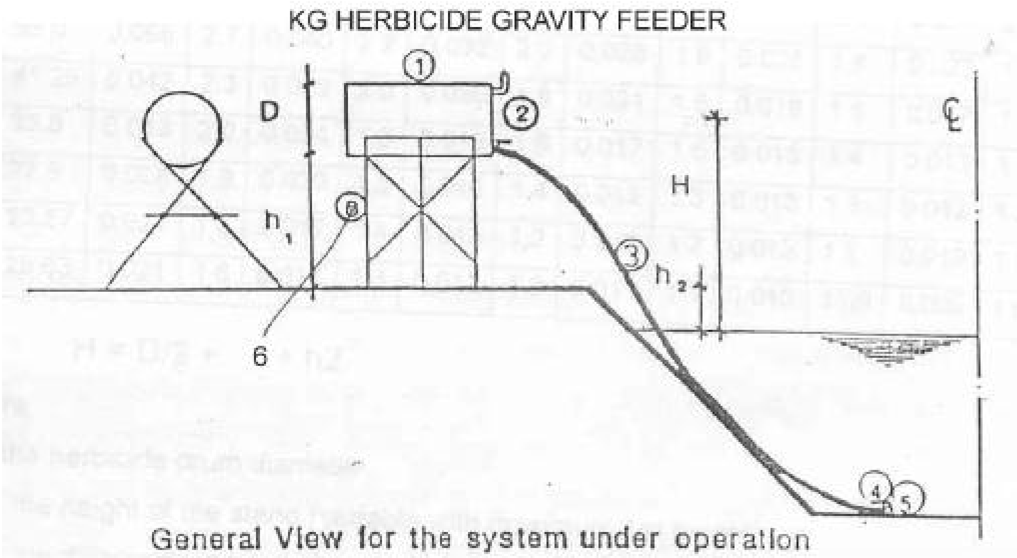

Fig.26. KG Herbicide gravity feeder

General view for the system under operation

H = $h_1 + h_2 + D/2$
h_1 = Height of stand (max. 1.0m)
h_2 = Difference between water level and the bank level
D = Diameter of the herbicide drum
① Magnacide H drum (165 1.)
② Valve ½ inch diameter connected to drum by an adaptor
③ PVC hose ¾ inch diameter
④ Coupler ½ inch diameter contains a filter + a calibrated orifice
⑤ T-1.5 inch diameter
⑥ Steel stand with variable height

Table 3. KG Herbicide gravity feeder
Discharge of magnitude H, area and diameter of the orifice at different heads

Head (m)		1		2		3		4		5		6	
T	Q	A	D	A	D	A	D	A	D	A	D	A	D
1	165	0.167	4.6	0.118	3.9	0.096	3.5	0.083	3.3	0.075	3.1	0.068	2.9
2	82.5	0.083	3.3	0.059	2.8	0.048	2.5	0.041	2.3	0.037	2.1	0.034	2.0
3	55.0	0.056	2.7	0.040	2.2	0.032	2.0	0.028	1.9	0.025	1.8	0.023	1.7
4	41.25	0.042	2.3	0.029	2.0	0.030	1.8	0.021	1.6	0.019	1.5	0.017	1.5
5	33.0	0.033	2.0	0.024	1.8	0.019	1.6	0.017	1.5	0.015	1.4	0.013	1.3
6	27.5	0.028	1.9	0.020	1.6	0.016	1.4	0.013	1.3	0.013	1.3	0.012	1.2
7	23.57	0.024	1.8	0.017	1.4	0.013	1.3	0.012	1.2	0.012	1.2	0.010	1.09
8	20.63	0.021	1.6	0.014	1.3	0.012	1.2	0.011	1.1	0.010	1.09	0.009	1.07

$$H = D/s + h1 + h2$$

Where,

D is the herbicide drum diameter.
h1 is the height of the stand (variable with maximum 1m height).
h2 is the different in levels between channel water surface and the bank or site of application.

(iii) **Dalapon**:

Dalapon (2, 2-dichloropropionic acid) is a translocated non selective, foliar applied herbicide. It is very effective in controlling grassy weeds like *Typha; Phragmites* etc., which are mostly emergent weeds. It can be used in controlling emergent weeds in lakes, ponds, ditchbanks, irrigation and drainage channels. It should be used when water level is minimal or water is drained several weeks before application.

Dalapon is applied at the concentration of 2-4% solution in water. It is necessary to use non – ionic surfactant at the rate of 0.1% to increase the absorption of herbicide in plant. Multiple treatments at lower rates are to be used for effective control of perennial grasses. It is advisable to prepare only as solution in water, that is consumed (sprayed) in 2 hours.

Dalapon is normally harmless to fish. The treated water normally is not suitable for irrigation and potable uses. It leaches readily in the soil and breaks down rapidly and completely in the soil. It is not degraded in plants.

Dalapon is widely used for controlling ditchbank and emergent weeds, in Egypt. A dose of 10 Kg/ha repeated after 2 weeks gave excellent control of *Typha domingensis; Phragmites australis* and *Echinocloa stagnina*. The chemical should be applied in summer when plants are actively growing.

(iv) **2,4-D**:

2,4-D is a translocated herbicide used for control of broad leaved weeds and sedges. In aquatic environment it is very effective in controlling floating, submerged and emergent broad leaved weeds. The salts and the long chain ester formulations are of sufficiently low volatility. Spray drift is to be discouraged to avoid damage to crops growing in nearby areas. Salt formulations have low volatility.

Plant roots absorb polar (salt) forms of 2,4-D most readily. Leaves absorb non-polar (ester) forms most readily. A rainfree period of 4 to 6 hours is adequate for uptake and effective control of weeds. It is effective in controlling water hyacinth; *Sagittaria* and *Alamos* spp., water lettuce (*Pistia spp*), *Nymphaea* and other floating and broad-leaved emergent weeds. It can also control water hemlock, milkweed (*Asclepias spp*) and other poisonous species often found on ditch banks and in drains. Post emergence spray applications are effective. Apply 2,4-D when weeds are in active growth phase. If surface sprays are used, they are most effective if entire plant is treated. Therefore in the case of ponds and other reservoirs, decrease in water level will increase herbicide effectiveness. In case of emergent ditch and bank weeds like *Ipomea carnea* such situation develop during March-June in subtropical part of the world when it is most effective time for spray treatment as water levels are low and crops not in nearby vicinity. 2,4-D being volatile in nature is toxic to crop plants and nearby forest vegetation. Therefore, spray drift is to be avoided especially when aerial applications are to be considered.

2 to 4 kg 2,4-D/ha is an effective rate for controlling floating and emergent weeds. Granule formulations are effective against submerged weeds in still water conditions. Addition of wetting agent to 2,4-D increases herbicide activity.

Pure 2,4-D acid, 100 ppm concentration caused slight mortality of finger lings and large mouth sodium salt was slightly more toxic. Ester formulations being oil like and contain oil soluble materials are toxic to fish.

Successful use of 2,4-D for control of broad leaved floating and emergent weeds have been reported from USA, Europe, Africa, Asia and Australia.

(v) **Glyphosate**:

Glyphosate is a post emergent, non selective herbicide. When applied to the foliage, it penetrates and translocates through out the leaves, stems and reproductive parts above the ground. In addition, it moves with the food chain down the plant into the food storage and reproductive tissues below the ground. The mode of action is primarily based on inhibition of protein synthesis.

Glyphosate is effective in controlling grassy, broad-leaved weeds & sedges. It is equally effective on annual & perennial weeds. Therefore, Glyphosate is classified as a broad spectrum herbicide.

The visibility of mode of action of glyphosate is relatively slow. Visual symptoms consists of wilting and yellowing of weed foliage. This advances to complete browning of weed above ground and to a complete destruction of roots and rhizomes below the ground. It may take 7 to 10 days or more to observe the symptoms and may take 30 days or more for complete destruction. Glyphosate must be applied to perennial weeds when sugars or food is being produced in the leaves and moved into roots. The maximum movement of food takes place when growth phase is ending and reproductive phase (flowering) starts. Application of glyphosate in young growing plants/weeds will kill the weed above the ground but may not always kill the underground reproductive organs which otherwise kills the complete plant. The perennial weeds/plants will then send up more shoots from the roots or rhizomes and will continue to live.

Annual weeds are much more easily killed by glyphosate because they germinate from seeds and not the roots or underground vegetative reproductive organs. They can be killed any time after they emerge from the soil surface.

Plants/weeds treated with glyphosate should not be disturbed for 7-10 days after herbicide application. Glyphosate may be used effectively and safely around aquatic environment such as dry ditches, ditch and canal banks and over water in canals, streams, ponds and large reservoirs. It is very effective in controlling emergent vegetation where glyphosate can be applied directly on the foliage. When applied to foliage glyphosate will translocate through the plant and destroy the roots and rhizomes systems even though they are under water. However, if all the vegetation is under water and glyphosate is applied to the surface of the water, it will not provide effective control.

Fig.27. Influence of Glyphosate @1.5 kg/ha. on Ipomea carnea (Effect visible after 10 days)

Fig.28. Influence of Glyphosate @ 1.5 kg/ha. on Ipomea carnea (Effect visible after 20 days)

Glyphosate provide effective control of large number of aquatic weed species. The amount of glyphosate required for some common weeds is as follows:

Name of the weed	Kg/ha
Eichornia crassipes	1.5 – 2
Glyceria maxima	*1.5 – 2*
Phragmites communis	*2.0 – 3*
P. karka	*2.0 – 3*
Typha angustifolia	*2.5 – 3*
T. latifolia	*2.5 – 3*
Ipomea carnea	*2.0 – 3*
Paspalum distichum	*2.0 – 3*

Glyphosate residues

Glyphosate formulation is completely water soluble. It therefore will disperse rapidly and will not accumulate at a high concentration in the water profile. In many field situations, the concentration drops with in a few hours to 1 ppm or less as it continues to disperse throughout the body of the water. Glyphosate is rapidly degraded in water by microorganisms. The degradation takes place in water in a manner similar to what happens when applied on land. The half life in water is about 14 days. Within 30 days, the concentration is generally less than 0.1 ppm. The chemical is adsorbed from the water on to bottom sediments and gets degraded by soil micro-organism which are in rich bottom sediments. The concentration in bottom sediments is usually less than 0.5 ppm.

Dissipation of glyphosate is faster in flow water than for ponds or reservoirs because of mixing action of the running water. Flow water contains a higher oxygen content and microbial activity is usually greater resulting in faster dissipation.

Glyphosate has no effect on water oxygen. It does not hydrolyze in water to produce a toxic substance. It generally will not create a situation of oxygen depletion in water because the decaying of plants is very slow. However, as a precaution, a large body of standing water with heavy weed cover should not be treated in one lot. It should be treated in sections to ensure that decay of plants does not deplete all oxygen thereby starving fishes of oxygen enriched water. Fishes and other aquatic life are quite tolerant to glyphosate due to low toxicity (4900 mg/kg); low concentration and rapid dissipation and being water soluble is readily excreted from the body.

Aquatic ecological risk assessment

Scenario	**Predicted exposure concentration (PEC) mg/l***			**Safety margin (LC50/PEC)****
	Pond depth	O hour	96 hours	
Direct addition	1.0 m	0.9	0.13	25
Margin application	1.0 m	0.13	0.02	160

* 96 hours PEC values were calculated for Roundup ® herbicide (9 L/ha) using EXAMS assessment model (Burns, 1987)

** Based on the lowest Roundup ® Herbicide 96 hour LC 50 (3.2 mg/L) ratios > 10 are considered to pose minimal risk in accordance with US EPA (1986)

In Australia, the acceptable residue limit in irrigation water as set down by the National Health and Medical Research Council is 0.1 ppm and in natural water ways into which sprayed drains discharge, the limit is 0.01 ppm. In Egypt, the MPWWR (Ministry of Public Works and Water Resources) started to use glyphosate for controlling ditch banks and emergent weeds. Results showed that concentration of 2% is enough to kill all types of common ditchbank and emergent weeds. The herbicide should be applied between June to August when temperature is more than 30^{o}C.

Glyphosate is being used for controlling aquatic weed vegetation in USA, Europe, Australia, New Zealand, Philippines and other Asia and African countries.

vi) **Diquat and paraquat**:

Diquat and Paraquat are contact, non selective herbicides and are very effective for control of submerged aquatic weeds and algae. Water treatment with diquat may be applied by injecting Diquat below the water surface by pouring it directly from the container in to the water while moving slowly over the water surface in a boat. Distribute evenly over the infested areas. It can be applied on the aerial parts of the floating weeds by applying thoroughly wetting foliage.

They should be applied (0.5 to 1.0 ppmv) before the weed growth reaches the surface of the water. They are effective against *Utricularia spp*, *Ceratophyllum spp*, *Elodea canadensis, Myriophyllum spp., Potamogeton spp., Spirogyra spa*. Diquat and paraquat can effectively control floating weeds like water hyacinth and water lettuce (*Pistia spp*.) with foliar application at 1-1.5 kg/ha. *Potamogeton nodosus* is tolerant to diquat. A mixture of diquat or paraquat and CSP (or Cu chelates) has proved effective on control of *Hydrilla verticillata*. Diquat controls some of the algae but is not effective on *Chara, Cladophora* and waterbloom. Diquat is also effective on *Lemna spp., Pistia stratiotes* and *Eichornia crassipes*. The use of Diquat and Paraquat is not permitted in fisheries.

Diquat bromide has been widely used in USA, Europe and other countries for control of submersed weeds at 0.25 to 1.5 ppm. The effect of herbicides is dependent on the clarity of the water. Application to turbid or muddy water or where water bodies are subjected to wind stirring may cause suspension of soil sediments which may adsorb herbicide cations and inactivate the chemical resulting in poor weed control.

Other herbicides:

There are large number of herbicides which have been tested and suggested for specific use in aquatic weed management. Some of them are amitrole; endothall, fenac, silvex, simazine, diuron, ametryne, dichlobenil, maleic hydrazide.

vii) **Amitrole**:

It is a non selective translocated herbicide, used especially to control perennial weeds. It is effective on *Typha spp*. and amitrol-T is effective on water hyacinth, alligator weed and other weeds belonging to emergent and floating categories. It is applied at 5 to 10 kg/ha active ingredient as foliar spray. This herbicide is safe on fishes when applied at recommended rates of application.

viii) **Dichlobenil**:

It is a powerful inhibitor of germination and of actively dividing meristems and acts primarily on growing points and root tips. It is therefore used largely as exposed bottom treatment of ponds, tanks, ditches. In reservoirs or other confined water bodies it can also be used in water directly after initial weeding to prevent the regrowth of perennial weeds. In the case of flow water systems water is to be drained out and herbicide is to be applied on hydrosoil. The water supply may be restored 5 weeks after the treatment of exposed bottoms. Dichlobenil is applied to exposed bottoms at 5 to 10 kg/ha and in standing water 10 to 15 kg/ha. It is effective on *Ceratophyllum demersum; Elodea canadensis; Ranunculus;*

circinatus; Polygonum amphibium; Hyrophyllum verticillatum; Chara spp., R aquatilis. Dichlobenil is highly volatile in its liquid form, therefore granules are used in field operations.

Some of the other herbicides suggested include Endothall, Fenac, Silvex, Simazine, Diuron, TCA etc. Most of them were tested and found effective on aquatic weed vegetation but their toxicological and residue problems did not encourage larger use in aquatic weed management programs. The newer more recently developed herbicides are far more acceptable in terms of efficacy, toxicity, residues and general fate in the environment.

Annex 1 provides a tabulated information on commonly used chemicals to control various group of aquatic weeds and species along with rate of application.

CHEMICAL CONTROL OF AQUATIC WEEDS

EMERGENT WEEDS

GROUPS AND SPECIES	CHEMICALY/ACTIVE INGREDIENT OR FREE ACID EQUIVALENT	RATE OF APPLICATION	REMARKS
Sagittaria sp.(Arrow head)	2,4-D Ester 2,4-D Amine 2,4-D Sodium Paraquat	0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 kg/ha	Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage
Scripus actus Muhl. (Bulrush)	2,4-D Ester 2,4-D Amine 2,4-D Sodium Paraquat	0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 kg/ha	Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage
Typha spa. (Cattail)	Dalapon Paraquat Glyphosate	1 to 2% solution + 0.1% surfactant 0.5 kg/ha 1 to 2 kg/ha + surfactant at 0.1%	Wet foliage at 4-6 leaf stage Wet foliage to point of run off Wet foliage of active growing plants at bloom stage or later.
Jussiaea repens L. Var. glabrescens Ktze (Creeping water primrose)	2,4-D Ester 2,4-D Amine 2,4-D Sodium Paraquat	0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 kg/ha	Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage
Phragmites karka (Phragmites)	Glyphosate	1.5 to 2 kg/ha + surfactant at 1%	Wet foliage full bloom stage during autumn repeat treatment required.
Nuphar advena (Ait) (Spatterdock)	Glyphosate	1.5 to 2 kg/ha + surfactant at 1%	Wet foliage full bloom stage during summer or fall.
Justicia americana L. (water willow)	2,4-D Ester 2,4-D Amine 2,4-D Sodium Paraquat	0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 kg/ha	Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage

FLOATING WEEDS

Lemna minor L. (Common duckweed)	Use one of the following : a. Endothall (Potassium salt 422 gm/L or 10% G) b. Diquat Cation (790 mg/L) c. Simazine (80-wp)	 a. ¼ Cup/18.18 L b. 1 Cup/18.18 L c. 0.5 ppm	 a. Apply to leaves b. Apply to leaves c. Apply to total water volume.
Wolffia columbiana Kasst (water mela)	a. Simazine (80-wp)	1 ppm	Apply to total water volume.
Potamogeton nodosus (American pond weed)	a. Endothall (10% G) b. Endothall (Potassium salt 422 gm/L)	b. 1 ppm b. ½ cup/4.546 L	b. Spread on water b. Apply to leaves
Nymphaea spa. (water lilies)	a. Dichlobenil (aquatic granules 10%). b. 2,4-D (20%G)	a. 2.26 kg/A b. 90.720 kg/A	Spread on water
Eichhornia crassipes (water hyacinth)	2,4-D Ester 2,4-D Amine 2,4-D Sodium Paraquat	0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 to 1 kg/ha 0.5 kg/ha	Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage Wet foliage at 3-4 leaf stage

SUBMERGED WEEDS

Ranunculus trichlordyll (white butter cup)	Diquat cation (790 mg/L)	0.5 ppm	Apply below water surface

Najas flexilis (Slender naiad)	Use one of the fllowing : a. Copper-ethylened-iamine complex b. Diquat cation (790 mg/L) c. Diquat cation/copper triethanolamine complex d. Endothall (Potassium salt 422 gm/L or 10.G) e. Dichlobenil (aquatic granules 10%)	a. 0.5 – 1.0 ppm (copper) b. 1 ppm or 6.819 L/surface A. c. 0.5 ppm diquat cation plus an equal volume of copper triethanolamin-e complex d. 3 ppm (total or large scale application) 4 ppm (marginal application) e. 36.28 kg/A.	a. Apply below water surface. b. Apply below water surface. c. Apply on or below water surface d. Same as above. e. Pre-emergent application.
N. guadalupensis (southern naiad)	a. Copper ethylene diamine complex b. Diquat cation (790 mg/L) c. Diquatcation/Coppertriethanolamine complex d. Endothall (potassium salt 4229m/L or 10% G) e. Dichlobenil (aquatic granules 10%)	a. 0.5-1.0 ppm copper b. 1 ppm or 6.81 L/surface c. 0.5 ppm Diquatcation plus an equal volume of copper triethanolamine complex d. 3 ppm (total or large scale application) 4 ppm (marginal application) e. 36.28 kg/A	a. Apply below water surface. b. Apply below water surface. c. Apply on or below water surface. d. Apply on or below water surface. e. Pre-emergent application.
Potamogeton crispus L. (curly leaf pond weed)	a. Endothall (Potassium salt 4229 gm/L or 10% G)	a. 0.3 ppm (total of large scale application) (a.)1.0 ppm	a. Apply on or below surface

		(marginal application).	
	b.Diquat cation (790 gm/L)	b. 0.5 ppm or 4.546 L/surface A.	b. Apply on or below surface
	c.Dichlobenil (aquatic granules 10%)	c. 36.38 kg/A	c. Pre-emergent application
	d.Fenac	d. See manufactures direction	d. Must be applied to exposed pond bottom
	e. Diquat cation copper triethanolamine complex	e. 0.25 ppm diquat cation plus an equal volume of copper triethonat amine complex	e. Apply on or below water surface
	f. Simazine (80-wp)	f. 0.5 ppm	f. Apply to total water volume.
P. foliosus Raf. (leaf pound weed)	Use one of the following : a. Endothall (Potassium salt, (422 gm/L or 10% G) b. Diquat cation (7909 m/l) c. Dichlobenil (aquatic granules 10%) d.Fenac (10% G) e. Simazine (80 wp)	a. 0.3 ppm (total or large scale application) 1.0 ppm (marginal application) b. 0.5 ppm of 4.546L/ surface A. c. 54.432 kg/A d. See manufactures directions e. 0.5 ppm	a. Apply on or below water surface. b. Same as above. c. Pre-emergent application. d. Must be applied to esposed pond bottom e. Apply to total water volume.
P. Pectinatus L. (Sago pond weed)	Use one of the following : a. Endothall (Potassium salt, (422 gm/L or 10% G)	a. 0.3 ppm (total or large scale application) 1.0 ppm (marginal application)	a. Apply on or below water surface.

	b. Diquat cation (7909 m/l) c. Dichlobenil (aquatic granules 10%) d. Fenac (10% G) e. Simazine (80 WP)	b. 0.5 ppm of 4.546 L/surface A. c. 54.432 kg/A d. See manufactures direction. e. 0.5 ppm	b. Same as above. c. Pre-emergent application. d. Must be applied to exposed pond bottom e. Apply to total water volume.
P. pusillus L. (Small pond weed)	a. Endothall (Potassium salt, (422 gm/L or 10% G) b. Diquat cation (7909 m/l) c. Dichlobenil (aquatic granules 10%) d. Fence (10% G) e. Simazine (80 wp)	a. 0.3 ppm (total or large scale application) 1.0 ppm (marginal application) b. 0.5 ppm of 4.546 L/surface A. c. 54.432 kg/A d. See manufactures directions e. 0.5 ppm	a. Apply on or below water surface. b. Same as above. c. Pre-emergent application. d. Must be applied to exposed pond bottom e. Apply to total water volume.
Heteranthera Lubia (water star grass)	a. Diquat cation (790 mg/L) b. Endothall (Potassium Salt 422 gm/L or 10% G)	a. 1 ppm or 9.09 L/Surface A. b. 5 ppm.	b. Apply on below water surface b. Apply on below water surface
Ceratophyllum demersum L. (Common coontrail)	a. Endothall (Potassim salt 4229 m/L or 10% G) b. 2,4-D ester (20% G) c. Diquat cation (790gm/L).	a. 2 ppm b. 2 ppm c. 1 ppm or 9.09 L/surface A	a. Spread on water b. Spread on water c. Apply below water surface

	d. Diquat cation/copper tricthanolamine complex	d. 0.5 ppm diquat cation plus an equal volume of copper triethanolamine complex	d. Apply on or below water surface
Elodea canadensis Micha (Elodea)	a. Copper ethylenediamine complex b. Diquatication 790 gm/L). c. Diquat at cation/copper-triethanolamine complex	a. 0.5-1.0 ppm (Copper) b. 1 ppm or 9.09L/ Surface A. c. 0.5 ppm diquat cation plus an equal volume of copper tricthanolamine complex	a. Apply below water surface b. Apply below water surface c. Apply on or below water surface
Myriophyllum spp. (watermilfoil)	a. 2,4-D ester (20% G) b. Endothall (Potassium salt 422 gm/L or 10% G) c. Diquat cation (790 gm/L) d. Dichlobenil (aquatic granules 10%) e. Fenac (10% G)	a. 2 ppm b. 3 ppm 3 ppm of10%G. c. 1 ppm d. 45.36-68.04 kg/A e. See manufacturers directions	a. Spread on water b. Apply below water surface c. Apply below water surface d. Spread on water e. Must be applied to exposed pond bottom

ALGAE

Chara spp. (has cylindrical whorled branches and resembles, in form, some of the plants mentioned above).	a. Dichlobenil (aquatic granules 10% G) b. Copper sulfate c. Aquatic Herbicide system M**	a. 18.14 kg/A b. 1 ppm c. 6.8 kg-11.3 kg/A	a. Pre-emergent application only. b. Post-emergent application c. Apply on water surface

Filamentous algae	a. Copper sulfate. b. aquatic herbicide system M** c. Simazine (80-wp)	a. 1 ppm b. 6.804 kg/A c. 0.5 ppm	a. Post emergent b. Spread on water c. Apply to total water volume.

** A copper containing formulation developed by the company and distributed under the trade name of Mariner.

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