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AQUATIC PLANTS AND WASTEWATER TREATMENT
(AN OVERVIEW)

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AQUATIC PLANTS AND WASTEWATER TREATMENT

Man like all other animals, depends upon a symbiotic relationship between green plants and microorganisms for his existence on earth. Photosynthesizing plants produce oxygen and regulate its atmospheric concentration, in addition to utilizing and controlling the concentration of carbon dioxide and other gaseous chemicals produced by man, animals, and microorganisms during their metabolic processes. Plants in conjunction with microorganisms also recycle man's waste and produce his food. These fundamental facts have been known and taken for granted by man for hundreds of years. What man has not known, but is beginning to realize, is the potential of plants in conjunction with microorganisms for correcting environmental imbalances caused by industrial development and environmental abuse.

With the exception of rice, aquatic plants have received little recognition for their contributions to the environment or man. The value to man of aquatic plants in the past has been restricted to their aesthetic or ornamental qualities or usefulness to wildlife. The more aggressive aquatic plants such as water hyacinths (Eichhornia crassipes [Mart.] Solms.), however, have caused serious problems in some parts of the world as nuisance weeds that clog slow moving streams and lakes.

Only during the past 20 years has the benefit of aquatic plants in improving water quality been widely recognized. Boyd (2), Cornwell et al. (3), Sheffield (25), Steward (27), Wooten and Dodd (54) and Yount (55) were among the first scientists to demonstrate the nutrient removal potential of aquatic plants. Seidel (24), Wolverton and Harrison (38), Wolverton and McDonald (42,48,50), Wolverton et al. (51) and Wolverton and McKown (53) were among the first scientists to demonstrate the importance of aquatic plants in removing organic chemicals from aquatic environments. The importance of aquatic plants in wastewater treatment has grown significantly since the early research conducted in this area starting in the 1960's. Only during the past 15 years has the ecology of natural wetlands been studied extensively. Udum (15) and Kadlec (11) were some of the most active scientists studying the ecology of natural wetlands in the United States during recent years.

The first international conference on biological control of water pollution was held at the University of Pennsylvania in 1976. Although, only six papers in the area of aquatic plants and wastewater treatment were published from this conference, the overall concepts were established (32). The work of Kathe Seidel (24) at the Max Plank Institute in Germany with bulrush along with that of Wolverton et al. (37) of the National Aeronautics and Space Administration (NASA) at the National Space Technology Laboratories (NSTL) in south Mississippi with water hyacinth was presented at this conference.

The continued rapid growth of technology in this area led to another conference on aquaculture systems for wastewater treatment at the University of California at Davis in September 1979 (1). The Davis Conference was the first introduction of wastewater engineers to aquatic plants as a potential tool in wastewater treatment. Their participation in this conference added a new and important dimension to aquatic plant applications since engineers primarily design and approve wastewater treatment systems. Since the Davis conference, a large amount of additional data has been accumulated on the use of aquatic plants in wastewater treatment, as evidenced in the number of papers in this book. NASA has been one of the leaders in developing this technology because of its potential importance in future

Closed Ecological Life Support Systems (CELSS) for space applications (35). Although NASA's primary goal in plant research is to develop technology utilizing plants as a component of a CELSS for a future space station, Figure 1, most of the NSTL research has been funded through the NASA Technology Utilization Office (TU). This office supports the utilization of space developed technology for applications directed toward solving earthly problems such as wastewater treatment (see Figure 2).

SCIENTIFIC BASIS FOR USING AQUATIC PLANTS IN WASTEWATER TREATMENT

The scientific basis for waste treatment in a vascular aquatic plant system is the cooperative growth of both the plants and the microorganisms associated with the plants. A major part of the treatment process for degradation of organics is attributed to the microorganisms living on and around the plant root systems.

Once microorganisms are established on aquatic plant roots, they form a symbiotic relationship in most cases with the plants. This relationship normally produces a synergistic effect resulting in increased degradation rates and removal of organic chemicals from the wastewater surrounding the plant root systems. During microbial degradation of the organics, metabolites are produced which the plants absorb and utilize along with nitrogen, phosphorus, and other minerals as a food source. Microorganisms also use some or all metabolites released through plant roots as a food source. By each using the others waste products, this allows a reaction to be sustained in favor of rapid removal of organics from wastewater. Electric charges associated with aquatic plant root hairs also react with opposite charges on colloidal particles such as suspended solids causing them to adhere to the plant roots where they are removed from the wastewater stream and slowly digested and assimilated by the plants and microorganisms. Aquatic plants have the ability to translocate oxygen from the upper leaf areas into the roots producing an aerobic zone around the roots which is desirable in domestic sewage treatment. Aquatic plant roots are also capable of absorbing, concentrating and in some cases translocating toxic heavy metals and certain radioactive elements, therefore, removing them from the water system (14,33,40,42). In addition, aquatic plants have demonstrated the ability to absorb certain organic molecules intact where they are translocated and eventually metabolized by plant enzymes as demonstrated with systemic insecticides (38).

The biological reactions that take place between environmental pollutants, plants and microorganisms are numerous and complex, and to date are not fully understood. But there is enough information available to demonstrate that aquatic plants serve more of a function than simply supplying a large surface area for microorganisms as some scientists and engineers have suggested.

FLOATING, EMERGENT AQUATIC PLANTS WITH EMPHASIS ON OPERATIONAL SYSTEMS

WATER HYACINTH

The water hyacinth has been one of the most studied aquatic plants because of its detrimental and as well as beneficial affects on the environment. An astounding growth in the number and extent of research projects since the first work in the '60's involving the water hyacinth has occurred in recent years (6,7,9,13,16,19,21,22,23,26,41,44,45). A review was published by Pieterse (18) which covered all aspects of water hyacinth research that had been accomplished up to 1978.

The first operational water hyacinth wastewater treatment system for treating domestic sewage was installed at NSTL in 1976 and has been functioning very effectively for the past ten years (46). The system consists of a single cell lagoon with a surface area of 2.02 ha (5 acres) and an average depth of 1.22 m (4 ft). The average flow rate was 473 m^3/d (125,000 GPD) in 1976 and approximately 606 m^3/d (160,000 GPD) in 1985 (unpublished data). The BOD_5 loading rate in 1976 averaged 24.6 kg/ha/d (22 lbs/ac/d) but has increased to approximately 33.7 kg/ha/d (30 lbs/ac/d) today (unpublished data).

The first operational water hyacinth system for treating photographic and laboratory chemical wastewater was also installed at NSTL in 1975 (42). Although this water hyacinth system has been very effective in treating chemical wastewater during the past eleven years, it was recently upgraded with a rock-plant microbial filter system designed according to the concept described in Wolverton et al. (48) using more cold-tolerant aquatic plants such as the reed (<u>Phragmites communis</u> Trin.) and cattail (<u>Typha latifolia</u> L.).

In 1978 a tertiary wastewater treatment system was designed for the Coral Springs Improvement District at Coral Springs, Florida using water hyacinths to treat 378.5 m^3/d (100,000 GPD) of secondary effluent from an activated sludge wastewater treatment plant (29). The system consists of a series of 5 ponds with total water surface area of 0.50 ha (1.25 ac), and average water depth of 0.38 m (1.25 ft). The total retention time for all 5 ponds was 6 days. In this case, the water quality parameters of primary concern were total nitrogen and phosphorus. Total nitrogen levels into the ponds were reduced by 91% from 10.12 mg/L to 0.94 mg/L. Total phosphorus concentrations were reduced by 38% from 6.12 mg/L to 3.77 mg/L which indicates that nutrient uptake by the water hyacinth was nitrogen limited. During several months of the year there was a 50% reduction in volume from influent to effluent due to high evapotranspiration rates. If the nitrogen and phosphorus concentrations were adjusted for water loss, the effluent phosphorus concentration would have been approximately 1 mg/L as required for advanced wastewater treatment. The total nitrogen was well below the 3 mg/L level required.

In 1979 a joint project involving NSTL, EPA and the Reedy Creek Improvement District (Disney World at Orlando, Florida) was initiated to evaluate the use of water hyacinths for treating primary effluent from the wastewater reclamation plant at Disney World (12). The wastewater was pumped from a primary clarifier with a 2 hour detention time. The average BOD_5 and TSS leaving the clarifier were 150 and 80 mg/L, respectively. Channels, 8.84 m W x 0.61 m D x 109.73 m L, were constructed to contain the water hyacinths. A detention time of approximately 5 days was maintained. After 5 days in the water hyacinth channels, both the monthly average BOD_5 and TSS had been reduced to 20 mg/L or below. Over the past several years emphasis for this system has shifted from just waste treatment to a combination waste treatment/biomass production due to support from the Department of Energy and the Gas Research Institute (GRI).

One of the most ambitious wastewater treatment systems in the United States is located in San Diego, California. The present system, which went into operation in July 1984, is designed to convert raw sewage into potable water with water hyacinths being used as the major wastewater treatment component of this system.

DUCKWEED

Duckweed (*Lemna*, *Spirodela*, and *Wolffia* sp.) has had limited investigation compared to the water hyacinth for use in wastewater treatment (4,20,28). However, this plant has a much wider geographic range in the United States than water hyacinths because it can vegetate at temperatures as low as 1° to 3° C which makes it more suitable for temperate climates. This small, floating plant can be easily harvested using a continuous belt skimmer similar to those used for removing oil from water surfaces. Because these plants are so small, wind and wave action hinder maintaining a continuous mat of plants on large surface areas without floating barriers. A continuous mat of duckweed cover will prevent algal growth in wastewater but also, severely reduces the exchange of oxygen between the atmosphere and water. Therefore, a shallow water depth should be used with duckweed systems to prevent total anaerobic conditions from developing (4). A duckweed mat will also prevent mosquito breeding and development which sometimes causes problems with water hyacinth systems that become anaerobic.

In May 1979, NASA assisted Cedar Lake Development in North Biloxi, Mississippi in evaluating a two cell lagoon wastewater treatment system which had become infested with a mixed duckweed culture of *Lemna*, *Spirodela* and *Wolffia* sp. (34). This system which receives 52.8 m^3 (14,000 GPD) of domestic sewage consists of a primary lagoon with a surface area of 0.083 ha (0.205 ac) and a depth of 2.4 m (8.0 ft) followed by a duckweed-covered lagoon. The duckweed lagoon has a surface area of 0.075 ha (.185 ac) and a depth of 1.5 m (5 ft). The average BOD_5 influent and effluent levels were

31 and 15 with TSS concentrations of 94 and 18 mg/L respectively. Because of the depth of the duckweed lagoon, the discharged effluent dissolved oxygen (DO) level averaged 1 mg/L. The DO increased to an average concentration of 5.3 mg/L after being discharged over a 0.9 m (3 ft) drop into a receiving ditch.

ROOTED, EMERGENT AQUATIC PLANTS WITH EMPHASIS ON OPERATIONAL SYSTEMS

ARTIFICIAL WETLANDS

Although the floating water hyacinth is effective in wastewater treatment, its usefulness is limited to tropical and semi-tropical climate zones for year-round effectiveness and survival. To extend the useful temperature range of vascular aquatic plants systems and eliminate the need for restocking of plants in the spring when extended winter freezes killed the floating plants, NASA at NSTL is studying the use of more temperate vascular aquatic plants in artificial wetlants. A system designed as an artificial wetland is currently being installed at the NSTL to upgrade the effluent from one of NSTL's facultative lagoon systems. This artificial wetland will be stocked with giant bulrush (*Scirpus californicus* [C. A. Mey.] Steud) and duckweed. Bulrush for waste treatment was previously studied by DeJong (5) and Seidel (24). The retention time is 5 to 7 days and the maximum depth 38 cm. Another artificial wetland which uses a shallow reservoir with a maximum depth of 38 cm and total surface area of 4 ha was recently installed at Collins, Mississippi to treat 1325.5 m^3/d (350,000 GPD) of effluent from a facultative sewage lagoon. The City of Arcata in California conducted a pilot wetland wastewater treatment study for several years where oxidation pond effluent was used as the influent to artificial wetland channels (10). When hard-stem bulrush (Scirpus acutus Muhl.) was used as the only aquatic plant in the wetland system, average influent BOD_5 levels of 50 mg/L were reduced to 10 mg/L in the effluent. Such promising results from unharvested wetland systems with 6 - 7 days retention times are very encouraging and demonstrate a wide geographic potential application for such systems.

VASCULAR PLANT/MICROBIAL FILTERS

The integration of emergent aquatic plants with microbial rock filters has produced one of the most promising wastewater treatment technologies since development of the trickling filter process in 1893 (36,39). This process is a lateral flow trickling filter containing rooted aquatic plants. By adding aquatic plants to the rock filter a different biological process is established. Once the microorganisms are established on the rocks and plant roots, a symbiotic relationship develops between them which enhances the wastewater treating capability of both processes.

By using long, shallow (<60 cm in depth) rock-plant filters with hydraulic retention times of 6 - 24 hours, mean cell residence times of several hundred days can be maintained within the plant-rock filter. Operational data with small systems have demonstrated the importance of maintaining dissolved oxygen levels within the filter of 1.5 mg/L or greater (36, 39). This oxygen level is required to achieve odor free, low BOD_5 (<10 mg/L) levels in the discharged effluent. This method of treatment has been used in conjunction with existing waste treatment facilities as discussed below as well as small septic tank systems (52).

This type system can be designed to achieve the desired maximum level of BOD_5 and TSS, ranging from secondary levels of 30 mg/L each to tertiary levels of 5 mg/L each. The plant-rock filters can also be planted with more aesthetically desirable plants such as the canna lily (*Canna flaccida* Salisb.), pickerelweed (*Pontederia cordata L.*) and arrowhead (*Sagittaria latifolia* Willd.). Two rock-plant wetland systems capable of treating approximately 1326 m^3/d (350,000 GPD) of effluent from facultative lagoons will begin operation at Benton and Haughton, Louisiana in May 1987. A 15151 m^3/d (4,000,000 GPD) system at Denham Springs, Louisiana will be put on line by late 1987 to upgrade facultative lagoon effluent to advanced secondary levels. The retention time of each of the above systems is 24 hrs.

BIOMASS: A RESOURCE

With a large number of aquatic plant wastewater treatment systems projected to be in operation within the next several years a vast potential for plant biomass production will be available. The conversion of plant material into energy, feed and fertilizer has already been demonstrated (4,8,17,30,31,43,47,49). Most of the research on methane production in this area has been conducted using water hyacinths. Animal feed studies have been conducted with both water hyacinth and duckweed. As more aquatic plant wastewater treatment systems become operational, additional research is expected to expand the uses of harvested plant material.

SUMMARY

1. The technology for using water hyacinth to upgrade domestic sewage effluent from lagoons and other wastewater treatment facilities to secondary and advanced secondary standards has been sufficiently developed to be used where the climate is warm year round.
2. The technology of using emergent plants such as bulrush combined with duckweed is also sufficiently developed to make this a viable wastewater treatment alternative. This system is suited for both temperate and semi-tropical areas found throughout most of the U.S.
3. The newest technology in artificial marsh wastewater treatment involves the use of emergent plant roots in conjunction with high surface area rock filters. Smaller land areas are required for these systems because of the increased concentration of microorganisms associated with the rock and plant root surfaces. Approximately 75% less land area is required for the plant-rock system than is required for a strict artificial wetland to achieve the same level of treatment.

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FIGURE 1

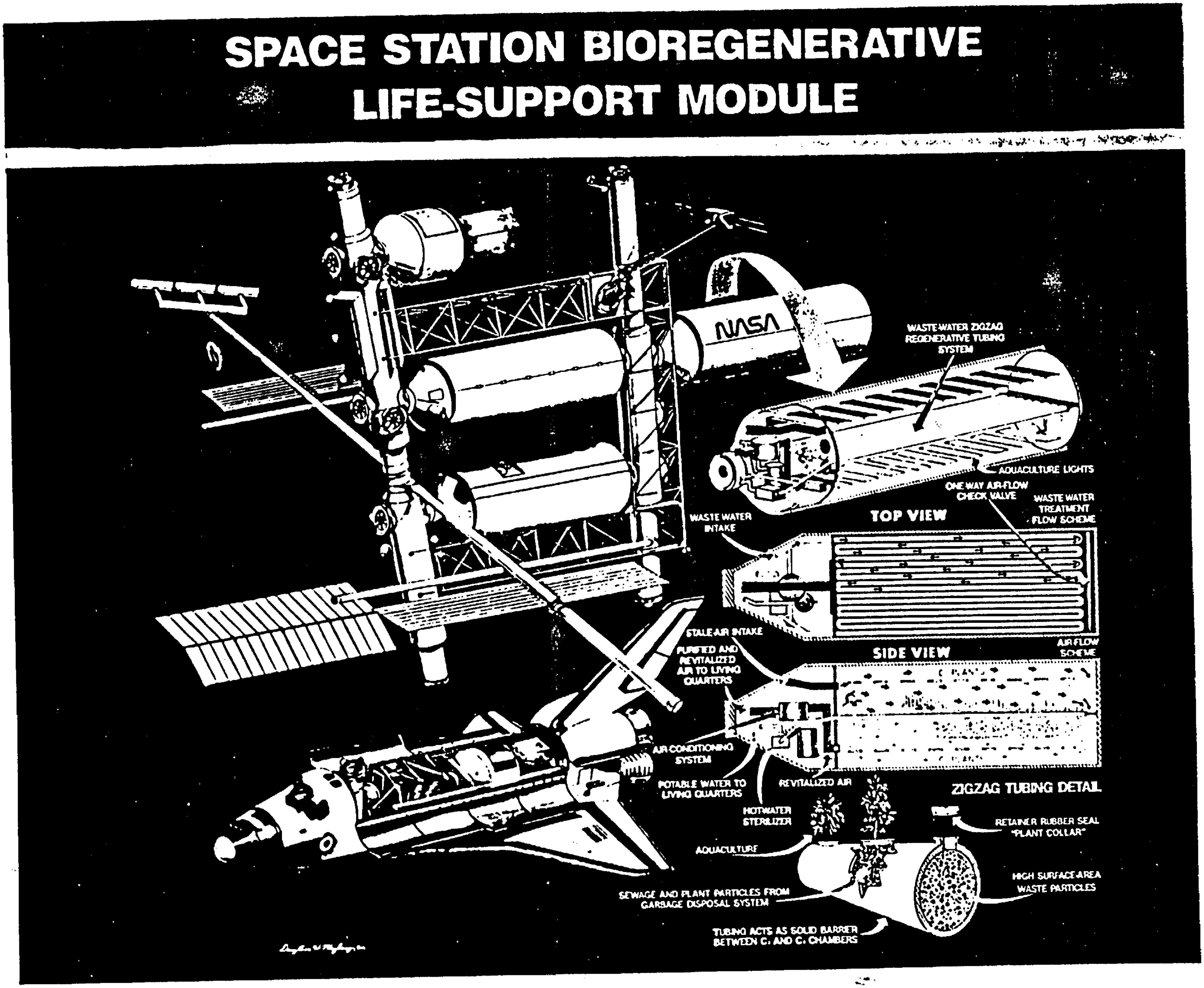
SPACE STATION BIOREGENERATIVE
LIFE-SUPPORT MODULE
NASA
WASTE-WATER ZIGZAG REGENERATIVE TUBING SYSTEM
AQUACULTURE LIGHTS
ONE WAY AIR-FLOW CHECK VALVE
WASTE WATER TREATMENT FLOW SCHEME
TOP VIEW
WASTE WATER INTAKE
STALE-AIR INTAKE
PURIFIED AND REVITALIZED AIR TO LIVING QUARTERS
SIDE VIEW
AIR FLOW SCHEME
AIR CONDITIONING SYSTEM
POTABLE WATER TO LIVING QUARTERS
REVITALIZED AIR
ZIGZAG TUBING DETAIL
HOTWATER STERILIZER
RETAINER RUBBER SEAL "PLANT COLLAR"
AQUACULTURE
HIGH SURFACE-AREA WASTE PARTICLES
SEWAGE AND PLANT PARTICLES FROM GARBAGE DISPOSAL SYSTEM
TUBING ACTS AS SOLID BARRIER BETWEEN C. AND C. CHAMBERS

FIGURE 2

PLANTS FOR POLLUTION ABATEMENT PAST AND PRESENT