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Project Summary

Wastewater Treatment with Plants in Nutrient Films

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The nutrient film technique (NFT) is a unique modification of a hydroponic plant growth system which utilizes plants growing on an impermeable surface. A thin film of water flowing through the extensive root system provides nutrients for plants and associated microbial growth. Root masses up to 15 cm thick or more have been obtained. This self-generating plant system could be used as a filter to immobilize and use the gross and trace organics in wastewater. The goal of this study was to determine the economic, technical, and practical feasibility of using plants grown in the NFT system as pollution control systems.

NFT systems appear capable of providing secondary quality treatment with some nutrient removal on a relatively small area compared to overland flow systems. At loading rates of 10 cm per day the effluent quality with primary settled sewage was often less than 10 mg/l for suspended solids and biochemical oxygen demand. The influent sewage temperature was 9°C. Estimated area needs of an NFT system designed for BOD and SS removal appear to be approximately 3 hectares for a community of 10,000 people, whereas up to 10 times this amount may be needed to provide nutrient control.

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This Project Summary was developed for EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The use of plants in wastewater treatment has most often been limited to slow rate land treatment and the use of nuisance plants of limited value in hydroponic systems. A simple advanced hydroponic system referred to as the "Nutrient Film Technique" (NFT) enables all species of plants to be considered for use in water pollution control systems.

There is increasing interest in the use of low-cost natural systems that have existing or built-in pollution control mechanisms. This project focuses on a new plant production system that could lead to new ways of treating wastewater and water supplies with a solar-powered pollution control system that could have a number of useful and valuable by-products. The main goal of this study was to:

determine the feasibility of using plants as pollutant-concentrating, pollutant assimilating, and nutrient-recycling facilities in a unique hydroponic system utilizing the Nutrient Film Technique.

The five specific objectives were to:

1. define advantages of using plants in the Nutrient Film Technique system over conventional systems to collect, concentrate, and assimilate pollutants;
2. identify research and development needs to support a long-term program to define the full potential of the Nutrient Film Technique system as a pollutant management/resource recovery system;
3. define the engineering require-

ments to establish a total plant-based pollutant control system. This will include area requirements, hardware, plants and plant production system;
4. gather baseline data on system performance using energy and mass balance to support econometric data; and
5. determine the feasibility of recovering energy, food, and nutrients from the plant material.

Design parameters were developed based on hydraulics and removal of nutrients, organics, trace organics and cadmium. Plant selection and management methods were investigated and are described. Finally, the potential evapotranspiration (ET) and actual ET and recovery of ET are discussed.

NFT Basic Concept

The NFT version of hydroponics utilizes plants grown directly on an impermeable surface to which a thin film of water is continuously applied (see Figure 1). The root production on this impermeable surface will result in a large mass of roots and accumulated matter with a large surface area. Root masses have been observed to accumulate up to 30 cm deep, separate from the stalk and fruit. Virtually all plants tested have been found to grow well in this system. The hypothesis here is that these large masses of self-generating root systems can be used as living filters. Plant top growth also provides nutrient uptake, shade for protection from algae, and water removal in the form of transpiration. Sludge that would settle in the root filter would be held in place by the roots, and the filter itself would gradually expand as the sludge accumulated and occupied more space. After removal of organics and suspended solids, the remaining refractory soluble organics, nutrients, and remaining toxic elements would continue to pass through the fine root filter. Since high flow rates are possible in the absence of large amounts of suspended and organic matter, subsequent loading rates would be related to the sorption rates of critical wastewater constituents such as nutrients. This general interaction of pollutants, plants and water lead to the following hypothesized wastewater treatment system.

The hypothesized system would be composed of three distinct sections, with plant characteristics dependent upon the pollutant removals required:

1. Roughing or preliminary treatment: plant species with large root systems capable of surviving and growing in a grossly polluted condition. Large sludge accumulations, anaerobic conditions, and trace metal precipitation and entrapment would characterize this section. A large portion of the BOD_5 and SS would be removed in this section.
2. Nutrient conversion and recovery: an active nutrient uptake, high biomass and/or food production section would follow the first section. The major interaction here would be nutrient conversions, but suspended solids and trace organic removals would improve.
3. Water polishing: the third section would be a polishing section that would necessarily have nutrient-limited plant production, depending on the required effluent water quality.

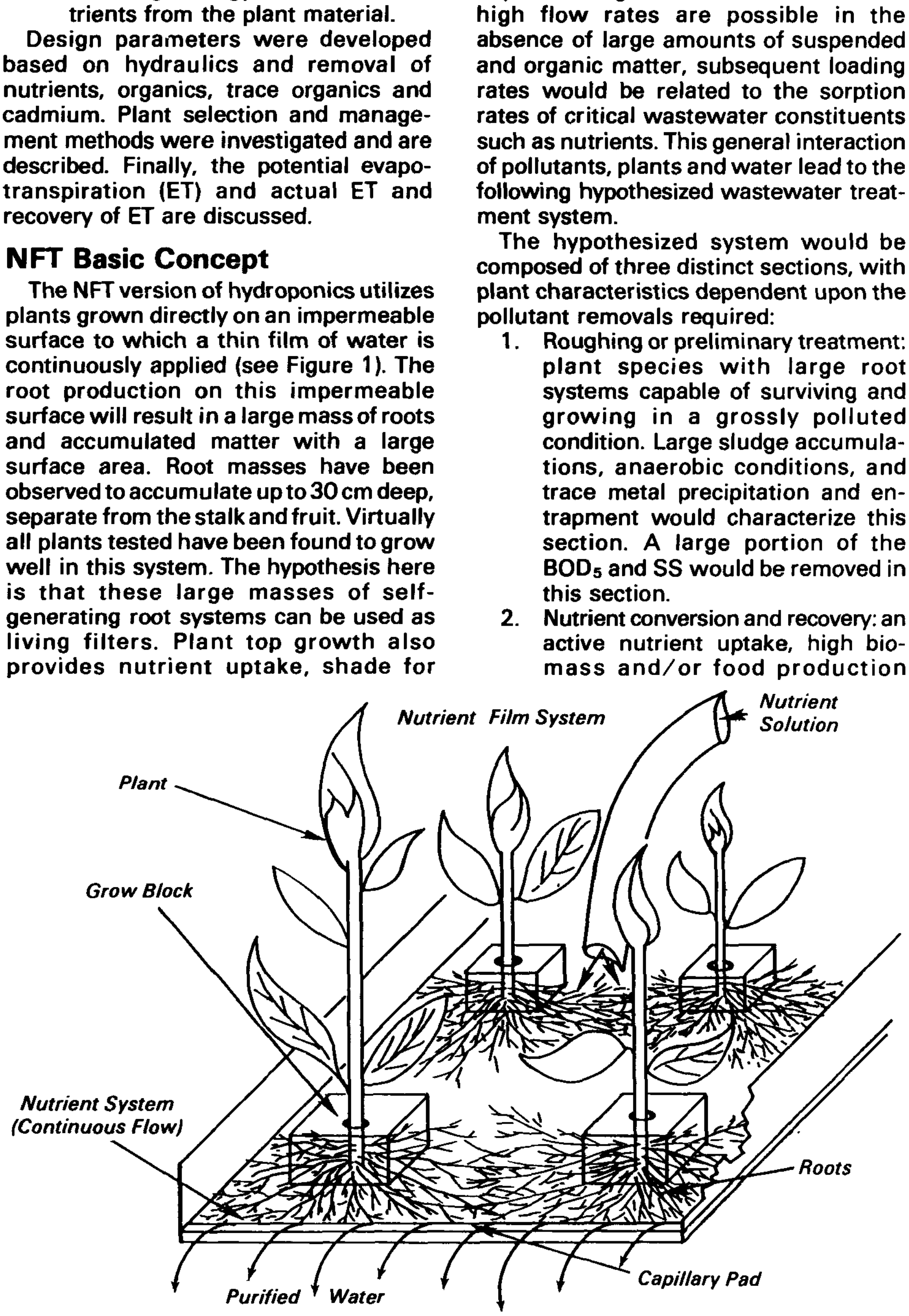

Figure 1. The nutrient film technique variation of hydroponic plant production systems.

A schematic of the three-plant series wastewater treatment system, showing the major pollution control functions and the by-products produced in each section, is presented in Figure 2.

Obviously, the three modules in the NFT treatment system can also be used separately for different levels of treatment of varying input water quality.

Conclusions and Recommendations

The Nutrient Film Technique (NFT) has been shown to be a viable alternative for domestic sewage treatment in this 3-year multidisciplinary effort. Pilot scale units up to 36 meters long have been operated continuously with domestic sewage at flow rates of up to 11,000 l/d (3000 gpd) in New York and New Hampshire. Data presented here should be considered conservative since most experiments were conducted under "worst case" climate and temperature conditions. No attempt was made to control the plant environments during most of the testing.

The general approach of this study was to choose one plant species to demonstrate the concept, and then to test a wide range of species under conditions that would lead to the definition of process controlling parameters. Reed canary grass was selected as the main test species that could accomplish all phases of treatment (i.e., roughing treatment through nutrient polishing). Wetland plants and commercially valuable plants, such as ornamental roses, were ultimately tested. Reed canary grass grown in the NFT system from seed and from transplanted sod resulted in the production of better than secondary effluent quality at an application of 10 cm/day of settled domestic sewage and synthetic wastewater applications throughout the year. Application rates at 20 cm/day were found to result in the destruction of the reed canary grass. Attempts to optimize multiple species systems that could exist in low dissolved oxygen environments eliminated the 20 cm/d limitation.

Example data for a 36-meter long unit for synthetic wastewater are shown in Figure 3. Note that the higher loading

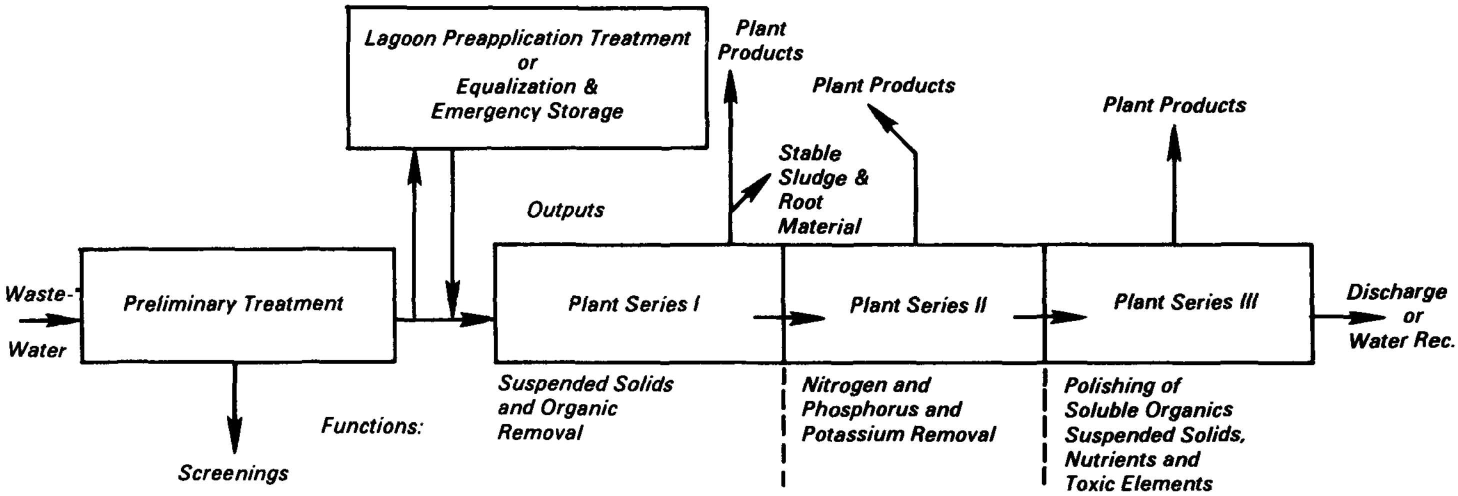

Figure 2. Schematic diagram showing three-stage hypothesized NFT treatment system for domestic wastewater with functions for each stage and fate of all materials.

rates tested are equivalent to a system area required to treat sewage generated by 10,000 people to secondary level of less than 2 ha.

The suspended solids removal capability was one of the most efficient characteristics of the NFT. Even at high loading rates the turbidity of the effluents were low and the suspended solids less than 10 mg/l.

After some of the removal mechanisms were defined, a small optimized unit was constructed and operated for a short time on raw domestic sewage (unsettled sewage). Optimized operation included rapid batch addition of the sewage followed by slow withdrawal and a brief resting phase to encourage aeration. The following represents typical results obtained at a loading rate of 30 cm/d (equivalent to a land area requirement of 1.3 ha to treat the sewage from 10,000 people):

	Influent Quality	Effluent Quality
Total COD, mg/l	320	92
TSS, mg/l	140	15
TKN, mg/l	40	17

Removal Mechanisms

This study was able to define some of the general pollutant removal mechanisms. By accumulating large quantities of biomass in the form of fine roots, the possibility of removing pollutants is greatly enhanced. The solids entrapped in the roots provide the largest capability of

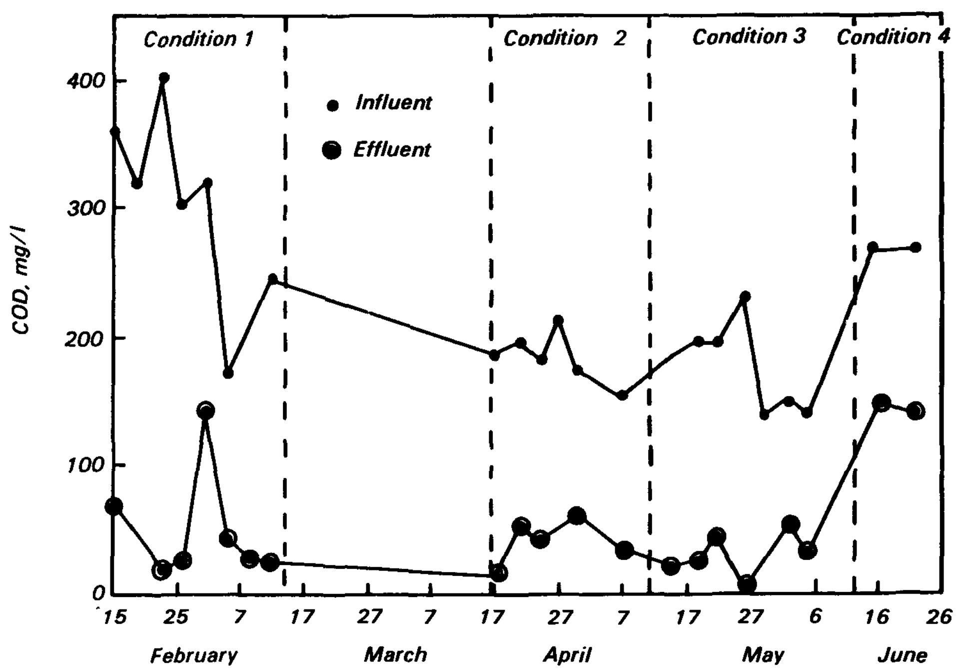

Figure 3. Influent and effluent chemical oxygen demand for the Cornell NFT treating synthetic wastewater in spring, 1981. Conditions correspond to areal loadings of 6.9, 10.2, 20.3, and 40.6 centimeters per day, respectively, for a 36 m long unit.

this treatment system. Measurements of the solids within the roots indicated that over 1,000 gm/m^2 of entrapped solids were accumulated. These solids represent significant potential for manipulation of pollutant cycles. If, for example, this biological organic material can be utilized for pollutant removal, then the solids retention time becomes important. In such operations, reasonably high loading rates result in solids retention times of greater than 100 days. This indicates that the process could be stable and provides an efficient treatment system.

Organic removals are limited by the level of aeration. The capillary mat of dense root systems may significantly increase aeration. The use of plants such as cattails that translocate air to their roots could also be a significant factor. Additional studies are needed in this area.

The fine suspended solids were found to biocoagulate in the system, and high

clarity effluent was achieved under high loading rates.

A major goal of this study was to manipulate the nitrogen cycle using both plants and microbial interactions via nitrification-denitrification. Nitrification was rarely observed during the study and produced only 2 or 3 mg/l of nitrate-nitrogen under the lowest loading condition during the warmer time periods. This lack of nitrification resulted in limited capability for control of the nitrogen cycle with the NFT.

Phosphorous removal appeared to be limited by the plant nutrition requirements. Due to the stress condition of most of the testing that occurred, phosphorous removal rates were low in the NFT system.

The energy that is contained in domestic sewage is likely to provide enough heat to maintain plant cultures in the NFT in most areas of the U.S. where low cost solar greenhouses can be utilized. In some locations the greenhouse cover of the NFT system may be minimized due to this available energy.

The kinetics of pollutant removal was examined using several different approaches. Due to the large number of variables, no comprehensive model was established that would predict the process efficiency. The following rates indicate the range of observed nutrient and organic removals that were obtained in the system:

Parameter	*Removal Rate kg/ha-d*
BOD	*44-166*
TOC	*26-97*
COD	*99-247*
SS	*17-164*
N	*2.8-12.7*
P	*0.4-1.8*

Both heavy metal and organic toxic materials were examined in this system. Cadmium was added to the synthetic wastewater tested. Trace organics were added to the domestic sewage in the New Hampshire test facility. It is proposed that the removal mechanisms for the metals and the organics were the extensive root surface area and the large accumulated biomass. Between 91 and 98 percent of the following trace organics were removed: chloroform, tetrachlorethylene, benzene, toluene, trichloroethylene, xylene, bromoform, M-nitrotoluene, PCB 1248.

Kinetic Analysis

An attempt was made to define the relationship of hydraulic loading rates and hydraulic retention time within the root zone. Due to the large number of factors that affected the plants and the flow through the system, only general comments can be made.

The most promising empirical approach provided by the kinetic analysis of data indicated that the loading rate/effluent quality relationships would hold over a limited range for domestic sewage. These relationships will be of limited value in designing the NFT system for other wastewaters.

This study attempted to conduct parallel testing with actual domestic sewage and a synthetic sewage. Parallel comparison of these systems indicated that it was possible to simulate the domestic sewage systems with the synthetic wastewaters. Since the synthetic sewage contained soluble substrates only, it was not possible to simulate solids behavior or interactions with the synthetic sewage.

Evapotranspiration Water Recovery

The water balance was established for a number of bench scale and pilot tests. Although in many circumstances the expected loss of water through evapotranspiration was equal to literature values of approximately 50,000 l/ha-day, several test conditions resulted in water losses up to 100,000 l/ha-day. These exceptionally high values of evapotranspiration represent a potential source of high quality water.

The energy and process requirements to recover evapotranspired water from the greenhouse were examined. Energy costs of ET recovery are extremely high and prohibit this alternative unless a low cost energy source is available. The potential alternative that was identified was the use of the temperature differential between the influent wastewater and the greenhouse air.

NFT Plants for Sewage Treatment

Although reed canary grass was examined in the majority of tests in this study, a wide range of plants was cultured and propagated to examine their viability in the NFT system when applied to wastewater treatment. The following summarizes those plants that grew well and those that were less acceptable under adverse conditions:

Plants that Flourished	*Plants with Marginal Growth*
Cattails	*Bristly sedge*
Bulrush	*Chrysanthemums*
Strawflowers	*Carnations*
Japanese millet	*Tomatoes*
Roses	*Comfrey*
Napier grass	*Reed canary grass*
Marigolds	*Soft rush*
Wheat	*Cucumbers*
Phragmites	

The above list of plants includes some that have high monetary value. Reed canary grass, when grown under relatively low nutrient conditions, resulted in biomass with a total nitrogen content of 5 percent with most values greater than 4 percent. This indicates a total protein content of greater than 30 percent of the total dry weight in many cases and a plant that would have a significant animal food value. Plants with ornamental value such as shrubs, trees, and roses would represent plants with significant commercial value. Other plants that showed promise in this study were several food plants that would be useful for propagation purposes. Certain plants with a high value, such as berry plants, could be cultured in this system. The potential carry-over of toxic materials would be a concern with food products.

The growth of plants in sewage, where the organic and suspended solids loading rates are high, results in an optimum condition for inhibition of plant yield and pest invasions. The application of hearty plants such as cattails in the roughing sections of the NFT eliminated most of the plant pathogen problems that were observed; however, fungus invasions, insect attack on many of the plants, and other problems of greenhouse plant production were common. All the problems were controlled when advice from specialists was sought and implemented. The destruction of a total treatment system by pests or by contaminants in wastewater is a concern that needs careful evaluation prior to full scale implementation.

Feasibility Considerations

This study outlines a new approach to the use of plants as solar-powered water and wastewater treatment devices.

The area requirements and necessity for a greenhouse cover will vary depending on the location of the system. An NFT secondary treatment system is shown in Figure 4. The area needs appear to be approximately 2.7 ha (6.6 acres) for a wastewater flow from a population of 10,000 people. This would be divided into two sections. The first section would be a roughing section of approximately one hectare. It would be subdivided into relatively small sections so that the wastewater could be rapidly introduced, allowed to remain in a quiescent state for approximately 1 hour, and then removed slowly so that laminar flow conditions would occur. The second section would be a polishing and nutrient removal section of about 2 ha. The capital investment of such a system appears to be attractive, and energy requirements would be low since only low head pumping would be required in such a system. Although a detailed economic analysis was not completed in this study, it appears that the capital investment would be less than conventional secondary treatment alternatives.

The application of the NFT for nutrient removal is subject to the limitations of all plant systems. Even with maximum growth rates the nutrient removal rates are relatively low in comparison to high rate nutrient manipulation processes such as microbial nitrification-denitrification. However, partial nutrient polishing could be achieved in NFT units of 10 ha or larger for flow rates produced by 10,000 people.

The estimates for tertiary treatment or water reclamation with the NFT indicate area requirements that may not be competitive with a conventional unit process unless the plant products have a commercial value. If plant management techniques are achieved that allow plant products to enter commercial markets, the use of the NFT as a water reclamation facility shows significant promise.

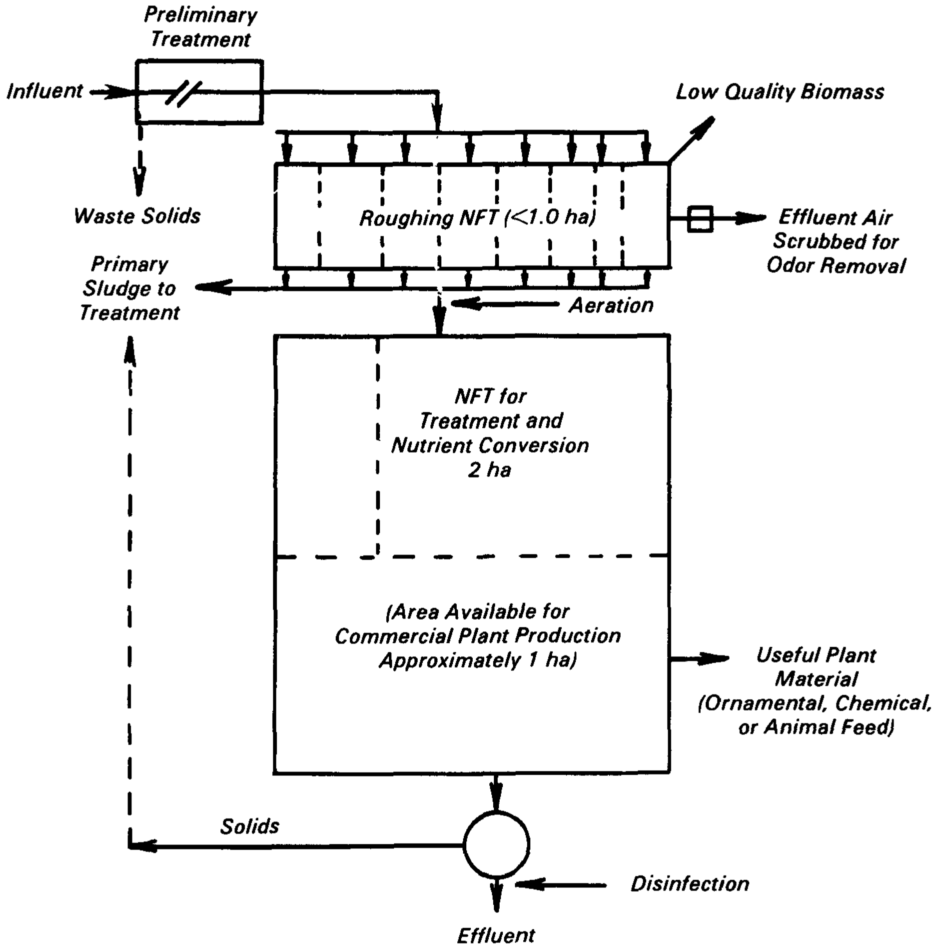

Figure 4. Schematic of NFT treatment facility capable of treating domestic sewage from 10,000 people.

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***William R. Duffer** and **J. L. Witherow** are the EPA Project Officers (see below).*

The complete report, entitled "Wastewater Treatment with Plants in Nutrient Films," (Order No. PB 83-247 494; Cost: $44.50, subject to change) will be available only from:
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