A Trickle Irrigation System for Recycling Residential Wastewater on Fruit Trees

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Certainly trickle (or drip) irrigation is not new to horticulture. In the early 1970s Chapin (1, 2, 3, 4), Gustafson (7, 8), and Hall (9) pioneered its use in horticultural crops in the United States. Kenworthy (10, 11, 12, 13) had introduced the concept of trickle irrigation to fruit growers in western Michigan by 1972. It appeared to be a "natural"; many growers already had deep wells (for hydrocooling cherries) available as excellent water sources. Since then the use of trickle irrigation has spread rapidly throughout the horticultural industry on a worldwide scale. Most draw on deep-well water or on canal, river, or lake water, which may require treatment, filtration or both to render it usable. However, the use of a trickle system for waste disposal was a new application of an existing technology.

THE PROBLEM

Michigan is known as the "water wonderland". In addition to being bordered by 3 of the 5 Great Lakes, it contains hundreds of freshwater lakes. The Michigan Dept. of Natural Resources, which monitors the quality of these lakes, discovered a situation that was unacceptable by its standards in Grattan Township, Kent County. In this township alone, containing 38 lakes, the shorelines had undergone substantial residential and resort development. High water tables and relatively impermeable soils rendered the on-site sewage treatment (septic tanks) and disposal systems (drain fields) inadequate. Public health hazards would continue and a gradual degradation of nearby lakes and the groundwater (the area's source of water supply) would occur unless corrective measures were initiated (14).

THE SOLUTION

Alternatives

The township board of supervisors studied the consequences and the costs of several proposed solutions to the wastewater problem, including taking no action. However, after conducting public hearings and receiving testimony from representatives of county and state departments of public health, they determined that central sewage collection and treatment was most appropriate. The Michigan Dept. of Natural Resources requested land disposal of the treated waste (14).

Preliminary studies

A consulting engineer with an agricultural background and familiar with trickle irrigation was retained to study the feasibility of disposal of treated wastewater in existing fruit orchards. A small test plot was established in a mature apple orchard adjacent to the proposed treatment facility. Water was pumped from a nearby pond and distributed through polyethylene tubing to emitters. Soil moisture was measured at 0.5-, 1.0-, 1.5-, and 2-m levels by tensiometers and Bouyoucos blocks. This trial allowed the engineers to study soil-water movement and utilization by the trees. Their findings indicated that 5 cm of wastewater per week could be applied to the orchard soils. The project received approval and funding was obtained. Construction of a collection system, treatment facility, and disposal system was begun.

Collection system

Grinder pump stations. Raw wastewater from individual homes flows by gravity into grinder pump chambers. These are fiberglass cylinders 1 m in diameter that collect the wastewater and also contain pumps and float controls. A "pump on" switch is activated by a float-level control as the wastewater level increases in the chamber. Wastewater is then pumped through a polyvinyl chloride (PVC) pipe to the gravity collection system. Another float-level control inactivates the pump as the wastewater level decreases (Fig. 1).

Submersible pump stations. In addition to the grinder pump stations, there are 7 pump stations that lift and transmit wastewater between the gravity collection systems and eventually to the treatment facility. These pump stations are similar to the grinder pump stations but are larger and have greater pumping capacities. All stations consist of 2 submersible pumps located inside a precast concrete manhole, which is the wastewater storage chamber. Wastewater enters the pump chamber from one or more pipes. The "pump on" float-level control activates one of the pumps as the level increases. The pump continues to operate until the water level lowers and the pump is shut off by the "pump off" float-level control. Only one pump is needed to discharge the water from the well. A control relay indexes after each pumping cycle so the 2 pumps operate alternately. A high-water float control activates the 2nd pump should water continue to rise in the chamber with one pump running (Fig. 2).

Forcemain system. With force mains the wastewater is pumped under pressure from the grinder pumps and the pump stations. The forcemains are constructed of PVC pipe and range in diameter from 3.2 cm at the grinder pumps to 20 cm at the final...
pump station. The forcemains follow the ground contour and are at a depth of about 1.7 m.

Air release valves are located at high points in the forcemain and allow air to escape. Air-vacuum release valves along the line vent large quantities of air when filling the line and allow air to reenter the line when drained. Clean-out structures are provided for access to the forcemains with cleaning equipment.

**Wastewater treatment facility**

**General description.** The wastewater treatment facility consists of 4 oxidation-reduction ponds or "cells" (Fig. 3). Cell 1 has an area of 2 ha at the high-water level and is designed to have a maximum water depth of 2.5 m. Cell 2 has an area of 1 ha and is designed to have a maximum water depth of 2.5 m. Cells 3 and 4 are each 0.65 ha in area with a maximum water depth of 3.4 m.

Raw wastewater from the collection system is pumped from the final pump station through a forcemain 20 cm in diameter to an air-break manhole at the treatment facility. Wastewater flows by gravity from this manhole to cell 1. Normal series operation allows wastewater then to be transferred to cell 2, and finally to cells 3 and 4 for storage before pumping to the disposal site.

**Treatment process.** Multiple treatments occur almost simultaneously within the first oxidation-reduction cell. First, most of the solids settle out to the lagoon bottom as sludge deposits because of a significant reduction in the waste flow velocity. This sludge is biodegraded by both aerobic and anaerobic processes. Elements of the raw sewage exhibiting an oxygen demand react with O2 supplied by natural biological processes in the cell. The sewage waste flow next enters a relatively slow-moving zone where further sedimentation, clarification, and biochemical reduction occur. The waste flow then enters the piping of the primary cell outlet and is transferred to cell 2. A secondary oxidation-reduction zone is immediately encountered. Beyond the inlet zone is another clarification zone for further sedimentation and biochemical reduction. The waste is then discharged into cells 3 and 4 for limited further treatment, but mostly for storage until transferred to the disposal area.

Under normal operating conditions, the upper meter of water in a stabilization pond is aerobic. Blue-green algae, which should grow in the shallow water near the edges, supplies O2 used by aerobic bacteria to decompose the sewage. The entire lower 0.5 m of water in a stabilization pond is environmentally favorable for anaerobic reduction processes. Between the bottom sludge zone and surface aerobic zone is a region of both aerobic and anaerobic reduction reactions (5).

**Wastewater transfer and storage.** The objective of treatment is to achieve effluent of the highest quality possible. Therefore labo-
ratory testing of wastewater determines the timing of transfers of effluent between cells within the hydraulic limits of the system. The system has the capacity (cells 3 and 4) to store wastewater during the season when disposal by irrigation is not possible.

**Effluent discharge and irrigation system**

Treated wastewater is discharged by irrigation to provide tertiary treatment. Nutrients, such as N and P, are not removed in the stabilization ponds. These nutrients accumulate in the soil during irrigation and are used by vegetation. In addition, pathogenic bacteria and viruses in the domestic waste, if not eliminated by chlorination, are retained by the soil. The irrigation system (Fig. 3) consists of chlorination equipment, 2 pumps, a filter system, piping, and a drip irrigation system.

**Chlorination.** The mechanically and biologically treated wastewater from cells 3 and 4 flows into the Cl contact chamber and pumping chamber, where Cl is injected through a plastic pipe 2.5 cm in diameter. The Cl is mixed by the wastewater flow through the contact chamber and into the pump chamber. The Cl has disinfection capability, but its main purpose is to complex with Fe and S to prevent bacterial slime buildup within the drip system, which could plug the emitters (6). Residual Cl concentration should not exceed 1 mg·liter⁻¹ in the irrigation areas (16).

**Pumping system.** Two vertical turbine pumps, located on the pumping chamber, pump the treated effluent to the irrigation filter system housed in a maintenance building.

**Filter system.** The irrigation filter system (Fig. 4) consists of 3 media (sand) filters followed by 2 screen filters. The media filters eliminate particulate matter that may not flush from the irrigation emitters. They are equipped with automatic backwashing, which can be manually overridden. Screen filters serve as a backup system to the media filters but in addition trap debris, including sand, that may be washed or backflushed from the media filters.

**Drip irrigation.** Flow is directed from the filters via a 20-cm PVC main, which divides and terminates in 7.6 cm or 5-cm headers at 3 irrigation areas. The header is tapped in each irrigation area at 3.7 or 4.9-m intervals depending on tree row spacing. At these points 1.9-cm polyethylene tubing is attached; it is installed just below the soil surface at a depth of about 5 cm following the rows of apple trees. Emitters are located along these laterals at 2-m or 2.5-m intervals depending on tree row spacing. Treated wastewater is dripped from these self-flushing, pressure-compensating emitters at a rate of 8 liters per hour (Fig. 5).

Irrigation areas consist of established apple orchards with grass as a ground cover. Subsoil drains were constructed 1.7-m deep to

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Fig. 4. Filter flow diagram (no scale). Top = filter room floor plan. Bottom = front elevation.
The self-flushing capability of the emitters almost completely drains the irrigation system when it is shut down, but drain valves are located in dry wells at low points in each zone (Fig. 6).

Another advantage of self-flushing emitters is that minor slime buildup is purged from the system at the beginning and end of each irrigation cycle. The laterals also may be manually flushed by depressing the spring-loaded end plug. Should slimes be detected, the chlorination rate may be increased.

The 16-ha irrigation area is divided into 5 separate zones (Table 1). Approximately 18,380 emitters can discharge at a designed rate of 8 liters-hr⁻¹ at a designed pressure of 141–281 g-cm⁻² (20–40 psi). Emitters are designed to compensate for the pressure; i.e., the 8 liter-hr⁻¹ rate is maintained when pressure remains within the 141–281 g-cm⁻² range. The flow rate increases considerably when the operating pressure drops below 35 g-cm⁻², as indicated in Fig. 5.

Fig. 5. Irrigation emitter flow rates designed for 2 gal-hr⁻¹

Table 1. Irrigation zones.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Area (ha)</th>
<th>No. emitters</th>
<th>Discharge (liter-hr⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.3</td>
<td>3560</td>
<td>26,952</td>
</tr>
<tr>
<td>2</td>
<td>2.3</td>
<td>3560</td>
<td>26,952</td>
</tr>
<tr>
<td>3</td>
<td>4.6</td>
<td>3820</td>
<td>28,920</td>
</tr>
<tr>
<td>4</td>
<td>4.6</td>
<td>3820</td>
<td>28,920</td>
</tr>
<tr>
<td>Reserve</td>
<td>2.5</td>
<td>3620</td>
<td>27,406</td>
</tr>
</tbody>
</table>

A silicone rubber unit within the emitter "closes" as pressure increases. Therefore the irrigation system must be operated within the designed range. Application rate. A hydrogeology and agronomy study conducted as a part of the design of the treatment facility indicated that about 5 cm of effluent per week could be applied over the irrigation areas (14). At the designed flow rate of 1900 liter-min⁻¹ the irrigation system should be operated about 72 hr a week to achieve the maximum design application rate. This can be accomplished by operating 12 hr a day for 6 days.

Irrigation season. The treatment facility has been designed to accommodate wastewater flows over a 20-year design period. The capacity of the storage ponds should not be needed for many years. However, the design allows for storage of wastewater over a 7-month period (October–April).

The irrigation season corresponds to the normal growing season for the area, extending for 155 days (May–September). The designed average application rate of 5 cm a week can be decreased or even stopped during periods of heavy rainfall and increased during extended dry periods.

Should any overirrigation occur that results in effluent moving through the aerated cropping depth of 1.7 m, the "under drain", or subsoil drain system, is designed to collect and return this water to the treatment ponds.

EVALUATION

Construction cost of the disposal system described here was slightly higher than those of other land disposal methods (center pivot, solid set, furrow, or side roll). Reasons for this include the conservative design of this pioneer system, extra involvement by various regulatory agencies, and the unfamiliarity of contractors with this means of waste disposal.

Advantages of this method of waste disposal are 1) odor-free operation of the disposal system and 2) low operating costs. The orchard property is leased back to the former owner at a rate that pays one-half of the operating cost of the entire (collection, treatment, disposal) wastewater system (15).

Fig. 6. Irrigation piping schematic (no scale).
Recycling Irrigation Runoff on Container Ornamentals

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Public Law 84-660 was approved by the U.S. Congress in 1956 (1) and amended as Public Law 92-500 by the Congress in 1972 (2). These laws are the Water Pollution Control Acts that set the standards for clean water. These laws prescribe point-discharge requirements of the federal government, the states, and Regional Water Quality Control Boards to prevent pollution and to maintain the integrity of receiving waters. In addition the state of California has the Porter-Cologne Water Quality Control Act (3).

The U.S. Environmental Protection Agency (EPA) does not have specific parameters for irrigation runoff; however, it delegated the regional boards to set the standards for their areas. The Los Angeles Water Quality Control Board is particularly strict. In anticipation of regulatory enforcement, we began research aimed at reducing the amount of N in the environment in 1970.

The Los Angeles Water Quality Control Board has set certain parameters for discharge water (Table 1), and in 1975 we were asked to monitor discharges for these constituents plus pH, temperature, and toxicity to fish. In addition a National Pollution Discharge Elimination System permit to discharge water had to be obtained from the Los Angeles Water Quality Control Board. In a public hearing we protested these parameters and some of the monitoring requirements on the basis that either the constituents in question were not being used (e.g., Cr) or that some of the required monitoring tests were unnecessary since it was decided to recycle the runoff water (Recycling eliminates discharge).

For example, a nurseryman applying ammonium nitrate as a source of N usually uses 150–200 ppm N. In that 200 ppm N, half, or 100 ppm, is nitrate N. In an overhead irrigation system using fortified water (constant feed), the runoff contains 100 ppm nitrate N.

We began our research with lysimeters. Subsequently, preliminary tests were run with dirty runoff with no intent to do any water treatment. These tests showed that some plants respond exceedingly well, others not as well. One thing was certain—overhead irrigation with dirty water results in dirty plants. The suspended clay must be removed from the water.

We studied the following alternatives to meet pollution discharge requirements: discharging into sewers, denitrification, and recycling. Discharging into sewers did not seem feasible because: a) the discharge is limited to off-peak hours (10 pm–6 am only), b) the size of existing sewers would probably limit accommodation to \(7.6 \times 10^6\) liters of discharge in 8 h, c) a holding reservoir is necessary to store the runoff during peak periods, and d) there are fees (Table 2).

Denitrification also did not seem feasible because a) an anaerobic reservoir would have to be built to accommodate at least \(22.7 \times 10^6\) liter of water, b) an organic energy source would have to be supplied to the denitrification bacteria, and c) the removal of N from the water, just to be able to discharge the water, is waste of energy (energy to produce the original N and energy to denitrify the water) and a waste of water.

The decision to recycle was based on concern for conservation of water and energy and was intended to reduce pollution and regulatory constraints. Recycling resulted in a zero discharge and consequently did not require a permit.

### Table 1. Limits set by the Los Angeles Water Quality Control Board for constituents in discharge waters.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Limit</th>
<th>mg-liter−1</th>
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</thead>
<tbody>
<tr>
<td>Suspended solids</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Biological O₂ demand</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Oil and grease</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Total dissolved solids</td>
<td>750</td>
<td></td>
</tr>
<tr>
<td>Nitrate N</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Chloride</td>
<td>175</td>
<td></td>
</tr>
<tr>
<td>Chloride and sulfate</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Total Cr</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Surfactants</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Total identifiable</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>chlorinated hydrocarbons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbidity</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Settlement solids</td>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>