INTEGRATED POND SYSTEMS
FOR SUBDIVISIONS

William J. Oswald, Clarence G. Golueke, and Robert W. Tyler

Among the many factors which currently influence the peripheral growth of American cities, one of the most dominant is the long-term water absorption capacity of the soil. This dependence is especially pronounced during the early phases of municipal or urban growth, in which the septic tank is the accepted method of decentralized waste disposal. The dependence exists because inadequate soil absorption and area eventually lead to functional failure of a septic tank. Second only to catastrophes such as landslides, floods, or earthquakes, prolonged septic tank failure imposes a severe burden on the affected family. Comfort and sanitation decline as water use must be curtailed. Property damage usually occurs, the value of the property declines, while remedial action of any type always is expensive, usually ineffective, and sometimes hopeless. Thus, homeowners, builders, and public authorities alike have learned through bitter experience that, where septic tanks must be used, soil water absorption cannot be ignored.

Effect of Soil on Development

The anticipated capacity of septic tank leaching fields, based either on percolation tests or on prior experience, is used by local health and engineering authorities as a guide in approval of building or development permits and in determining minimum lot size. Since lot size and zoning to a large extent determine the future population density and existing population density determines the course of suburban development, a community literally grows where its soil is most porous.

On level land where the soil is porous and the groundwater table is well below the ground surface, leaching fields perform well and lot sizes as small as ¼ acre (0.1 ha) sometimes have been approved for subdivisions. More frequently, however, because of adverse experience with leaching field failures on small lots and because of uncertainty regarding percolation capacity of the area in question, minimum lot sizes may be restricted to ½, ⅔, or even to ¾ acre (0.13, 0.2, or 0.3 ha). From the inexperienced homeowner’s viewpoint, large lots may appear desirable, but the management of such large lots becomes a burden to all but the most affluent and ambitious. Usually, after a fruitless effort to keep up with the work involved in eternal manuring of his backyard, the disillusioned homeowner turns to more entertaining, lucrative, or intoxicating pursuits. The net result is that most large lots, although necessary to assure underground waste disposal, constitute an incredible waste of land which more frequently than not is ultimately given up to the semi-squalor of unattended backyards. From the developer’s or subdivider’s viewpoint, it is much less economical to construct homes on large

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lots; and as general land values have increased, it has been less and less profitable to develop new areas where access to an existing sewer system is not available.

Clearly, a gap exists in areal planning between the situation where, because of high population density, sewers can be provided only by connection to, or construction of, a major sewer, and the situation where lot sizes must be zoned extremely large to assure that approved septic tank leaching fields will not fail. It is the purpose of this paper to demonstrate that existing knowledge of waste pond technology can be used to bridge this gap and thereby fulfill the desire of planners to be less dependent on restrictions in community development imposed by the use of septic tanks, the desire of homeowners for smaller, less expensive, and more manageable lots, and the need of subdividers, designers, and builders to undertake economically feasible projects.

These desires and needs can be attained today in many places through the use of a design concept which we term integrated pond systems. The term “integrated” is used to differentiate the well-known sewage lagoon or stabilization pond (1) from the type of pond system to be described herein. Sewage lagoon systems usually are constructed essentially as a treatment and disposal plant at the end of a relatively long outfall. They should be conceived and designed as expandable systems which can be enlarged to meet future population growth, and ultimately to amortize themselves when an improved tax base permits installation of a more intensive method of disposal. The integrated pond system, on the other hand, is conceived as a non-expandable system designed to serve a specific and essentially fixed population in a defined and fixed area. Just as a septic tank-leaching field system should be integrated into the design of a single lot, so should the integrated pond system be made an integral part of the plan of the subdivision or trailer park it is to serve. Thus, regardless of future waste disposal, the area set aside would remain as a green belt or open space.

Although the use of waste ponds as an integral part of a residential area would have been regarded as daring or even foolhardy in the past, current information clearly indicates that through proper design it can be done without nuisance or health hazard and with significant benefits. The integrated pond therefore is presented as an engineering design concept to be seriously considered by planners as an alternative to the use of septic tanks wherever access to major sewer systems does not currently exist (2).

Fundamentals

Before the details of the integrated pond design concept and the experimental evidence of the plan’s feasibility are presented, a review should be made of certain fundamental factors common to all types of waste ponds. These factors are discussed in much greater detail elsewhere (1) (3); hence, only the essentials required as background to the integrated pond system concept will be described here.

Ponds may be divided biologically into three major classifications: anaobic, facultative, and aerobic. Distinguishing design features of these classes of ponds are as follows:

Anaerobic ponds, which by definition are predominantly anaerobic throughout their depth, should be designed as combined settling and digestion ponds. They may be designed to receive organic loads in excess of 500 lb/day/acre (56 g/day/sq m) without excessive nuisance. However, as will be demonstrated later, such high loads will never be required in properly designed integrated systems. Anaerobic ponds should be constructed 8 to 12 ft (2.4 to 3.6 m) deep and have retention periods of 20 to 30 days. Within the anaerobic pond, settleable solids and grease are
removed. The settleable solids enter an anaerobic zone where they are converted by microbes to methane and nitrogen which escape from the pond in the form of gas bubbles. Grease is skimmed over appropriately designed skimmers and returned to the influent system. The supernatant is discharged into a facultative pond to receive further and necessary treatment.

The facultative pond is aerobic at its surface and becomes anaerobic at depths near its bottom. It is designed so that aerobic microorganisms will grow near the oxygen-rich surface and will settle into an oxygen-void zone near the bottom where digestion occurs. Facultative ponds may be loaded with as much as 200 lb BOD/day/acre (22 g/day/sq m) without nuisance, but loads of this order of magnitude do not occur in the integrated ponds. Facultative ponds usually are designed to be 5 to 7 ft (1.5 to 2.1 m) deep and to be operated at detention periods of 20 to 30 days. In the usual series system facultative ponds are discharged into aerobic ponds.

Aerobic ponds are designed to be aerobic throughout their depth, and unless they are mixed, they must be loaded at less than 20 lb BOD/day/acre (2.2 g/day/sq m) to remain this way. When operated as unmixed ponds, they are valuable mainly as disinfection devices in which coliforms die away with the passage of time. Unmixed aerobic ponds may be constructed to have depths of 4 to 5 ft (1.2 to 1.5 m) and to operate at detention periods in excess of 60 days.

References made above to detention period, depth, and loading should now be defined more precisely.

As described elsewhere (1), influent detention period \( D \) is

\[
D = \frac{V}{Q_{in}} \quad \quad \quad 1
\]

in which \( D \) is the detention period in days, \( V \) the pond volume, and \( Q_{in} \) the volume of influent per day. If \( V \) and \( Q_{in} \) are expressed in the same volumetric units, \( D \) is expressed in days.

A pond of depth \( d \) having an influent detention period \( D \) has a hydraulic loading velocity, \( u \):

\[
u = \frac{d}{D} \quad \quad \quad 2
\]

If the pond depth is expressed in inches and the pond detention period is expressed in days, the hydraulic loading velocity will have the units inches per day.

The organic load \( L_o \) on a pond is

\[
L_o = k u L \quad \quad \quad 3
\]

in which \( d \) is the pond depth, \( L \) the ultimate BOD of the waste in mg per liter, and \( k \) is a constant which converts mg/liter to the desired loading units used. Normally, pond loadings are expressed in lb/day/acre for which the conversion factor \( k \) in Equation 3 is 0.26; thus,

\[
L_o = 0.226 u L \quad \quad \quad 4
\]

It is generally recognized that ponds may be designed with overall loadings of 25 to 35 lb BOD/day/acre (2.8 to 4.0 g/day/sq m) without nuisance of any sort, and essentially without taking climate into consideration. If we assume an intermediate value of 30 lb of ultimate BOD/day/acre (3.4 g/day/sq m), an ultimate BOD concentration of 300 mg/l, substitution of these values in Equation 4 and solution for \( u \) yields a value of about 0.45 in./day (1.14 cm/day). Experience has shown that any domestic wastewater pond which is properly designed with regard to depth, detention period, and series configuration and which has a hydraulic load of less than 0.45 in./day (1.14 cm/day) will adequately treat the applied waste and create no odor nuisance. Furthermore, effluent from or water in the last pond in a properly designed series of more than four ponds will constitute no significant hazard to health.
Hydraulic Balance

In order to relate pond design to soil and climatic conditions, it is necessary to introduce the concept of hydraulic balance. In such a balance all input and output factors are expressed as velocities having the same units such as in./day. The velocities of water entering a pond are:

\[ U_{in} + i + J \]

in which \( i \) represents rainfall, \( J \) represents infiltration, and \( U_{in} \) represents the influent flow.

The velocities of water leaving a pond are

\[ U_{out} + P_e + E \]

in which \( U_{out} \) denotes the the overflow velocity, \( P_e \) represents the exfiltration or percolation, and \( E \) denotes evaporation.

The hydraulic balance in a pond thus is

\[ U_{in} + i + J = U_{out} + P_e + E \]

or

\[ U_{in} - U_{out} = (E - i) + (P_e - J) \ldots 5 \]

In Equation 5 the term \((E - i)\) is termed net evaporation, \( E_n \), and the term \((P_e - J)\) is called net percolation, \( P_a \). In the integrated pond system concept complete disposal on the land is desired; hence, \( U_{out} \) should be equal to 0, that is, no overflow should occur.

Substituted in 5, the no-overflow values yield the expression:

\[ U_{in} = E_n + P_a \ldots \ldots \ldots \ldots 6 \]

in which all symbols are defined above.

Net evaporation is determined by subtracting precipitation from evaporation on a month-by-month basis and constructing a mass diagram such as that shown in Figure 1. In the example shown in Figure 1, the average net evaporation over a period of one year is 0.122 in./day (0.31 cm/day).

Percolation rates are more difficult to evaluate than net evaporation rates and, therefore, are subject to greater uncertainty. Short-term field percolation tests usually indicate rates which are far in excess of those to be found on a long-term basis in an operating pond. This is because soil sealing occurs with the constant application of wastewater, and because a mound is created on the groundwater table which somewhat restricts vertical water movement. If a saturated soil has a primary percolation rate of less than 0.1 vertical in./day (0.25 cm/day), this rate must be taken as the terminal rate because it is unlikely that any surface soil clogging action will reduce the rate below this value. On the other hand, if the apparent rate is initially greater than 0.2 in./day (0.51 cm/day), a terminal rate between 0.1 and 0.2 in./day (0.25 and 0.51 cm/day) probably will be attained. It has been assumed that as water moves through a series of ponds, it becomes more and more pure and less and less likely to clog the soil; however, there is no published experimental evidence of the extent or manner in which percolation rates tend to change with degree of treatment in ponds. Frequently, percolation evaporation rates (P.E. rates) of 0.25 to 0.35 in./day (0.63 to 0.89 cm/day) have been observed. However, it cannot be over-emphasized that P.E. rates for each local situation must be evaluated independently to assure an adequate design.

The volume of waste removed from a pond is determined by the area over which the P.E. velocity occurs. Extended over an area of 1 acre (0.4 ha), a P.E. velocity of 0.25 in./day (0.63 cm/day) is equal to 6,800 gpd (26 cu m/day) and a velocity of 0.35 in./day (0.89 cm/day) is equal to 9,500 gpd (36 cu m/day). Assuming 100 gpd/cap (379 l/day/cap) of wastewater, a liberal amount for a subdivision, the indicated equivalent populations are 68 persons and 95 persons/acre (168 and 235 persons/ha) of pond, respectively. Even at low waste flows of 80 gpd/cap (303 l/day/cap) with indicated equivalent
FIGURE 1.—Net evaporation from a pond as a function of time of year.
(In. × 2.54 = cm.)

populations of 85 and 118 persons/acre (210 and 291 persons/ha) of pond, populations are an order of magnitude greater than the actual population density of an area. Thus, only a fraction of a subdivided living area would be required for waste disposal.

Integration in Subdivision Planning

If plot sizes of 5,000 sq ft (465 sq m) and a mean family size of 4 are assumed, the theoretical residential population density will be from 28 to 32 persons/acre (69 to 79 persons/ha). This exceeds the density normally allowed for single-family residences. In areas where septic tanks would be required, the population density probably would be limited to 12 to 16/acre (30 to 40/ha) with lot size ½ acre or 10,000 sq ft (929 sq m). If septic tanks were used, the extra 5,000 sq ft (465 sq m) of lot required for leaching area would be associated with individual lots whereas, with the use of an integrated ponding system, it would
be located in an area set aside for waste disposal. In the case cited, viz., 100 gpd/cap (379 1/day/cap), and P.E. at 0.25 to 0.35 in./day (0.63 to 0.89 cm/day), the required disposal site for the ponding system would be from 32/95 to 28/68 or from 34 percent to 40 percent of the total area available for waste disposal.

An idealized general relationship between population density, wastewater flow, net evaporation + percolation, and percent of total available area required for an integrated disposal system is illustrated in Figure 2. Figure 2 was constructed on the basis of a waste flow of 100 gpd/cap (379 1/day/cap). For other flow rates the values should be multiplied by the ratio of the flow to 100. For example, if the rate is 75 gpd/cap (284 1/day/cap), area percentage should be multiplied by 0.75.

Of particular interest in Figure 2 are P.E. rates greater than 0.12 in./day (0.31 cm/day), because at these rates true savings in land use can be attained through use of integrated ponds as compared with the use of septic tanks. Consider an acre to be subdivided in the conventional manner, that is, into 10,000-sq-ft (929-sq-m) lots as shown in the left portion of Figure 3. The probable population would be 16 persons/acre (40 persons/ha). For a P.E. rate of 0.12, about 50 percent of the available area would be needed for waste disposal with an integrated pond system. Because septic tanks would not be needed, the balance of the property could be subdivided into 5,000-sq ft (465-sq m) lots and thereby accommodate the same overall average number of persons per acre. However, in the second case, the half acre ascribed to waste disposal could be contiguous area and, therefore, could be managed on a community basis, i.e., used as a combined park-disposal area. Should the P.E. rate be 0.30 in./day (0.76 cm/day) and the population density 16, only 25 per-
FIGURE 3.—(left) Conventional subdivision (schematic); (right) subdivision with integrated disposal area (schematic).

cent of the available area would be required for waste disposal and the balance could be used as added park or subdivision. As shown in the right portion of Figure 3, in the absence of the need for septic tanks, 5 residences per acre (population of 20) could be built on the remaining area on lots of 5,000 sq ft (465 sq m) each. With P.E. rates of 0.50 in./day (1.27 cm/}

FIGURE 4.—Pond system in park of subdivision design.
day), wastes of 20 persons could be accommodated on 15 percent of the area, while the plot size would be nearly 7,000 sq ft (650 sq m); or the wastes of 24 persons (6 residences) could be accommodated on about 17 percent of the area and lots of about 5,500 sq ft (510 sq m) could be used.

The preceding examples illustrate the saving in land which results from the application of the integrated pond concept. This land saving is reflected in desirable park area rather than land-consuming backyards.

The need for maintenance of the integrated park-disposal area should be emphasized. Park and pond maintenance should be carried out jointly by trained personnel paid for by the community. Although this would be most feasible in a case where several hundred dwelling units would be involved, it would also be possible in smaller subdivisions if special arrangements for part-time maintenance could be made with a contractor or with the residents. In no case should park and pond maintenance be left to chance or left in the hands of incompetent individuals.

In Figure 4 a concept of the potential relationship between the subdivision and the park pond system is shown.

**Pond Design**

Considerable attention must be given to the pond design itself. Basically, to avoid nuisance completely, the
pond system should have average applied loadings overall of less than 100 persons/acre (174 persons/ha) even though a high percolation evaporation capacity would indicate a greater capacity. To avoid danger of spread of infection, the system should have at least five ponds in series to give the highest quality of effluent. Furthermore, inasmuch as no overflow is desired, overall detention periods which are essentially infinite should be provided. Salt build-up and related problems may occur in this case and must be considered in the ultimate design of all systems for land disposal. However, to date, no severe problems related to salt buildup have been reported on non-overflowing ponds, possibly because soluble salts do escape with percolating water.

The basic pond design concept presented here is essentially that of six ponds in series. As is shown in more detail in Figure 5, the primary pond, designed as an anaerobic pond, is isolated at the center of the series and is surrounded by the second, third, fourth, and fifth ponds in series. As can be seen from geometry, these ponds are essentially equal in size. The series ponds in turn are surrounded by a buffer pond of indefinite size and shape designed mainly for water dissipation and aesthetic appeal. The landscape architect, through skillful design, can contribute immeasurably to community acceptance of the system.

Wastewater enters the primary pond at the bottom center through a vertical riser. Effluent is drawn from near the bottom of this primary pond so that heat and grease are retained within the pond. The outflow from the primary pond is injected into the center near one end of the secondary pond, whence it moves in series to the third, fourth, and fifth ponds. Except in the transfer from pond 1 to pond 2, in each case the surface water, which is the clearest, warmest water in the pond, is decanted and transferred to the next pond. Only indirect transfer to pond 6, the "personal contact pond" should be allowed. In the case shown in Figure 5, a shallow well is installed in the berm near the center of pond 5 from which water may be pumped into ponds 5 or 6 to maintain their water level, and from which irrigation water for the park may be drawn if there is an excess. The design of this well will depend largely on local conditions, but it is obvious that an appreciable quantity of the water from such a well will originate from the outer ponds. Gravel or sand packing of the well
may be provided where needed so that maximum yield from the well may be attained. The well may provide for maintenance of water level in all ponds in spite of variations in flow, or a supplementary water supply may be required in dry weather and in arid regions.

Operating Experience

Although it has not yet been possible to construct this ideal integrated pond system including the circular ponds, subdivision, and park as shown in Figure 4, an opportunity to design a system of lightly loaded series ponds was presented in conjunction with the waste disposal needs of the City of Esparto in Yolo County, California. Placed in operation in spring, 1962, these ponds now have been under observation for more than four years. Figure 6 shows an aerial view of the Esparto ponds shortly after construction. At the time of this photograph, the ponds contained only rainwater.

FIGURE 7.—Flow diagram of Esparto ponds. (Ft × 0.305 = m; acres × 0.405 = ha.)
TABLE I.—Operational Characteristics of Esparto Ponds (1965)*

<table>
<thead>
<tr>
<th>Pond Number</th>
<th>Hydraulic Load (in./day)</th>
<th>BOD†</th>
<th>Calculated Detention Time, V/02 (days)</th>
<th>Actual Detention Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 day (lb/day/acre)</td>
<td>Ultimate (lb/day/acre)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
<td>62.5</td>
<td>93.8</td>
<td>40</td>
</tr>
<tr>
<td>2</td>
<td>1.7</td>
<td>33.6</td>
<td>50.3</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>1.4</td>
<td>21.5</td>
<td>32.3</td>
<td>42</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>118</td>
<td></td>
</tr>
</tbody>
</table>

* After Kepple (4).
† BOD₅ represents the 5-day 20°C BOD which when corrected to an average concentration was found to be approximately 200 mg/l. BOD₅ (ultimate) was arbitrarily assumed 1.5 (BOD₅).
‡ Detention times in this column are the pond volumes divided by the average plant influent rate.
§ Detention times in this column represent the expected range of the actual particle detention time and are in general greater than those in the preceding column since they are based on each pond’s effluent flow which takes into account losses from evaporation and percolation and gains due to rainfall. Detention times during test period are shown in parenthesis.
¶ BOD loading rates are averaged using the accumulative areas of ponds 1 and 2 or 1, 2, and 3. Actual BOD loading of ponds 2 and 3 was extremely low.
Note: In./day × 2.54 = cm/day; lb/day/acre × 0.112 = g/day/sq m.

The City of Esparto is shown in the background. Figure 7 is a flow diagram of the ponds. In 1965, after 3 yr of operation, the ponds were receiving wastewater from approximately 1,000 persons and the flow was approximately 72,000 gpd (2.65 acre-in./day). Operational characteristics for the three ponds in series during April 1965 as reported by Kepple (4) are shown in Table I, and wastewater characteristics are shown in Table II.

TABLE II.—Esparto Ponds April 1965—Chemical and Biological Data*

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Raw Wastewater</th>
<th>Pond 1</th>
<th>Pond 2</th>
<th>Pond 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD₅ (20°C)†</td>
<td>203§</td>
<td>14#</td>
<td>7#</td>
<td>3#</td>
</tr>
<tr>
<td>COD (Dihromate) (mg/l)</td>
<td>452§</td>
<td>287§</td>
<td>265§</td>
<td>70§</td>
</tr>
<tr>
<td>Suspended COD (mg/l)</td>
<td>231§</td>
<td>207§</td>
<td>195§</td>
<td>9§</td>
</tr>
<tr>
<td>Total solids (mg/l)</td>
<td>903</td>
<td>685</td>
<td>606</td>
<td>514</td>
</tr>
<tr>
<td>Total volatile solids (mg/l)</td>
<td>201</td>
<td>379</td>
<td>229</td>
<td>197</td>
</tr>
<tr>
<td>Suspended solids</td>
<td></td>
<td>(mg/l)</td>
<td>166</td>
<td>90</td>
</tr>
<tr>
<td>Volatile suspended solids</td>
<td></td>
<td>(mg/l)</td>
<td>93§</td>
<td>75</td>
</tr>
<tr>
<td>Total nitrogen (mg/l)</td>
<td>35§</td>
<td>20</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Organic nitrogen (mg/l)</td>
<td>101</td>
<td>12</td>
<td>7.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Ammonia nitrogen (mg/l)</td>
<td>23§</td>
<td>8</td>
<td>4.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Nitrate nitrogen (mg/l)</td>
<td>No test</td>
<td>No test</td>
<td>No test</td>
<td>0.5–0.3</td>
</tr>
<tr>
<td>Orthophosphates (mg/l)</td>
<td>68</td>
<td>No test</td>
<td>No test</td>
<td>9</td>
</tr>
<tr>
<td>Alkalinity (mg/l)</td>
<td>455§</td>
<td>405§</td>
<td>340§</td>
<td>340§</td>
</tr>
<tr>
<td>Coliform bacteria, membrane filter (org./ml)</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>(15 avg)</td>
</tr>
</tbody>
</table>

* After Kepple (4).
† BOD samples from ponds were centrifuged at 500 × g for 10 min to remove algae prior to incubation.
‡ Samples of raw sewage were 2-hr mid-afternoon composites. A factor of 80 percent has been applied to those values indicated so that they more nearly represent a 24-hr average.
§ Only one test made.
¶ Suspended solids were determined by 10-min centrifugation at 500 × g. It is expected that values are low for raw sewage.
# The algae were centrifuged before dilution and incubation.
TABLE III.—Esparto Ponds March 1966—Chemical and Biological Data

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Raw Wastewater</th>
<th>Primary Pond Effluent</th>
<th>Secondary Pond Effluent</th>
<th>Tertiary Pond Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD (mg/l)</td>
<td>119</td>
<td>9</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Filtered BOD (mg/l)</td>
<td></td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Suspended solids (mg/l)</td>
<td>1.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Settleable solids (mg/l)</td>
<td>138</td>
<td>54</td>
<td>52</td>
<td>34</td>
</tr>
<tr>
<td>ABS (mg/l)</td>
<td>2.1</td>
<td>0.26</td>
<td>0.17</td>
<td>0.14</td>
</tr>
<tr>
<td>PO4 (mg/l)</td>
<td>34.2</td>
<td>32.3</td>
<td>18.1</td>
<td>8.1</td>
</tr>
<tr>
<td>Nitrate nitrogen (mg/l)</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>Ammonia nitrogen (mg/l)</td>
<td>20.0</td>
<td>10.8</td>
<td>7.5</td>
<td>0.48</td>
</tr>
<tr>
<td>Organic nitrogen (mg/l)</td>
<td>9.0</td>
<td>8.9</td>
<td>5.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Average pH</td>
<td>8.08</td>
<td>8.18</td>
<td>8.22</td>
<td>9.04</td>
</tr>
<tr>
<td>Total alkalinity (mg/l)</td>
<td>385</td>
<td>386</td>
<td>369</td>
<td>311</td>
</tr>
<tr>
<td>DO (mg/l)</td>
<td>2.8-5.9</td>
<td>1.4-5.0</td>
<td>1.2-3.0</td>
<td>4.3-6.7</td>
</tr>
<tr>
<td>Total plankton (organisms/ml)</td>
<td>—</td>
<td>Micractinium</td>
<td>Euglena</td>
<td>Euglena</td>
</tr>
<tr>
<td>Predominant organism</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coliforms* (MPN/100 ml)</td>
<td>(16 samples)</td>
<td>Range 2.3×10^4-240×10^4</td>
<td>62,000-620,000</td>
<td>2,300-62,000</td>
</tr>
<tr>
<td>Median</td>
<td>6.2×10^4</td>
<td>62,000</td>
<td>2,300</td>
<td></td>
</tr>
<tr>
<td>Fecal coliforms* (MPN/100 ml)</td>
<td>(16 samples)</td>
<td>Range 230,000-62×10^4</td>
<td>62,000</td>
<td>2,300</td>
</tr>
<tr>
<td>Median</td>
<td>6.2×10^4</td>
<td>62,000</td>
<td>2,300</td>
<td></td>
</tr>
<tr>
<td>Fecal strep (MPN/100 ml)</td>
<td>(16 samples)</td>
<td>Range 940,000-6.2×10^8</td>
<td>2,300-62,000</td>
<td>&lt;45-620</td>
</tr>
<tr>
<td>Median</td>
<td>960,000</td>
<td>13,000</td>
<td>230</td>
<td></td>
</tr>
</tbody>
</table>

* Courtesy of the California State Health Department.

In April 1965 an intensive analytical study of the ponding system was made by Keple (4) and in March 1966, when the flow was approximately 10 percent greater, another study was made by the California State Health Department (5). However, during 1966, flow was conveyed through pond 2, whereas in the earlier study pond 2 was bypassed. Results of these studies are shown in Tables II and III.

An intensive study, concurrent with Keple's, of the microbial quality of effluent from the several Esparto ponds...
was made by Ringsage and Micone (6) during the spring of 1965 when pond 2 was bypassed. A summary of their results is presented in Figure 8. Results of a similar bacteriological study made by the California State Health Department (5) are shown near the bottom of Table III.

During the entire period of observation of the Esparto ponds, odors have been absent and the ponds have become a haven for wildlife. The third and fourth ponds teem with small fish which have thus far survived the year round. These ponds have for three years provided a valuable supply of fish for biological control of mosquitoes in the Yolo County rice paddies.

Discussion

The results of the Esparto studies clearly show the improvement in water quality which results from series ponding, and strongly support the hypothesis that no sight or odor nuisance or hazard to health would result from using the integrated pond-park concept outlined above.

Experience at Santee, California (7) (8), has shown clearly the feasibility of employing ponded wastewater in parks for viewing and for contact sports, including even fishing and swimming. The Santee experience also has demonstrated substantial increases in property values because landscaping made possible by the ponds enhanced scenic beauty (9).

In view of the high degree of wastewater treatment demonstrated in three and four ponds in series at Esparto, it is obvious that the proposed five ponds in series followed by filtration through the ground into a well or through a specially prepared levee would provide water of very high quality in the sixth or buffer pond. Chlorination should not be required in the integrated system because several barriers of greater reliability than field chlorination would exist in the system. The first barrier would be the isolated series ponds, each decanting surface water. The second barrier is time. Retention times within the system would exceed 100 days. Retention in excess of 100 days is always accompanied by die-away of coliform bacteria to the near vanishing point. A third barrier is temperature. Surface water in ponds always becomes heated to some extent on sunny days. By drawing only from the surface, warmed water would be transferred from pond to pond and it is well known that coliform die-away and virus disappearance is greatly accelerated even by small increases in temperature. The Esparto studies indicate that the predicted MPN of effluent from the fifth pond, if there were any effluent, would be less than 5/100 ml at the peak time of the year. As a fourth barrier, filtration through 50 ft (15 m) or more of porous sand between ponds 5 and 6 would insure removal of any remaining E. coli, and, of course, any larger pathogens. Thus, human contact with water in the buffer pond would involve a negligible risk.

Direct contact with the inner five ponds by persons using the buffer pond for recreational purposes should be prevented by a chain link fence of adequate height surrounding the four ponds peripheral to the central pond with gates closed and locked when not in use. As an assurance to the population and to assure healthful standards, the buffer pond should be subjected to routine tests for quality criteria including the MPN on a regular schedule.

One problem in all series ponds is contamination of the recovered water in the ponds containing treated water by birds and other wildlife attracted to the water by a wealth of food and perhaps by curiosity. This contamination leads to high MPN’s due to bird feces. Daily use of the buffer pond for sailing and other sports probably would limit the contact time which shore birds would have with the water
and lessen such contamination. However, at Golden Gate Park in San Francisco, where chlorinated activated sludge effluent has been used for park watering and make-up water in the scenic lakes for many years, a large duck population is accepted without question. High MPN resulting from fecal contamination by countless ducks is taken as a matter of course, as is an occasional failure in the activated sludge effluent chlorination system.

Perhaps the major problem in bringing integrated ponds into general use for isolated subdivisions will be acceptance of the concept by local authorities who must approve or disapprove a developer's plans for waste disposal. It is often difficult to get responsible authorities to approve treatment designs which depart even slightly from the conventional. For example, in one case a principal chose to overlook a septic tank upwelling in a grammar school playground because he feared correction would involve the use of "smelly open ponds." Fortunately, most knowledgeable authorities now recognize the fact that properly designed ponding systems will give performance superior to that of any other combination of treatment and disposal systems presently available.

Many areas near cities are highly desirable for residential development in every way except for the problem of inadequate waste disposal. In addition to scenic beauty, the area usually has access to high-voltage electricity, a modern high-pressure water supply, and paved roads. However, because of remoteness, access to modern sewers will not be available within the foreseeable future, or even though access appears to be foreseeable, the connection cost may be prohibitive in view of the limited tax base in the developing area. On the other hand, studies by local authorities may have indicated that percolation rates are so limited that septic tanks will not work. No development of the area then can take place without application of the integrated-pond concept.

In the absence of sewers, it is rarely that local zoning ordinances will permit home construction on plots less than \( \frac{1}{4} \) acre (0.10 ha) in extent; frequently, plots of \( \frac{3}{4} \) acre or \( \frac{3}{4} \) acre (0.13 or 0.20 ha) are required. Although larger lots may have some advantages with respect to privacy, the added degree of privacy afforded by a \( \frac{1}{4} \)-acre (0.20-ha) lot as compared to a \( \frac{3}{4} \)-acre (0.10-ha) lot would be difficult to measure. Other than privacy and prestige, the only apparent justification for subdivision lots larger than \( \frac{1}{4} \) acre (0.07 ha) is the areal requirement for septic tank leaching fields. Through use of integrated ponding systems, the use of leaching fields would be obviated; hence, the smaller and more manageable lot size would be adequate for normal usage. Thus, there is no apparent reason why septic tank leaching field capacity should continue to predominate in the planning of remote residential developments. Rather, if running water and electricity are available, local authorities should be willing to consider use of integrated pond disposal systems, thereby attaining a greater degree of freedom in community planning, to say nothing of a more prosperous and productive population and a more wholesome environment.

In the case of subdivisions which will, within a foreseeable time, have access to major sewer systems, integrated ponds should be located so that the installed collection system may be intercepted easily by a future main. In fact, one of the great benefits of the integrated pond system concept is that connection with a larger sewer system can be made on a community basis with no loss of capital due to abandonment of existing facilities, as is always necessary in septic tank areas when sewers are installed. Normally, the park-pond system could be retained as a park utilizing groundwater or storm-
water for years after it has been abandoned as a waste disposal facility. Thus, no significant loss would occur when centralized sewerage becomes available.

With respect to odor, pond site selection is not critical because properly designed and managed ponds will give off much less odor than a properly vented septic tank. However, proper site selection with respect to future interceptor sewer location cannot be overemphasized. To make best future development of a new area feasible, a drainage basin-wide survey should be made to determine the probable site of future storm drains and sanitary sewers, the probable location of future pumping stations, and the most reasonable ultimate location of waste treatment and disposal sites. Regardless of any special purposes, such basin-wide surveys should be encouraged by county, state, or interstate authority on a national basis in conjunction with the new state and federal pollution control programs. Through development and use of modern techniques of aerial surveying, basin-wide studies can be made swiftly and economically, thus avoiding practically all duplication in future sewerage construction.

Basic requirements for the use of integrated pond subdivision development design are control of lot size within the area to be subdivided, a willingness to allocate the necessary portion of the subdivided area to open park, lawn, and water area permanently, and a willingness to employ on a guaranteed permanent basis an adequate staff of competent park-pond maintenance personnel. Also required is an area where net evaporation and net percolation is always less than the anticipated flow, a large overflow would be required, and therefore integrated ponds could hardly be justified on an economic basis.

The use of integrated ponds is not practical in a situation in which an immediate connection with a major sewer system would be obviously economically feasible, where the local surface water or groundwater supply is used for drinking water, or where progressive development of an expanding subdivision would lead to hydraulic or organic loadings exceeding design values in the integrated ponds.

To summarize, temporary integrated ponds should be used for subdivisions which are to be constructed in areas where sewerage is not yet available and will not be available within several years. In this case the ponds must be located near the future sewer site. The use of integrated ponds also is indicated in areas where building is desirable but connection with a major sewer system probably never will be available and septic tanks are not feasible because of experience of failure or percolation tests show that required leaching field areas are greater than the size of existing lots. In this case the ponds should be located most conveniently for the site. If sewers are ultimately to drain the subdivided area, application of the integrated lagoon concept for temporary waste disposal would eliminate the immediate need to construct a long outfall sewer or to construct individual septic tanks. Thus, great capital savings for homeowners and investors and better control of community development should result.

Conclusions

One of the beneficial uses of water is enhancement of beauty in our environment. Where water is at a premium and where waste disposal hitherto was a matter either of septic tanks or of no treatment at all, we now should strive to use our knowledge of waste pond
technology so that the land wasted as squalid, land-consuming backyards accommodating septic tanks can be combined into well-designed, well-managed arcedian areas of recreational potential and architectural beauty.

A wastewater disposal system consisting of an anaerobic pond, several facultative ponds, and an aerobic pond operated in series, loaded so that evaporation and percolation equal waste flow, and maintained at a near full level, not only would remain odor-free and constitute no health hazard, but also could add to the scenic beauty and economy of the subdivision in which it is used. Therefore, it should be feasible to integrate such a pond system into a subdivision on a fixed-population basis with the following benefits: (a) avoidance of excessive lot size and better control of community development; (b) replacement of the initial cost of individual septic tanks with the cost of a defined permanent wastewater collection system; (c) avoidance of discomfort, economic loss, or health hazard resulting from the failure of individual septic tanks; (d) reduction in future expenditures required when connection with a major sewer system becomes possible; and (e) enhancement of the beauty of the environment through use of large open areas devoted to park and aquatic facilities.

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