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RAPID INFILTRATION LAND TREATMENT: A RECYCLE TECHNOLOGY

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RAPID INFILTRATION LAND TREATMENT: A RECYCLE TECHNOLOGY

The purpose of this bulletin is to introduce the concept and discuss the applications of rapid infiltration land treatment. To obtain an understanding of the process, it is helpful to consider what rapid infiltration is, why it is important, where it is being done, how it works, how much it costs, and what can be accomplished with rapid infiltration as an alternative to conventional wastewater treatment methods.

WHAT IS IT?

Rapid infiltration land treatment is the application of wastewater to very permeable soils, such as sands or loamy sands, and in level, enclosed, shallow, earthen basins. The wastewater is treated as it travels through the soil. Vegetation is not usually a part of the treatment process, although there are some exceptions.

[Photo of Ft. Devens, showing vegetation]

Land application of wastewater is normally preceded by some form of preliminary treatment such as primary sedimentation, as discussed later in this bulletin. The typical mode of operation is to apply wastewater to a basin for a few days and then to allow the basin to dry with no additional application of wastewater for several days to a few weeks. Drying is needed to reaerate the soil and restore the initial infiltration rate (rate at which wastewater moves into the soil), and will result in better overall treatment. Together, an application (or loading) period and a drying period are referred to as a hydraulic loading cycle.

[Aerial view of Hollister, California]

At some rapid infiltration sites, to maintain infiltration rates, to keep treated water from mixing with existing ground water, or to recover the treated water for reuse, the treated water is pumped or drained from the soil following infiltration. Alternatively, renovated water can be allowed to drain naturally from the soil into a nearby lake, river, or stream. Cross-sections of typical rapid infiltration systems are illustrated in Figure 1. These schematics illustrate the basic hydraulic pathway as well as the recovery and natural drainage pathways.

The principal objective of rapid infiltration systems is to treat applied wastewater by natural processes as it seeps through the soil. Other objectives have included (1) ground water recharge to maintain or supplement irrigation water supplies; (2) ground water recharge to prevent salinity intrusion; (3) ground water recharge to reduce land subsidence when fluids have been extracted; and (4) temporary, subsurface storage of treated water for planned withdrawal and reuse.

WHY IS IT IMPORTANT?

Frequently, communities must treat wastewater to a quality equivalent to tertiary effluent. Treatment requirements usually call for very low concentrations of biochemical oxygen demand (BOD) and suspended solids (SS). Treatment requirements may also include phosphorus or nitrogen removal or both. Conventional advanced wastewater treatment (AWT) systems capable of meeting these requirements are expensive to build, even more expensive to operate, and consume large quantities of energy and other resources. Rapid

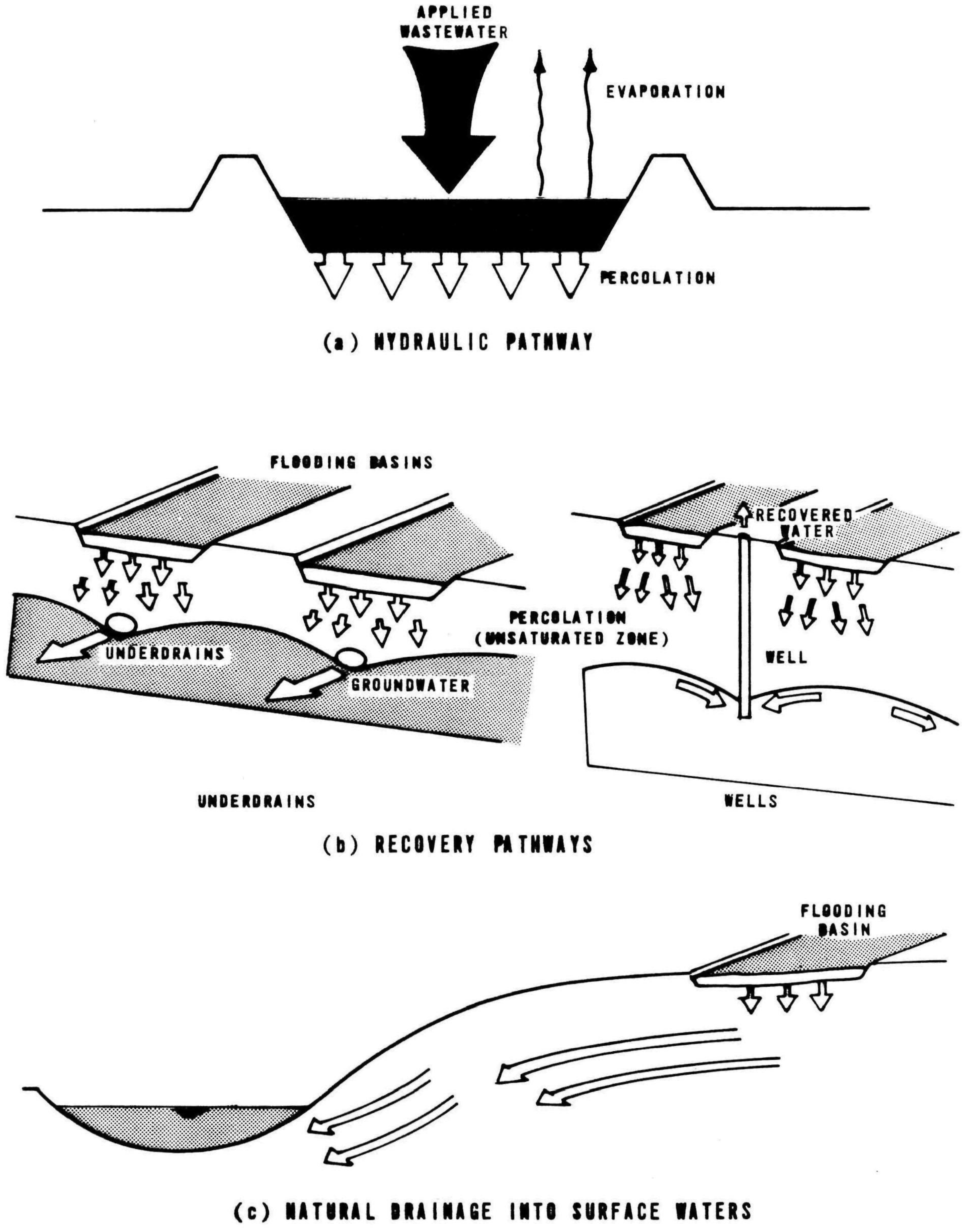

Figure 1. Typical rapid infiltration cross-section.

infiltration can often provide an effluent of comparable quality to that obtained from AWT systems, and do it for less cost in construction, operation, and maintenance, and with less consumption of resources.

As shown in Table 1, a well designed and operated rapid infiltration system provides better overall treatment than conventional secondary treatment and the listed AWT processes. Nitrogen is the only wastewater constituent of interest that rapid infiltration does not remove as well as some of the other treatment processes. Even so, nitrogen removal at rapid infiltration sites is higher than at conventional secondary treatment plants or AWT facilities designed for phosphorus removal.

Table 1. EXPECTED EFFLUENT QUALITY[a]
mg/L

System	BOD	SS	Total nitrogen	Total phosphorus
Rapid infiltration	5	2	10	0.5[b]
AWT				
Phosphorus removal	20	20	30	2
Nitrogen removal	15	16	3	8
Phosphorus and nitrogen removal	10	5	3	1
Secondary treatment	30	30	30	8

a. Adapted from reference [1].

b. For a travel distance of 15 ft or more through the soil.

In addition, AWT facilities must add chemicals to achieve phosphorus removal. These chemicals react with phosphorus to form a precipitate that settles out as sludge. Sludge treatment and disposal are the most expensive parts of an AWT system. Not only can rapid infiltration remove phosphorus without the addition of chemicals, no sludge is produced in the process. In summary, rapid infiltration can provide better phosphorus treatment without consuming chemicals, and without producing a phosphorus-containing sludge.

Rapid infiltration is a low cost land treatment process. This fact can be seen in Table 2, in which the total unit cost and typical monthly user charges of a new 1 Mgal/d treatment plant for various types of advanced wastewater treatment and rapid infiltration are compared. These values include both the cost of constructing new facilities and the cost of operating and maintaining the facilities after construction. Construction costs are spread out over a 20 year period. For a new 10 Mgal/d facility, total unit costs are lower for all alternatives, but the relative order of the unit costs is the same. In other words, user charges for a new rapid infiltration system can be considerably lower than user charges for a new AWT facility.

Table 2. TOTAL UNIT COST OF NEW 1 Mgal/d TREATMENT PLANT: RAPID INFILTRATION AND AWT ALTERNATIVES[a]

Treatment level	Unit cost, $/1,000 gal	Typical user charge, $/household/month
Rapid infiltration[b]	0.78	7.00
AWT		
Phosphorus removal	1.20	10.80
Nitrogen removal	2.10	18.90
Phosphorus and nitrogen removal	2.30	20.70

a. Adapted from reference [1].

b. Includes cost of land at $4,000/acre.

Furthermore, the Clean Water Act of 1977 offers economic incentives for the use of innovative or alternative technologies, including rapid infiltration. Two of the more important incentives are:

- A 15% advantage in the cost-effectiveness analysis. (Life cycle costs may be 15% greater than costs for conventional alternatives and still be considered cost effective.)
- The potential for a 10% bonus on construction grants (i.e., 85% versus 75%).

Advantages of the rapid infiltration treatment method compared with conventional wastewater treatment methods may be summarized as follows:

- Lower operating costs
- Higher quality effluent
- Lower energy requirements
- Limited use of chemicals
- Reduced sludge production
- Process stability and reliability
- Economic incentives in the Construction Grants Program

WHERE IS IT BEING DONE?

In 1978, there were about 300 municipal rapid infiltration systems operating or under construction in the United States. A list of selected rapid infiltration systems is presented by Environmental Protection Agency (EPA) region in the DIGGING DEEPER section of this bulletin. These systems are also shown by state in Figure 2.

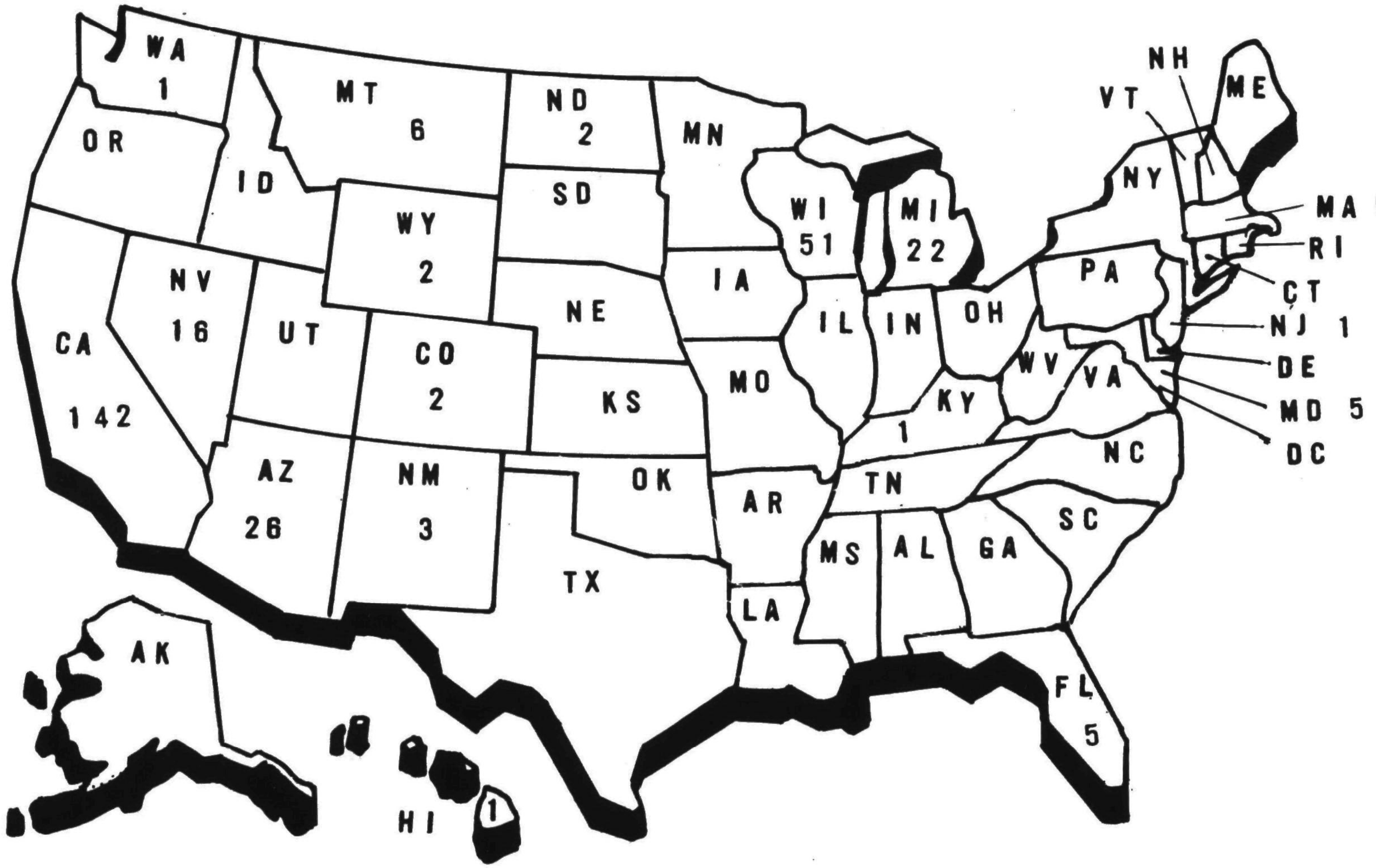

Figure 2. Locations of rapid infiltration systems.

Five representative municipal rapid infiltration systems selected to illustrate various aspects of rapid infiltration technology--located at Boulder, Colorado; Calumet, Michigan; Hollister, California; Lake George, New York; and Phoenix, Arizona--are described briefly. General features of these systems are compared in Table 3.

Table 3. COMPARISON OF REPRESENTATIVE RAPID INFILTRATION SYSTEMS

Location	Avg flow, Mgal/d	Area, acres	Preapplication treatment	User charge, $/household/yr
Boulder, Colorado	0.22	2.5	Trickling filters	--
Calumet, Michigan	1.6	15	Untreated	About 30
Hollister, California	1.3	39	Oxidation ponds	30
Lake George, New York	1.1	6.4	Trickling filters	About 61
Phoenix, Arizona	14	40	Activated sludge	22

The systems at Calumet, Hollister, and Lake George have all been operating successfully for many years. Data from these systems provide a good indication of the long-term capabilities of rapid infiltration systems. Although the system at Phoenix has not existed as long, much important research has been conducted at this site to determine how to optimize treatment and infiltration rates. Also, recovery and reuse of the renovated water has always been strongly emphasized at this system. The Boulder system is relatively new and is a pilot system. Because this system collects renovated water in fairly shallow underdrains, data from the Boulder system reflect the level of treatment afforded with even minimal soil travel distance. In addition, the ability of rapid infiltration systems to operate during cold weather has been demonstrated at Boulder, Calumet, and Lake George.

Boulder, Colorado

Since the fall of 1976, the City of Boulder Wastewater Utility Department has operated a pilot rapid infiltration system. At Boulder, raw wastewater is treated prior to rapid infiltration by means of a standard rate trickling filter, as indicated in Figure 3. Then, unchlorinated secondary effluent is conveyed to three infiltration basins, shown in Figures 3 and 4. These basins vary in size from 0.60 acre to 0.87 acre [2]. Each basin is separated by a berm and all three basins are surrounded by an impermeable clay-core dike. In addition, underdrains have been installed at a depth of 8 to 10 feet. Collected water flows by gravity to a manhole at the end of each basin, then to a central manhole for monitoring and sampling, and then into a wet well for pumping to Boulder Creek.

Because this is a pilot-scale operation, various site modifications and loading cycles have been used to determine optimum operating parameters for the Boulder site. For example, following 6 months of operation, the top loamy layer of soil was removed from two of the basins to increase the infiltration rates. A ridge and furrow system was also constructed in one of the two basins to further improve infiltration. Following removal of the topsoil from the two basins, loading rates three to eight times the initial rates were successfully used. The success of this operation indicates that sites with relatively tight surface soils can be modified to use rapid infiltration.

Initial studies at Boulder were conducted for about 2 years with secondary effluent. After the initial studies, primary effluent was applied to the basins from September 1978 to September 1979. The use of primary effluent did not cause

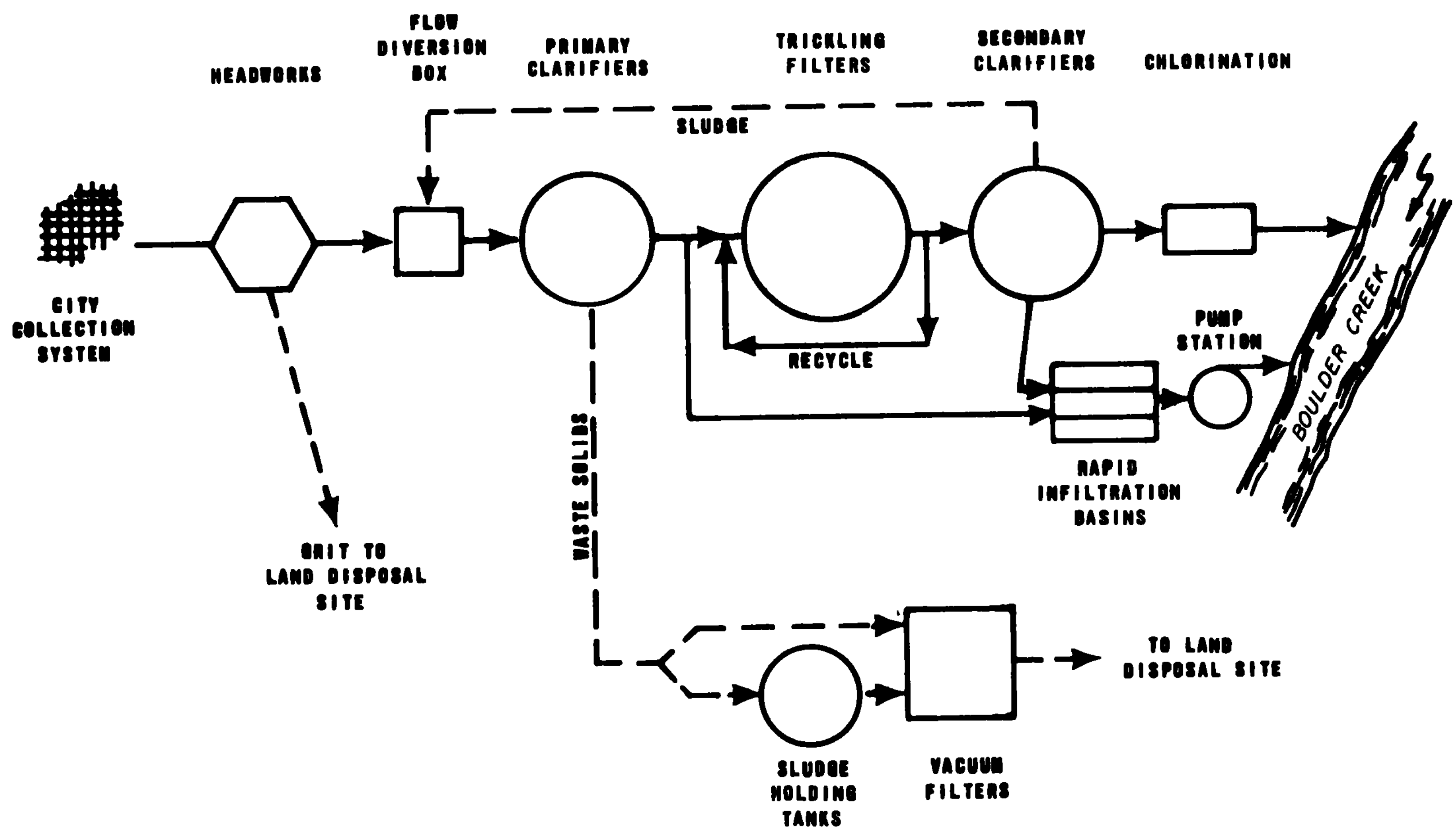

Figure 3. Schematic of Boulder wastewater treatment plant.

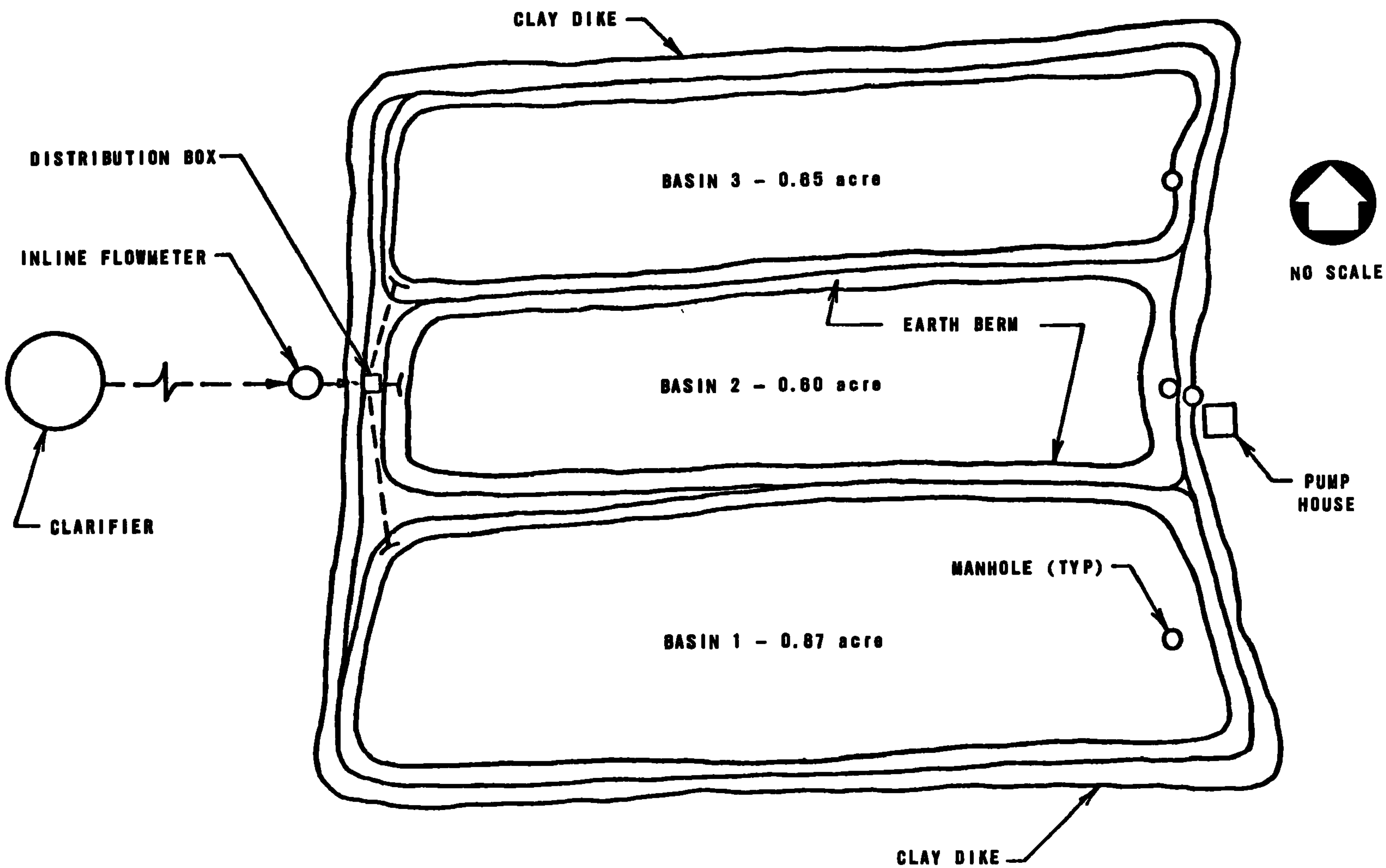

Figure 4. Rapid infiltration system layout.

any operational or aesthetic problems, even at loading rates of 144 and 120 ft/yr in the two modified basins. In fact, loading the basins with raw wastewater, which was done for a short period when the secondary treatment plant had an upset, did not cause a reduction in effluent quality. In summary, the rapid infiltration system proved to be very flexible and reliable.

At Boulder, the infiltration basins are filled with wastewater twice a week. Between applications, the wastewater infiltrates into the soil, leaving a dry surface. After 6 weeks on this application schedule, the basins are allowed to dry thoroughly. Before being put back into operation, the basins are scarified. This operation breaks up the mat of solids that accumulates on the soil surface, loosens up the soil, and restores the clean soil infiltration rates.

During summer and autumn, basins are allowed approximately 1 week to thoroughly dry. Complete drying may take 2 weeks or more during colder periods. Thus, a new application schedule begins every 7 weeks during summer and autumn and every 8 to 9 weeks during colder seasons.

Renovated water discharged to Boulder Creek must contain only small concentrations of ammonia. For this reason, one of the objectives of rapid infiltration at Boulder is to convert wastewater ammonium to nitrate. This process, called nitrification, occurs when short application periods, followed by longer drying periods, are used (see section entitled HOW DOES IT WORK?). The loading cycle used at Boulder has been ideal for promoting nitrification. About 98% of the nitrogen in the renovated water from one of the basins is present as nitrate ion, although ammonium concentrations in the renovated water increased somewhat during the coldest winter months. Solids and bacteria removals also have been consistently greater than 96% and 99%, respectively. As part of the pilot operation, Boulder plans to study methods for improving overall nitrogen removal in the near future.

Although ice forms on the surface of the applied wastewater in the cold winter months, the ice insulates the applied wastewater during infiltration and eventually collapses. The collapsed ice floats to the surface during the following wastewater applications. Thus, icing does not cause problems during wastewater loading.

Calumet, Michigan

Rapid infiltration has been used for municipal wastewater treatment in Calumet since 1887 [3]. Initially, the system was owned and operated by the Calumet and Hecla Consolidated Copper Company. Following the decline of the local mining industry, ownership passed to the Northern Michigan Water Company (1961) and then to the neighboring village of Laurium (1972). Ownership was transferred to Laurium so federal funds could be used to improve the site. The system continues to be operated by the Northern Michigan Water Company under a contract with the village of Laurium.

Currently, the system is used by about 8,100 people who contribute approximately 0.34 Mgal/d of wastewater. Large quantities of infiltration/inflow also enter the collection system, resulting in an average annual flowrate of 1.6 Mgal/d. Thus, although the wastewater is not treated prior to application, it is quite dilute, resembling primary effluent.

[Photo of open channel inlet]

As shown in Figure 5, the system consists of 17 irregularly shaped basins. Each of the basins is loaded at a rate of approximately 116 ft/yr, but, because of the high infiltration/inflow rate, day-to-day application rates are quite variable. The system does not have any underdrains, and two areas where water currently emerges from the ground in springs have been observed. Furthermore, the area receives an average of 180 in./yr of snow, which has caused some basin overflows during spring melting. Plans are underway to replace the ditch distribution system with piping and to otherwise improve distribution and drainage. Also, regular drying and scarification of the infiltration basins is planned for future operations. With these modifications, basin overflows should not occur.

[Photo of Calumet RI basin]

In spite of these existing deficiencies, analysis of samples taken at interior and perimeter wells indicates that phosphorus is being effectively adsorbed and that nitrogen removal is substantial. As required by EPA guidance on ground water protection, ground water at the system boundary meets the EPA drinking water standards.

Hollister, California

The City of Hollister, located in the San Juan Valley 22 miles inland from Monterey Bay, first applied wastewater to land in 1922 [4]. Controlled rapid infiltration was not practiced until about 1946, when infiltration basins were constructed.

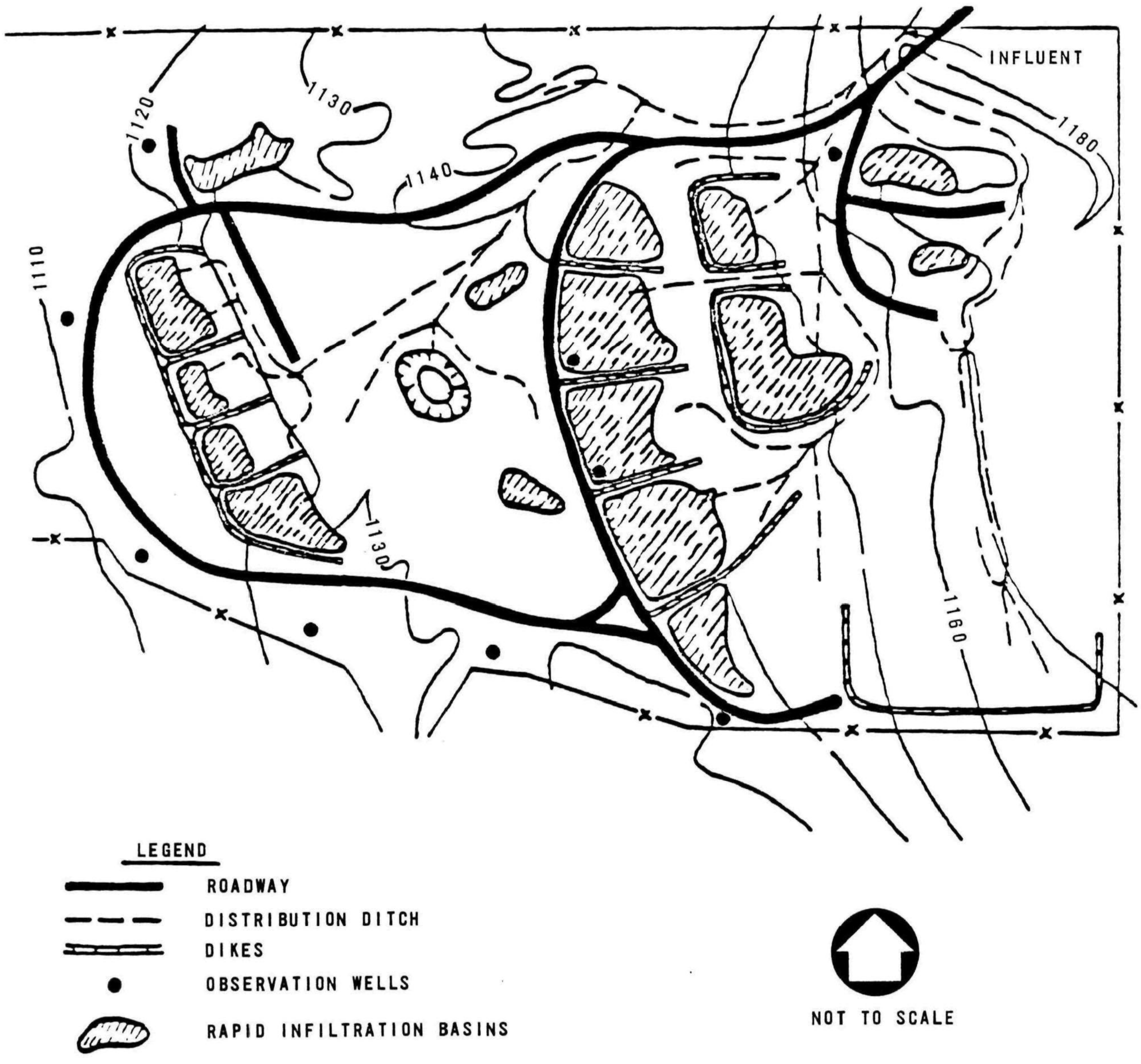

Figure 5. Rapid infiltration site at Calumet, Michigan.

From 1946 to 1980, the city operated the facilities shown schematically in Figure 6. In the mid 1970s, an earthen reservoir was constructed and used to store and thereby minimize wastewater flow peaks. In this way, flow leaving the equalizing basin and traveling through the clarifier was relatively constant. In this mode, the overall rapid infiltration system was monitored extensively from 1976 to 1977 for long-term effects on soil and ground water.

In early 1980, the city upgraded and expanded their facilities to meet the needs of a growing population. Preapplication treatment now includes lagoons, as shown in Figure 7. The new infiltration basins cover 39 acres of land. Currently, the plant wastewater flow averages 1.3 Mgal/d. About 20% of this flow is contributed by a paper recycler and a slaughterhouse. All other wastewater originates from nonindustrial sources.

[Photo of Hollister RI basin, drying]

At present, the lagoons are still filling with wastewater and the infiltration basins have not been used except during construction of the preapplication treatment lagoon. Eventually, the loading cycle should be similar to the cycle maintained with the old facilities. Until construction of the new facilities began, each infiltration basin was flooded for 1 to 2 days every 14 to 21 days, depending on basin size and season of the year. Using this cycle and primary effluent in 1977, there were no indications that trace elements or pathogenic bacteria were entering the ground water from the applied wastewater.

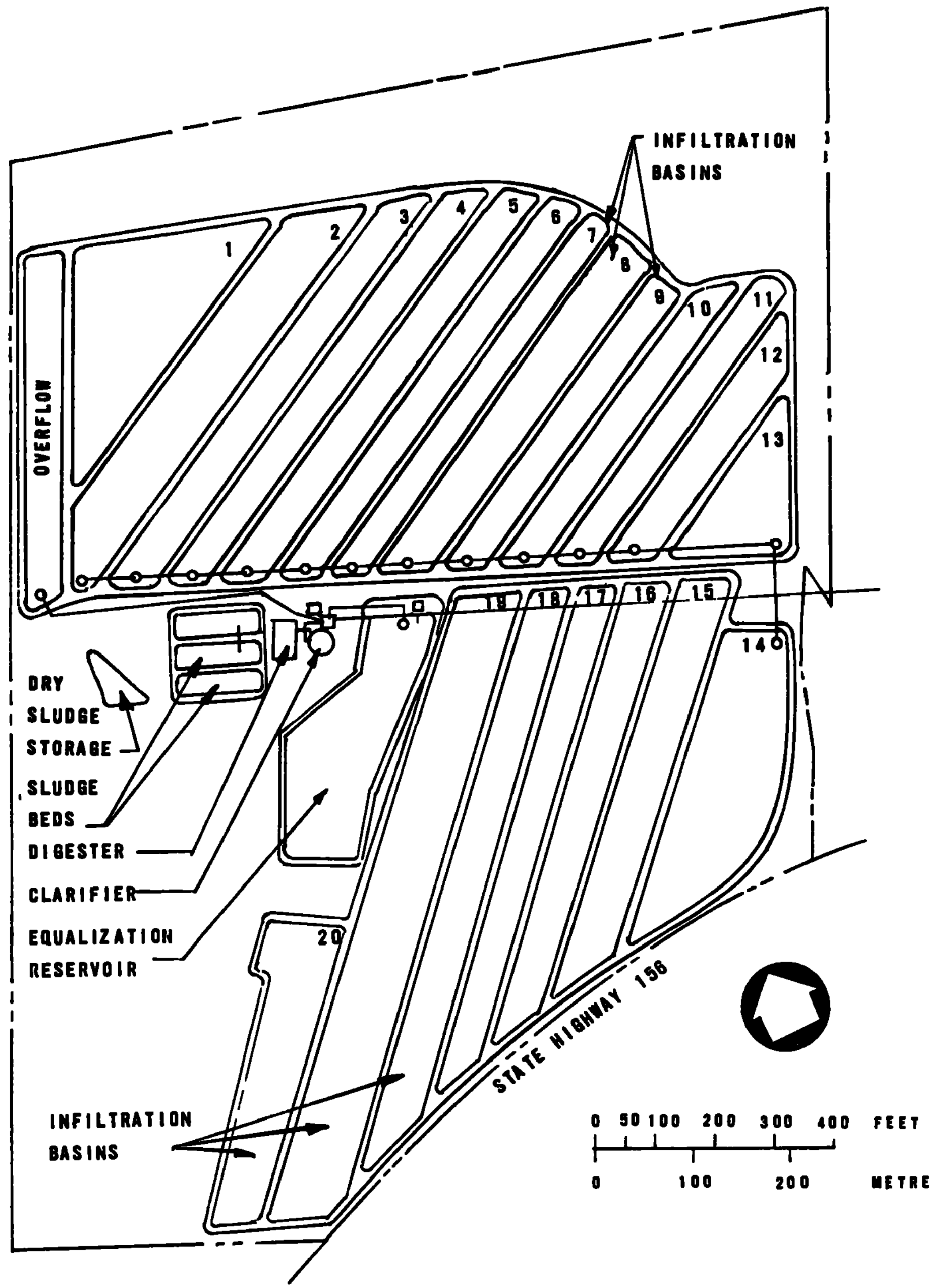

Figure 6. Schematic of pre-1980 Hollister rapid infiltration system.

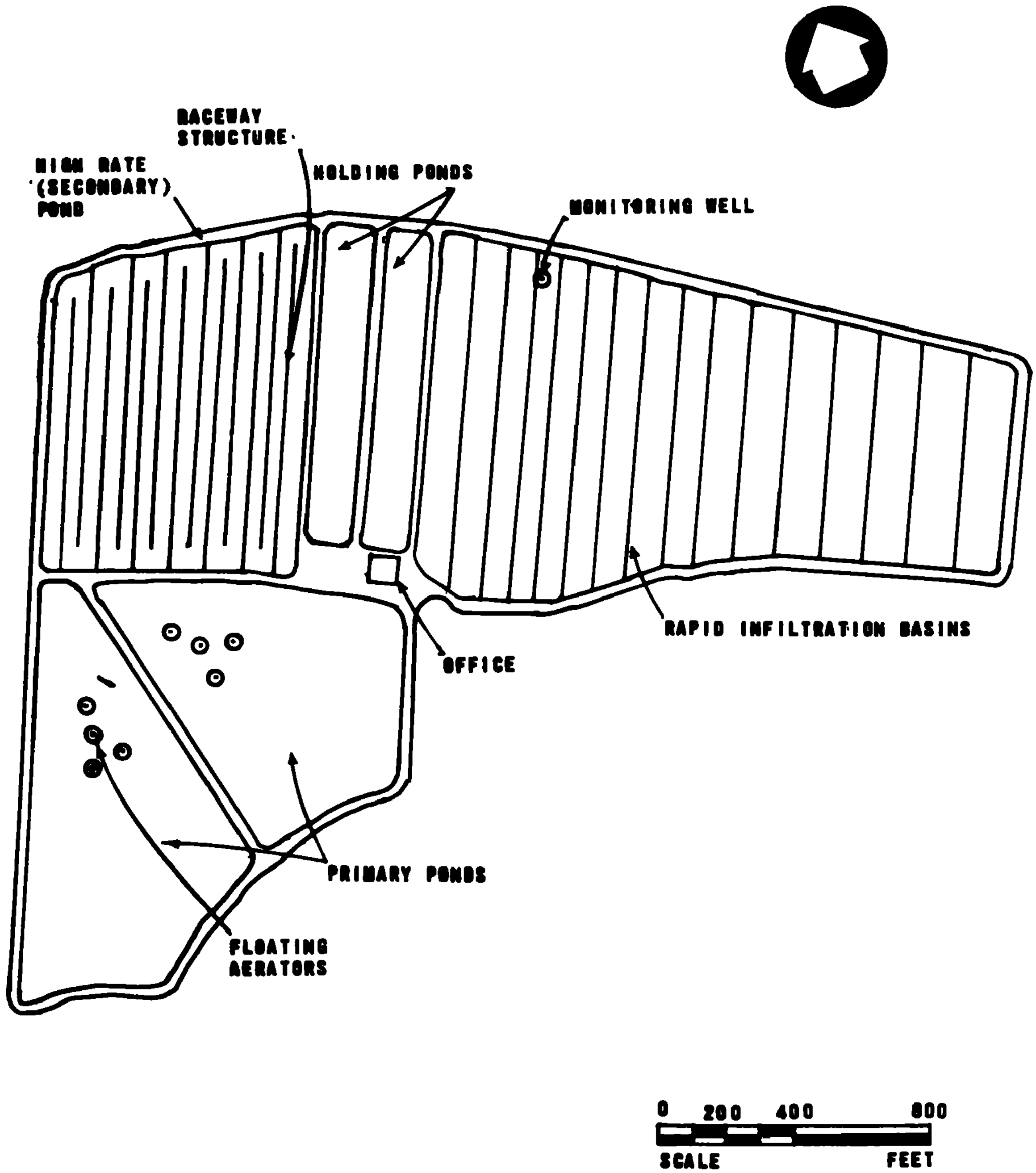

Figure 7. Schematic of new Hollister rapid infiltration system,

Similarly, chemical oxygen demand (COD), BOD, and total organic carbon (TOC) were being reduced to relatively minor amounts after percolation through 22 feet of gravelly and sandy loam. Almost complete nitrogen removal was being achieved as wastewater passed from the soil surface to the shallow ground water table. Thus, no detrimental effects were observed as the shallow ground water moved laterally to join the subflow of the San Benito River.

Lake George, New York

Because Lake George is a beautiful, clear lake and is used as a drinking water supply, wastewater discharges into the lake or into any waters discharging into the lake are prohibited [5]. When the Lake George Village wastewater treatment plant was constructed in 1936, this discharge prohibition was interpreted to mean no surface discharge to the lake or tributary streams. For this reason, a land treatment system was selected. The Lake George rapid infiltration system was put into operation in 1939 and has operated continuously since that time.

[Photos of Lake George system]

At Lake George, wastewater flow ranges from a low of 0.4 Mgal/d in the winter to an average of approximately 1.1 Mgal/d during the summer months. Preapplication treatment includes primary clarification, secondary treatment with trickling filters, and secondary sedimentation, as shown in Figure 8. A total of 21 infiltration basins are used; normally, 4 are dosed per day. Lake George does not follow an established basin cleaning schedule. Instead, beds are cleaned when they can be spared, when it appears that cleaning is necessary, and when plant personnel can take time to clean them.

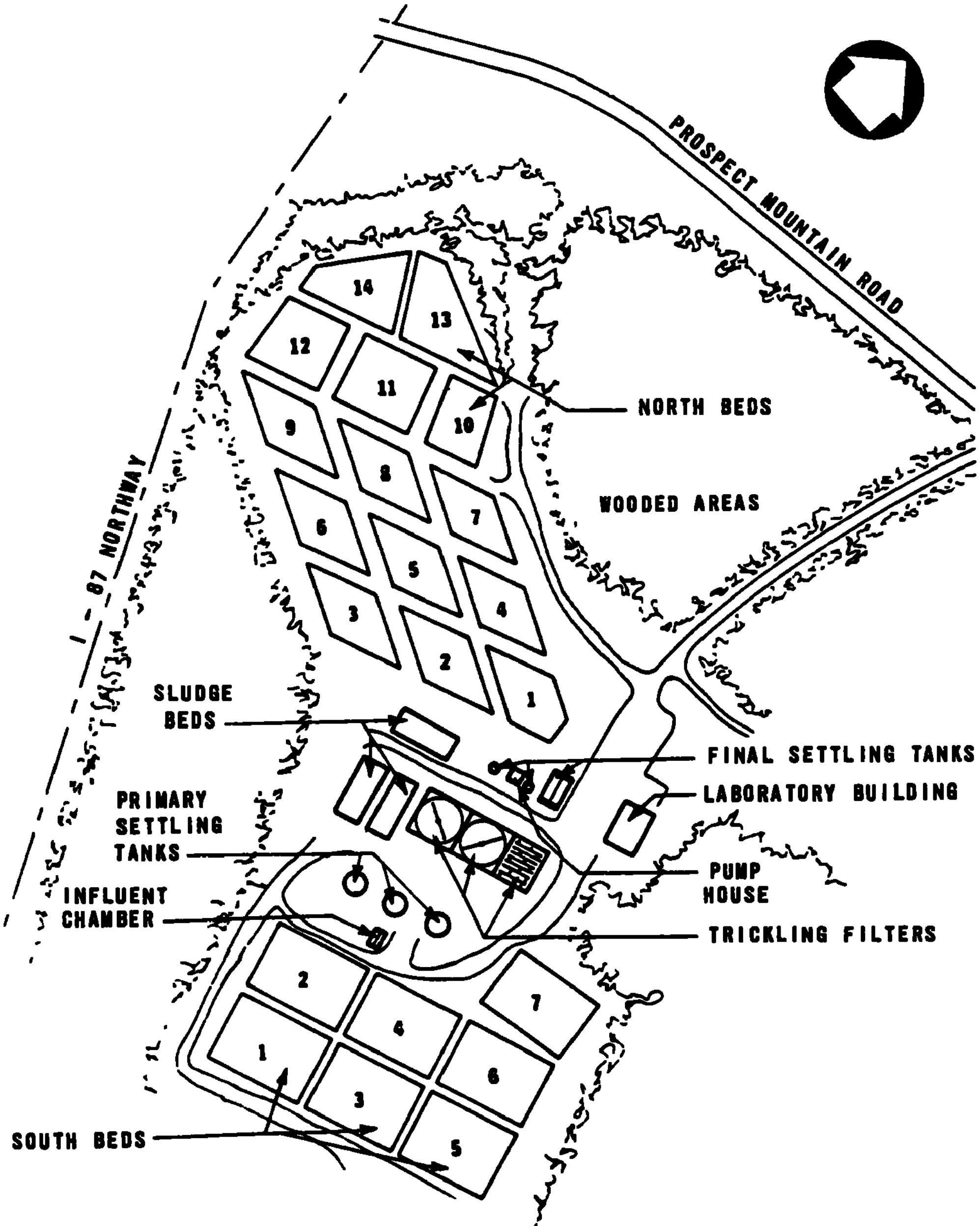

Figure 8. Plan of the Lake George Village wastewater treatment plant.

Within the first 10 feet of infiltration, BOD, COD, and indicator bacteria are effectively removed; nitrification is essentially completed; and orthophosphate concentrations are greatly reduced. Enough nitrogen is removed so that the concentration of nitrate-nitrogen meets drinking water standards at a depth of 60 feet. In summary, the renovated water quality is quite high.

It is ironic that the lake discharge prohibition that produced the rapid infiltration system now threatens its future. As a result of research studies conducted in the 1970s, the ground water flow that contains the treated water was traced to a stream that flows into the lake. The same research showed that no adverse effects were occurring as a result of the discharge. At this time, however, a legal remedy is required to allow the Lake George system to continue to operate.

[Photo of West Brook with fisherman]

<u>Phoenix, Arizona</u>

During 1967, a research project on rapid infiltration was constructed in the Salt River bed west of Phoenix, Arizona [6]. The purpose of the project was to study the feasibility of ground water recharge with secondary effluent. It was hoped that rapid infiltration could be used to provide water suitable for unrestricted irrigation, recreation, and other purposes with either high economic or social return. In this way, rapid infiltration would reduce ground water overdraft and slow down the decline of the ground water table, which had been as much as 10 ft/yr in some areas.

At the project, unchlorinated secondary effluent from an activated sludge facility was applied to the infiltration site. During the first 6 years of the research project, the loading cycle was adjusted to maximize the hydraulic loading rate. Maximum rates (300 to 400 ft/yr) were achieved by alternating flooding periods of 2 to 3 weeks with drying periods of 10 to 20 days. At these rates, however, nitrogen removal averaged about 30%.

In 1973, the loading cycle and rate were varied to promote nitrogen removal. Flooding periods were shortened, and the loading rate was lowered. Nitrogen removal increased to about 60% and remained fairly consistent during the remainder of the project.

To monitor results, water was pumped from the ground at depths of 20 to 100 feet immediately following treatment. Water quality was found to be suitable for both unrestricted irrigation and recreation.

Based on the results of the research project, a large-scale (13 Mgal/d) rapid infiltration system to treat secondary effluent was designed and constructed. Called the 23rd Avenue Project, this system was completed in 1974. As shown in Figure 9, this project uses secondary treatment (activated sludge process) for preapplication treatment. Unchlorinated secondary effluent is applied to four 10-acre basins.

[Photo of inlet to Phoenix RI basin]

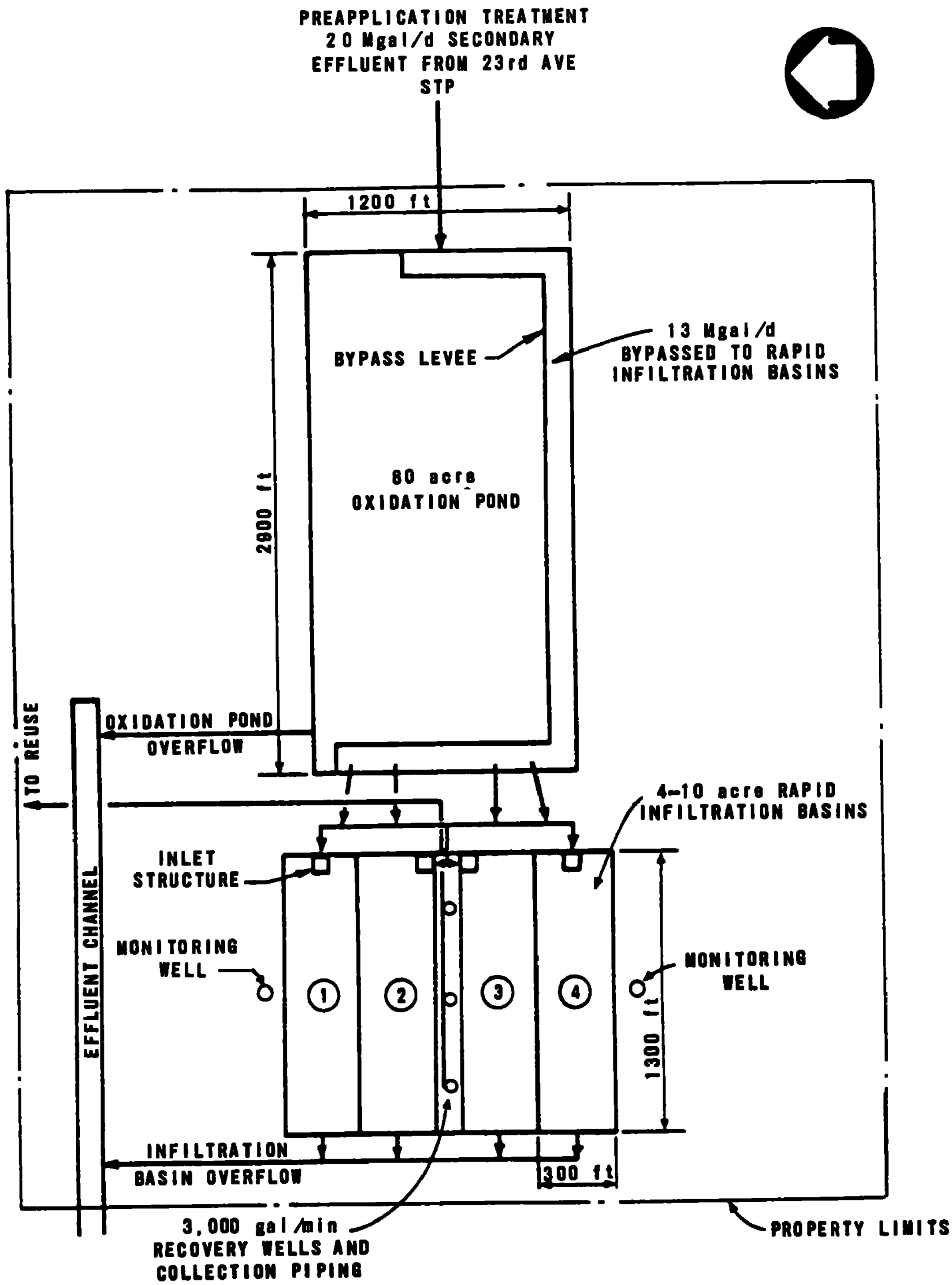

Figure 9. Layout of the 23rd Avenue rapid infiltration and recovery project.

Monitoring data from 1979 indicate that the system removes about 65% of the applied nitrogen and 75% of the applied phosphorus, and reduces the average fecal coliform concentration from 10^5-10^6 per 100 mL to 1.25-2.3 per 100 mL. In the near future, renovated water will be pumped from depths of up to 100 to 200 feet and used for unrestricted irrigation and recreation.

HOW DOES IT WORK?

Treatment Mechanisms

As wastewater travels through the soil, most of its contaminants are treated or removed. These wastewater constituents include organic matter, suspended solids, nitrogen, phosphorus, heavy metals, microorganisms, and trace organics. Many reactions and mechanisms are involved in the treatment process. Several are discussed in the following paragraphs.

Essentially all organic and other solids are removed by filtration as the wastewater travels through the uppermost soil layers. Soil bacteria consume both organic solids and most of the dissolved organic molecules, using them for growth and reproduction. As a result of the soil filtration and bacterial growth, a mat of solids forms at the soil surface. Drying the infiltration basins dries out this mat and allows oxygen that is needed for bacterial growth to enter the soil. Loosening the soil surface between applications ensures that high application rates can be maintained. Using these techniques, over 95% of the applied organic material (measured as BOD) and 99% of the applied suspended solids can be removed.

Nitrogen is removed primarily through a two-step biological mechanism known as nitrification-denitrification. In the applied wastewater, most nitrogen is present as ammonium. During the nitrification step, soil bacteria convert the ammonium to nitrate. This process requires that there be oxygen in the soil; thus, maximum nitrification occurs when short application periods followed by longer drying periods are used.

During the denitrification step, different types of bacteria convert the nitrate to nitrogen gas. The gas moves up through the soil and into the air. This step occurs only if no oxygen is present. Also, some dissolved organic molecules must be available to provide energy for the denitrification step.

At operating rapid infiltration systems, ammonium nitrogen removal is high, usually 95 to 99%. Total nitrogen removal ranges from about 50% to over 90%. Nitrogen removal improves as the lengths of the application and drying periods are increased and as the ratio of BOD to nitrogen in the applied wastewater is increased. Typically, a high BOD to nitrogen ratio is obtained by providing primary rather than secondary level treatment before land application of the wastewater.

Phosphorus is removed primarily by two chemical processes known as adsorption and precipitation. Adsorption is a rapid mechanism and occurs first. During adsorption, phosphorus adheres to soil particles and is not washed off by additional wastewater applications. Although all soils can adsorb phosphorus, soils with finer texture have more sites where adsorption can occur. In other words, the coarser the soil, the further the wastewater must travel before all phosphorus is adsorbed.

After a few days, the adsorbed phosphorus begins to precipitate. During the precipitation process, phosphorus combines with other elements, including iron, calcium, and aluminum, to form molecules that do not dissolve in water. This means that these molecules will not be dissolved by or contaminate water percolating through the soil. As phosphorus precipitates, it is released from the sites where adsorption occurs. In this way, adsorption sites are freed for adsorption of phosphorus from subsequent wastewater applications. If adequate soil travel distance is allowed, these two mechanisms can remove over 95% of the applied phosphorus.

Three types of microorganisms must be removed during wastewater treatment: bacteria, viruses, and parasitic protozoa and helminths (worms). During rapid infiltration, these microorganisms are removed by filtering, drying, solar radiation, predation, and exposure to other adverse conditions. Because of their large size, protozoa and helminths are filtered out at the soil surface. Bacteria are also removed by filtration at the soil surface, although some bacteria are adsorbed in the same way that phosphorus is adsorbed. Because they are so small, viruses are not removed by filtration but travel into the soil profile, where they are removed almost entirely by adsorption. If the distance between a rapid infiltration site and drinking water supplies or residential areas is adequate, microorganisms are not a problem.

Trace element removal is a complex process. Mechanisms that are involved include adsorption, precipitation, exchange of metals for other charged particles in the soil, and combination of metals with relatively large organic molecules that are not soluble in water. At most rapid infiltration sites, heavy metal concentrations in untreated wastewater are already lower than drinking or irrigation limits. For this reason, metal removal has not been a problem. If a community receives high concentrations of heavy metals from local industries, industrial wastewater pretreatment should be considered.

Trace organics can be adsorbed, or may evaporate from the soil surface or degrade with time. Based on limited data, trace organics concentrations in applied wastewater are low. Thus, trace organics removal at operating systems has not been a problem. If concentrations in the raw wastewater are high, industrial pretreatment should be considered.

Elements of a Rapid Infiltration System

The major elements of a rapid infiltration system are:

- Preapplication treatment
- Transmission
- Flow equalization or storage
- Distribution
- Drainage
- Land

Preapplication Treatment. The degree of preapplication treatment required depends on the relative isolation of the site, the expected treatment in the soil, and final effluent quality requirements. The EPA has recommended the following levels of preapplication treatment [7]:

- Primary treatment, when the location is isolated and public access is restricted

- Biological treatment using lagoons or inplant processes (trickling filter, activated sludge), when the location is urban and public access is controlled

Transmission. Often, wastewater must be transmitted to a site where land is available and soils are suitable for rapid infiltration. Pipeline transmission after preapplication treatment is quite common when land treatment is initiated after a conventional treatment plant has been constructed and the treatment plant is used for preapplication treatment.

Flow Equalization and Storage. A few days volume of wastewater storage may be required for flow equalization or for emergency backup in case of mechanical failures. Storage for adverse weather conditions is usually not necessary. If storage is necessary, the storage facilities can be designed as stabilization ponds, and they can provide both preapplication treatment and storage [8].

Distribution. For rapid infiltration, wastewater is normally applied to land by surface spreading, although sprinkling has been used. The distribution system should be designed so wastewater can be applied at a rate that will allow a constant basin water depth throughout the application period [8]. Multiple basins are used to maximize flexibility and allow variations in the application cycle.

Drainage. If natural drainage is inadequate, drainage facilities may be required to minimize ground water mounding and to ensure that infiltration rates do not decrease. Also, if renovated water is to be reused, some type of drainage will be necessary to transport the renovated water from underneath the soil surface to the reuse location. Three types of drainage are common:

1. Underdrains
2. Pumping
3. Natural flow to a surface water body (e.g., Lake George)

If pumps are used to extract renovated water, as they are in Phoenix, pumping costs may be a significant part of a system's annual operation and maintenance costs.

Land. The primary factors and general criteria considered in selecting a rapid infiltration site are listed in Table 4.

Table 4. SITE SELECTION FACTORS FOR RAPID INFILTRATION TREATMENT [8]

Factor	Criteria
Soil	Rapid permeability (such as sands and loamy sands).
Ground water	Minimum depth to ground water of 10 ft is preferred; lesser depths are acceptable if underdrainage is provided.
Topography	Slope is not critical but excessive slopes require much earthwork.
Climate	Although cold weather may require modified treatment plant operations, climate should not restrict plant siting.
Location	For economic reasons, siting should minimize distance and adverse grades between preapplication treatment site and infiltration basins.

The amount of land required for a rapid infiltration system depends on the loading rate, the loading cycle, and basin management practices such as the frequency of basin cleaning or soil turning. Land may also be required for wastewater storage, buffer zones, buildings, preapplication treatment, roads, or ditches. In addition, the availability of land for future expansions should be considered during site selection and acquisition.

Design criteria for rapid infiltration systems are summarized in Table 5. This table includes typical ranges for each criterion as well as actual values used at the five previously described rapid infiltration systems.

Table 5. DESIGN CRITERIA FOR RAPID INFILTRATION SYSTEMS [2-6, 8]

Design feature	Typical	Boulder, Colorado	Calumet, Michigan	Hollister, California	Lake George, New York	Phoenix, Arizona
Annual application rate, ft	20-400	100	120	37	140	250
Field area required, acres/Mgal·d	2-56	11.2	10.0	30	5.8	4.5
Preapplication treatment	Primary or secondary	Secondary	Untreated	Oxidation ponds	Secondary	Secondary
Basin surface cover	Bare or vegetated	Bare (2 basins); weeds (1 basin)	Bare	Bare	Bare	Bare
Hydraulic loading cycle						
On	1-14 days	1 day	1-2 days	1-2 days	8-24 hours	9 days
Off	4-14 days	2-3 days	7-14 days	12-20 days	4-5 days to 5-10 days	21 days

WHAT DOES IT COST?

The total cost of a rapid infiltration system may be distributed among several major components:

- Preapplication treatment facilities
- Transmission facilities
- Storage facilities
- Land
- Distribution system
- Drainage

Costs of new 1 Mgal/d and 10 Mgal/d rapid infiltration systems are presented in Table 6. These costs are based on hypothetical systems in which oxidation ponds are used for preapplication treatment. For cost estimating purposes, it was assumed that (1) 20 acres of land is needed for every 1 Mgal/d of wastewater treated, (2) land costs $4,000 per acre, (3) six 40-ft deep monitoring wells are required for every 100 acres of land, and (4) at least two monitoring wells are necessary [1].

Table 6. ANNUAL COSTS OF NEW RAPID INFILTRATION SYSTEM[a]
(1.0 Mgal/d and 10 Mgal/d)
$/household

	1.0 Mgal/d	10.0 Mgal/d
Capital	68	35
Operation and maintenance	17	9
Total	85	44

a. Adapted from reference [1].

As shown in Table 6, capital costs are nearly 80% of the total annual cost. However, because federal grant funds are available for capital expenditures but not for operation and maintenance costs, this ratio is advantageous to the operating agency. Rapid infiltration is considered alternative technology and is eligible for up to 85% funding of the capital cost under the Construction Grants Program. The local share of the treatment cost is the portion of the capital costs not paid by the federal government plus 100% of the operation and maintenance costs. Therefore, if two alternatives (e.g., rapid infiltration and a conventional system) have the same total cost, the one with the larger capital investment will have the smaller local share. Furthermore, inflation and increasing energy and resources costs cause operation and maintenance costs to increase each year. The alternative that requires the least amount of energy and resources probably would result in the greatest user savings.

To illustrate these two points, compare the costs associated with the rapid infiltration and conventional AWT alternatives shown in Table 7. Expenses included under the AWT alternative with phosphorus removal include primary sedimentation, activated sludge secondary treatment, chlorination, and ferric chloride addition. The AWT alternative with both nitrogen and phosphorus removal includes primary treatment, single-stage activated sludge/nitrification, ferric chloride addition, denitrification, filtration, and postaeration. As shown in Table 7, the local cost of a rapid infiltration facility can be much less than the local cost of an AWT plant.

Table 7. ANNUAL COSTS OF NEW 0.5 Mgal/d AND 50 Mgal/d SYSTEMS: RAPID INFILTRATION AND CONVENTIONAL AWT ALTERNATIVES[a]
¢/1,000 gallons

	0.5 Mgal/d			50 Mgal/d		
Costs	Rapid infiltration	AWT with phosphorus removal	AWT with phosphorus and nitrogen removal	Rapid infiltration	AWT with phosphorus removal	AWT with phosphorus and nitrogen removal
Capital	80	107	228	22	26	47
Operation and maintenance	20	62	112	6	23	36
Total	100	170	340	28	49	83
Local share[b]	32	79	146	9	27	43

a. Adapted from reference [1].

b. Assuming that the local share is 15% of the capital costs plus 100% of the operation and maintenance costs.

HOW CAN IT WORK FOR YOU?

It is quite possible that rapid infiltration land treatment can be used by your community. Although rapid infiltration will not work everywhere, in many communities it can be used as an environmentally sound and cost-effective solution to wastewater management problems. In some communities, innovative concepts can be used to tailor the process to the community's special needs.

Opportunities

Rapid infiltration systems can be used effectively in the following situations:

- Where there is a need for treatment without surface water discharge. At Lake George, a direct surface discharge prohibition has been met by using rapid infiltration for both treatment and disposal.
- Where there is a need for upgraded treatment. At Hollister, rapid infiltration is provided to improve the quality of the treated water so that it will be compatible with existing ground water quality.
- To reduce excessive operating costs for existing or proposed AWT facilities. Where primary treatment followed by rapid infiltration is feasible, the operating costs for conventional secondary treatment facilities can be avoided.

Innovative Concepts

Innovative modifications of the basic rapid infiltration process can be used by many communities. Several are noteworthy, for varying reasons.

First, many communities may want to consider using rapid infiltration together with another land treatment process, such as overland flow or slow rate treatment. If nitrogen concentrations in the renovated water must be very low, overland flow can be used prior to rapid infiltration to improve nitrogen removal efficiency. This technique has been demonstrated successfully in Ada, Oklahoma. At Ada, screened, raw wastewater was applied to an overland flow site and the treated runoff was applied to the rapid infiltration site. If crop irrigation (for slow rate treatment) is planned and the selected crop requires very high quality effluent, rapid infiltration can be used prior to slow rate treatment. Using this combination, even the most restrictive irrigation requirements can be met.

Second, renovated water from rapid infiltration systems can be recovered and reused for unrestricted irrigation or recreation. At Santee, California, rapid infiltration removes nutrients and pathogens, enabling the community to use the recovered water for recreational lakes. At Phoenix, wells are used to recover renovated water. Renovated water quality is suitable for either unrestricted irrigation or recreational lakes. At one time, the City of Phoenix considered using recovered water both for irrigation and for a proposed aquatic park along the Salt River channel. At present, the city is completing arrangements with a local irrigation district for the use of all recovered water.

Third, rapid infiltration systems can be modified for year-round operation in cold weather climates. Although many systems--including those at Lake George; Boulder; Calumet; Victor, Montana; and Fort Devens, Massachusetts--are able to operate in cold weather without any modifications, some communities use basin modifications to improve or ensure

Because rapid infiltration uses high loading rates, soils must be able to accept and pass on relatively large amounts of water during short periods. Soils containing substantial deposits of clay cannot do this. Where suitable soils cannot be found, rapid infiltration land treatment may not be practical.

Nitrification and oxidation of organic material require aerobic soil conditions. However, soil reaeration during resting periods cannot proceed if the soil is saturated with water. Therefore, the ground water table must be deep enough to allow drainage to occur and to keep infiltration rates from decreasing. In addition, to maintain high levels of treatment in the soil, the depth to the ground water table should be adequate. Ground water can be pumped to keep the table lower than it would be naturally, or underdrains can be used to alleviate high ground water problems.

In urban areas, land may be expensive enough to limit the use of rapid infiltration. Using March 1978 costs, the cost of land at which AWT becomes less expensive than rapid infiltration is $50,000/acre for a 10 Mgal/d facility. Even if the cost of land is not unaffordably high, it may be difficult to find an available site close to the urban area.

The reason most often cited for lack of public acceptance of a rapid infiltration alternative is fear of public health risks. Several health effects studies have been conducted or are in progress to determine if any health problems are caused by rapid infiltration land treatment. At Santee, where renovated wastewater has been used to create five recreational lakes, viral and bacteriological studies conducted in 1965 indicated that rapid infiltration provides a safe water supply for the lakes [9]. This assurance of public health protection, along with an ongoing monitoring program, has contributed to the public's enthusiastic acceptance of the recreational lakes, including the swimming area.

More recently, the Orange and Los Angeles Counties Water Reuse Study has investigated the health impacts of recharging ground water with renovated water. Ground water recharge, using effluent from the Los Angeles County Sanitation Districts' Whittier Narrows treatment facility, has been practiced in this area since 1962 with no known public health problems.

Factors contributing to public acceptance include improved surface water quality, low cost, and simplicity of operation. Compared with conventional treatment systems, savings can be realized in lower capital and/or operation and maintenance costs. These savings can mean lower user charges. Using rapid infiltration, water can be reclaimed and used for irrigation and/or recreation, instead of being discharged to nonconsumptive or less beneficial uses.

Implementation

Many communities have successfully implemented rapid infiltration systems. Here are a few examples of how this has been accomplished.

In 1959, the community of Santee was required to either upgrade or abandon their year-old treatment plant. If additional treatment was to be the selected alternative, the added cost would have to be justified by putting the water to beneficial use. At first, the Santee County Water

District proposed using stabilization ponds to reclaim water for recreational use. When this idea was rejected by the local health department, it was decided to treat about one-third of the wastewater using rapid infiltration followed by chlorination and recovery of the water for recreational lakes [9].

Four of the Santee recreational lakes were completed in 1961; a fifth was opened in 1965. By 1965, an estimated 75,000 people used the facilities each year. Since the lakes opened, the recreational program has expanded to include picnicking, boating, fishing, and swimming.

In 1936, there was concern that Lake George was being polluted by the increasing population of Lake George Village at the southern end of the lake. A secondary treatment plant, including trickling filters, was constructed to treat wastewater from the Village. Due to the efforts of the Lake George Association, organized in 1885, the lake was given an "AA" classification by the State of New York. This classification prohibits discharges into the lake or any waters that discharge into the lake. Because all of the surface waters in the area of Lake George Village discharge to Lake George, land treatment was necessary. Natural delta sand deposits were available, making Lake George Village an ideal site for a rapid infiltration system. Thus, this method of treatment was selected [5].

DIGGING DEEPER

The amount of reference material available on the research, design, and operation of land treatment systems is extensive, including: reports, design manuals, textbooks, movies, and short courses complete with individual study modules and slides. Abstracts of the key reference materials are followed by a listing of representative rapid infiltration systems (by EPA region), contacts for selected existing systems, and the references cited.

Process Design Manual for Land Treatment of Municipal Wastewater. Environmental Protection Agency. EPA 625/1-77-008. Center of Environmental Research Information, Cincinnati, Ohio. October 1977

Planning and design procedures and criteria for all land treatment systems are presented. Three case studies of rapid infiltration systems are included and a design example is provided. Treatment mechanisms for removal of nitrogen, phosphorus, pathogens, and heavy metals are detailed. Procedures for determining hydraulic capacity of sites are also included. An updated manual is scheduled for release in October 1981.

Proceedings of the International Symposium on Land Treatment of Wastewater. Volumes 1 and 2. Cold Regions Research Engineering Laboratory. Hanover, New Hampshire. August 20-25, 1978

There are 101 research-oriented papers included on subjects such as health considerations, public acceptability, mathematical modeling, existing systems, agricultural and forest use, and monitoring. This is one of the best of the proceedings of land treatment conferences held in the 1970s.

Loehr, R.C. et al. Land Application of Wastes. Volumes I and II. Van Nostrand Reinhold Co. New York. 1979

The text of this two-volume set represents the 21 self-study modules on land treatment developed as an educational package at Cornell University. In addition to the modules, over 1,000 slides, 16 cassette tapes, and an Instructor's

Program are available at the EPA Training Center in Cincinnati. These materials can be used in 2 to 5 day workshops or in individual study. The modules are basic in their coverage and are written for the uninitiated in land treatment.

Reed, S.C. et al. Costs of Land Treatment Systems. Environmental Protection Agency, Office of Water Program Operations. Washington, D.C. EPA-430/9-75-003. 1980

This report updates the 1975 publication "Costs of Wastewater Treatment by Land Application." The text is shortened and reflects current EPA policy on land treatment. Most of the original cost curves are retained along with the 1-page explanation of assumptions and items used in their development. Cost curves for transport, storage, preapplication treatment, distribution, underdrainage, wells, and monitoring are included.

Where Rapid Infiltration Systems Can Be Found

REGION I

Massachusetts

- Barnstable
- Chatham
- Concord
- Edgartown
- Fort Devens
- Nantucket (2)
- Wareham

REGION II

New Jersey

Vineland

New York

Birchwood-North Shore (Holbrook)
Cedar Creek (Wantagh)
College Park (Farmingdale)
County Sewer District (Central Islip)
County Sewer District (Holbrook)
County Sewer District (Holtsville)
County Sewer District #5 (Huntington)
County Sewer District #11 (Ronkonkoma)
County Sewer District #12 (Holtsville)
Heatherwood (Calverton)
Huntington Sewer District
Lake George
Riverhead
Strathmore Ridge (Brookhaven)

REGION III

Maryland

Calhoun Marine Engineering School
Fort Smallwood
Jensen's Inc. - Hyde Park
Quality Inn of Pecomore, Inc.
South Dorchester K-8 Center

REGION IV

Florida

Avon Park

Lehigh Acres

Sandlake (Orlando)

Tavares

Williston

Kentucky

Horse Cave

REGION V

Michigan

Bangor

Calumet

Decatur

Edmore

Gaastra

Cedar Springs (Grand Rapids)

Hopkins

Howard City

Leoni (Jackson)

Mackinaw

Marcellus

Marion

Olivet

Onekama

Ottawa County Road Commission

Pentwater

Shelby

Wisconsin

- Almond
- Baldwin
- Birchwood
- Coloma
- Deer Park
- Fenwood
- Fontana
- Hammond
- Lone Rock
- Maribel
- Milton
- Roberts
- Sextonville
- Spring Green
- Stone Lake
- Unity
- Wheeler
- Wild Rose
- Williams Bay
- Winter

REGION VI

New Mexico

- Hobbs
- Springer
- Vaughn

REGION VII

REGION VIII

Colorado

Boulder (R&D)

Sterling

Montana

Bazin

Bozeman

Corvallis

Plains

Stevensville

Victor

North Dakota

Parshall

Reeder

South Dakota

Madison

Wyoming

Jackson

Laramie

REGION IX

Arizona

Arcosanti (Cordes Junction)

Duncan

Kingman Hilltop

Lo Lo Mai Springs

Mammoth

Miami

Phoenix

Poston

Show Low

Snowflake

Thatcher

Marana (Tucson)

Ina Road (Tucson)

Green Valley (Tucson)

Avra Valley (Tucson)

Desert Museum (Tucson)

Corona de Tucson (Tucson)

Sells (Tucson)

Wickenburg

Willcox

California

Bieber

Bishop

Blythe

Burney

Ceres

Corcoran

Delhi

El Monte (Los Angeles County, Whittier Narrows treatment facility)

Escalon

Firebaugh

Fontana

Gilroy

Gridley

Hollister

Redlands

Ripon

Santee

Tahoe-Truckee

Whittier (Los Angeles County, San Jose Creek treatment facility

Yuba City

Hawaii

Kihei

Nevada

Beatty

Blue Diamond

Boulder City

Carlin

Eureka

Gabbs

Goldfield

Jackpot

McGill

Montello

Mountain City

Panaca

Paradise Spa

Paradise Valley

Tonopah

Wells

REGION X

Washington

Ritzville

Contacts for Selected Existing Systems

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or

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REFERENCES

1. Crites, R.W., M.J. Dean, and H.L. Selznick. Land Treatment vs. AWT - How Do Costs Compare? Water and Wastes Engineering. August and September 1979.

2. Smith, D.G., K.D. Linstedt, and E.R. Bennett. Treatment of Secondary Effluent by Infiltration - Percolation. U.S. Environmental Protection Agency. EPA-600/2-79-174. August 1979.

3. Baillod, C.R., et al. Preliminary Evaluation of 88 Years Rapid Infiltration of Raw Municipal Sewage at Calumet, Michigan. Proceedings of the Cornell Agricultural Waste Management Conference: Land as a Waste Management Alternative. R.C. Loehr, ed. Ithaca, New York. 1976.

4. Pound, C.E., R.W. Crites, and J.V. Olson. Long-term Effects of Land Application of Domestic Wastewater: Hollister, California, Rapid Infiltration Site. U.S. Environmental Protection Agency. EPA-600/2-78-084. April 1978.

5. Aulenbach, D.B. Long Term Recharge of Trickling Filter Effluent into Sand. U.S. Environmental Protection Agency. EPA-600/2-79-068. March 1979.

6. Bouwer, H., and R.C. Rice. The Flushing Meadows Project. Proceedings of the International Symposium on Land Treatment of Wastewater. Vol. 1. Hanover, New Hampshire. August 20-25, 1978.

7. U.S. Environmental Protection Agency. Revision of Agency Guidance for Evaluation of Land Treatment Alternatives Employing Surface Application. PRM 73-9. November 1978.

8. Process Design Manual for Land Treatment of Municipal Wastewater. U.S. Environmental Protection Agency. EPA 625/1-77-008. October 1977.

9. Merrell, J.C., Jr., et al. The Santee Recreation Project (Santee, California): Final Report. U.S. Department of the Interior, Federal Water Pollution Control Administration. Research Series Publication No. WP-20-7. 1967.

METRIC CONVERSIONS

acre	=	0.405 ha
acre-ft	=	1,233.5 m^3
acre/Mgal	=	1.07×10^{-7} ha/L
°F	=	0.555 (°F-32) °C
gal/d	=	4.381×10^{-5} L/s
ft	=	0.3048 m
in./wk	=	2.54 cm/wk
in./yr	=	2.54 cm/yr
lb/acre·yr	=	1.12 kg/ha·yr
miles	=	1.609 km
Mgal/d	=	3,785 m^3/d

ABBREVIATIONS

AWT	Advanced wastewater treatment
BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
EPA	Environmental Protection Agency
SS	Suspended solids
TOC	Total organic carbon