# Engineering Notes

*University of Wisconsin Sea Grant Advisory Services*

## #4

## Using Filtration and Induced Infiltration Intakes to Exclude Organisms from Water Supply Systems

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DRAFTED FEBRUARY 1992, REVISED SEPTEMBER 1992 — These notes provide an overview of the feasibility of designing and building filtration systems and infiltration intakes to exclude organisms from water supplies, based on international experience. The notes are for designers, engineers, contractors and operators of water intakes who want to consider sand filter intakes as a means of excluding zebra mussels (*Dreissena polymorpha*) from water supplies on rivers and lakes in North America.

### Key Terms

- **coefficient of uniformity (uniformity coefficient)** — the ratio of $d_{60}$ to $d_{10}$.
- **$d_{60}$** — size of sieve opening through which 60% of the material will pass.
- **$d_{10}$ (effective size)** — size of sieve opening through which 10% of the material will pass.
- **MGD** — million gallons per day.
- **NTU** — nephelometric turbidity units. Water with a turbidity of 0.1 NTU has a solids content of 0.1 mg/l, and if the particles were all 1-micron diameter spheres with a specific gravity of 1.01, there would be about 200 million particles/l (Cohen and Hannah 1971). Most of the particles that cause turbidity in water are 0.2-5.0 microns in diameter.
- **schmutzdecke (surface biological mat)** — the biological layer of living organisms that forms on the surface of a slow sand filter and extends several centimeters below the surface. This layer provides much of the fine filtering capability of the slow sand filter.

## Summary of Reported Sizes of Zebra Mussels in Europe

| LIFE STAGE | METRIC UNITS | ENGLISH UNITS |
|---|---|---|
| Planktonic Veligers | 40-70 microns at hatch,<br>(growing to 150-290 microns) | 0.0015-0.0027 inches<br>(0.0057-0.0110 inches) |
| Beginning to Settle | typically 175-200 microns | 0.0067-0.0076 inches |
| First-Year Juveniles | 1-14 mm | 0.038-0.5324 inches |
| Adults | 10-40 mm | 0.38-1.52 inches |

## Excluding Zebra Mussels by Filtration

Can zebra mussels be excluded by filtration? The answer appears to be "yes," based on conceptual grounds and on experience in successfully filtering out organisms of similar and smaller size.

It is widely accepted that the largest pore opening in a filter medium is only about 15% of the size of the medium (Baumann 1974; Huisman and Wood 1974; Clarke 1988). Therefore, a zebra mussel veliger or egg of 40 microns (0.040 mm) diameter, should be "strained out," or blocked, by a filter with uniformly sized media particles smaller than:

0.040 mm / 0.15 = 0.27 mm diameter (medium sand)

A zebra mussel veliger of 175 microns (0.175 mm) diameter, beginning to settle, would be strained by a filter with uniformly sized media particles smaller than:

0.175 mm / 0.15 = 1.17 mm diameter (coarse sand)

In reality, sand filters are constructed of sand with a size distribution, not of uniformly sized sand. A slow sand filter with an effective sand size of 0.30 mm diameter and a uniformity coefficient of 2.5 would have 10% of the sand passing through a sieve with an opening of 0.30 mm and 60% of the sand passing through a sieve with an opening of 0.75 mm. Sand with this size distribution should strain out settling zebra mussel veligers. Most of the pore sizes will be no larger than the pore size of a sand filter with a uniform size of 0.75 mm. That pore size is:

750 microns x 0.15 = 112.5 microns

Straining is the least important of a number of filtering mechanisms that include cake filtration, depth straining and depth filtration by interception, inertia, gravity and hydrodynamic action (Baumann 1974; Purchas 1987; Huisman and Wood 1974). However, these other filtering mechanisms greatly improve the filtering efficiency of a depth filter such as a sand filter bed, trapping smaller particles than those trapped by straining.

The sand infiltration bed intakes in the western Great Lakes are ultra-deep filters with flow rates comparable to slow sand filters. It is not known if these intakes develop a filter skin of living organisms on the surface of the filter sand, like the "schmutzdecke" that provides so much of the fine filtering capability in conventional slow sand filters.

## Characteristic Infiltration Intakes

| LOCATION | TYPE | DEPTH OF FILTER BED (ft) | SIZE (1,000 ft²) | PRESENT CAPACITY (MGD) | LAKEBED INFILTRATION RATE (gpm/ft²) |
|---|---|---|---|---|---|
| **Intakes on the Bed of the Great Lakes** | | | | | |
| Ludington, Mich. | sand/gravel | 10 / 6 | 44.0 | 6.0 | 0.12 |
| Grand Haven, Mich. | sand/gravel | 6 / 8 | 72.8 | 14.0 | 0.13 |
| Tilbury, Ont. | sand/gravel | 8 | 40.0 | 3.0 | 0.05 |
| Caseville, Mich. | sand/gravel | 2-4 / 6-7 | 23.7 | 1.2 | 0.04 |
| Charlevoix, Mich. | sand/gravel | 2 / 3,7 | 27.5 | 3.0 | 0.08 |
| **Treatment Plant Filters** (for comparison) | | | | | |
| Rapid sand filters | multi media | 3 | — | — | 2.00 - 8.00 |
| Slow sand filters | sand/gravel | 3 | — | — | 0.04 - 0.16 |

## Filtration Practice

The slow sand filter is characterized by a sand bed 0.5-1.2 m thick, with sand particles 0.15-0.50 mm effective size, and uniformity coefficients preferably <3 and certainly <5 (Huisman and Wood 1974; Purchas 1987; Visscher 1988 and 1990). The Metropolitan Water Board of London uses filter sand with 0.32 mm effective size and resands filters when the sand depth reaches a minimum of 0.3 m. Filter flow rates are 0.1-0.4 $m^3$ water / $m^2$ filter area / hr (0.04-0.16 gpm/$ft^2$).

The rapid sand filter is characterized by a sand bed 1 m thick, sand particles 0.4-2.0 mm effective size and uniformity coefficients of 1.3-1.5 (Baumann 1974; Purchas 1987; Huisman and Wood 1974; Letterman 1987). Filter flow rates are 5-15 $m^3$ water / $m^2$ filter area / hr (2-6 gpm/$ft^2$).

### Turbidity in Slow Sand Filters

Slow sand filters can apparently cope with turbidities of 100-200 NTU for a few days, and 50 NTU for a longer duration, but produce the best results when the average turbidity is <10 NTU, according to Huisman and Wood (1974). Other authors suggest a lower limit of 5 NTU, perhaps with a higher finished water quality in mind.

"Slow sand filters are capable of coping with turbidities of 100-200 mg/l for a few days, a figure of 50 mg/l is the maximum that should be permitted for longer periods, and the best purification occurs when the average turbidity is 10 mg/l or less (expressed as $SiO_2$)," according to Huisman and Wood (1974).

Montiel et al. (1988) described work in connection with the slow sand filter at the Ivry plant, which provides 15% of Paris' water supply. The filtration plant must slow down or shut down when there is excessive turbidity in the Seine River, where the turbidity can reach 100 NTU. Raw water passes roughing filters and then prefilters before reaching the slow sand filters, where the schmutzdecke layer does not "accept excessive turbidity."

"A raw water turbidity of more than 30 to 40 NTU is the maximum which may be treated at these preliminary stages to ensure that the water reaches the biological (slow sand) filters with a turbidity of 10 NTU ... Water arriving on these filters with a turbidity of more than 10 NTU will not be adequately treated," according to Montiel et al. (1988). Adequate treatment means not exceeding the turbidity standard of 1 NTU for treated water.

Cleasby et al. (1984), in their work with a pilot-scale filter using water from an Iowa quarry, suggested that turbidities of <5 NTU should be used as upper limits for the acceptability of raw water in slow sand filters.

When Slezak and Sims (1984) surveyed slow sand filtration plants across the United States, 27 respondents cited average raw water turbidities to these filters of 0.4-13.0 NTU.

Logsdon and Fox (1982) mentioned that slow sand filtration was not appropriate for treating water from the Mississippi River and its tributaries because water turbidities could exceed 1,000 NTU during flood stage.

Logsdon and Fox (1988) mentioned that rapid sand filtration can be successfully used to reduce turbidity from hundreds of NTUs to less than an NTU, but that such raw water turbidities "would quickly clog slow sand filters."

[Author Comments: Nothing was found in the literature to predict what effect turbidity would have on sand filter intakes (constructed like slow sand filters and operating at slow sand filter rates) in the beds of waterbodies. Unlike slow sand filters, sand filter intakes in waterbodies have currents, wind- and wave-induced crossflows of water above the filter, and the filter bed is much deeper. It is not known to what extent surface biological layers (schmutzdecke) form on these filter intakes, but such layers would be different from those in slow sand filters and would be likely to have different susceptibilities to turbidity.]

## Capacity Range of Slow Sand Filters

Logsdon and Fox (1988) listed 39 slow sand filtration facilities built in the United States since 1963. The largest of these are in Salem, Ore., where a 150,000-170,000 $m^3$/day facility was built in 1958 and a 190,000-260,000 $m^3$/day facility was built in 1970. The smallest slow sand filtration facility listed by Logsdon and Fox (1988) is the 45 $m^3$/day (8.3 gpm or 0.012 MGD) capacity plant at Twenty Mile, Idaho. The latter plant is described by Tanner and Ongerth (1990) in their evaluation of slow sand filter performance.

Leland and Damewood (1990) described a small slow sand filtration system with a daily capacity of 0.14 MGD, providing cost data and sketches for a pilot filter installation.

Seelaus et al. (1986) described the design and operation of a small slow sand filter with a capacity of 0.25 MGD. Logsdon and Fox (1988) mentioned U.S. Environmental Protection Agency (EPA) interest in slow sand filtration for small communities and American Water Works Association (AWWA) Research Foundation funding of a design and construction manual for slow sand filtration plants for small communities.

[Author Comments: The Salem, Ore., slow sand filtration plant built in 1958 has a large capacity equivalent to 40-45 MGD. The facility constructed in 1970 has a capacity equivalent to 50-69 MGD. Other large slow sand filtration facilities exist. The Ivry slow sand filter at Paris has a capacity of 175,000 $m^3$/day, or 46 MGD (Montiel et al. 1988). Amsterdam's water passes through slow sand filters with a capacity of 83 million $m^3$/year, or 60 MGD (Cornelius Van der Veen 1985). All of London's water passes through slow sand filters. These facilities are much larger than the 14 MGD lakebed sand filter intake at Grand Haven, Mich., the largest currently in the Great Lakes.]

**Flow Rates in Slow Sand Filters**

| Reference | m/hr | gpm/ft$^2$ |
|---|---|---|
| Huisman and Wood 1974 | 0.1 - 0.4 | 0.04 - 0.16 |
| Crowley 1976 | 0.6 | 0.25 |
| Letterman 1987 | < 0.2 | < 0.08 |
| Purchas 1987 | 0.1 - 0.2 | 0.04 - 0.08 |
| Visscher 1990 | 0.1 - 0.2 | 0.04 - 0.08 |

Flow rates in m/hr are $m^3$ water / $m^2$ filter area / hr.

Crowley (1976) cited experimental high-rate work in Switzerland (with a multi-media of sand and activated carbon) and at Walton, England (using pre-filtration ozone).

For comparison with the above table: the flow rates in sand filter intake beds of the western Great Lakes are 0.1-0.3 m/hr (0.04-0.13 gpm/ft$^2$).

## Exclusion of Organisms by Filtration

Early slow sand filters date from 1829 in England and are extensively used today. The infestation of British waterworks by zebra mussels has been described by Clarke (1952) and by Greenshields and Ridley (1957). The problems with zebra mussels occurred within the raw water feed tunnels, not downstream of the slow sand filters.

Jenner and Janssen-Mommen (1989) described measures to control zebra mussels and the mussel *Mytilus edulis* at power plants along the rivers and canals in the Netherlands. Chlorination is most common and heat treatment is done at a few plants. "At smaller plants, with a flow of 1-2 $m^3$/sec. (23-46 MGD), the installation of microsieves can be a good option. The required sieve diameter (opening) is about 80 microns. In the case of power plants, the method is less feasible. At plants of 600 MW, about 20-40 microsieve installations would be needed," according to Jenner and Janssen-Mommen (1989).

Clarke (1988) described the removal of a fibrillate centric diatom (*Cyclotella glomerata*), 5.1 microns average diameter, in a slow sand filter at the Lound Works of the East Anglia Water Company. The water above the filter contained 220,000 cells/ml. The water leaving the filter contained 4-22 cells/ml. Clarke (1988) also mentioned another diatom (*Cyclotella comta*) that was 20 microns in diameter without fibrils (hairs) and 250 microns in diameter when the fibrils were present.

"Diatoms with a diameter of 30 microns and a fibril length of up to 112 microns will pass right through a bed composed of uniform sand with a mean diameter of 1.0 mm, which would be expected to strain out material above a limiting size of 140 microns" (Clarke 1988). The diatoms passed through the filter bed because the fibril hairs bent easily.

Toms and Bayley (1988) reported on the 0.32 mm (320 micron) diameter sand (effective size) used in the London slow sand filters that: "This grade of sand should not physically permit particles much larger than 40 microns to pass through the lifter ... The presence of particles much larger than 40 microns is indicative of faults in the filter shell or the sand matrix."

A recent revival of interest in slow sand filtration in the United States is largely due to successful application elsewhere for the removal of bacteria and viruses and for the potential removal of the parasite *Giardia lamblia*, typically 7-12 microns in size (Logsdon and Fox 1988).

Pilot tests and evaluations of filtration plants indicate that *Giardia* cysts can be effectively removed in slow sand filters (Bellamy et al. 1985a, 1985b; Cleasby et al. 1984; Slezak and Sims 1984; Tanner and Ongerth 1990). However, such cysts will pass through filters if coagulant dosage and pH are not properly controlled (Tobiason and O'Melia 1988).

Records of mollusc infestation of water supplies in the United States deal principally with the European "faucet" snail (*Bythinia tentaculata*) and with the Asiatic clam (*Corbicula fluminea*).

Ingram's (1956) literature review indicates that troubles with molluscs usually appear prior to filtration or have been associated with distribution systems where water was not filtered. The routes that snails could use to get into filtered water are speculative. Shrinkage and cracking of the sand in filter beds could allow snails access to the bottom of a filter and then into the finished water system.

Ingram (1956) concludes that "Control of mollusk infestations of finished water supplies can be accomplished by chemical coagulation, filtration, and watchful filter maintenance...Chemical application for control of mollusks, as a part of the routine water treatment operation, does not appear to be warranted if the above precautions are taken as preventive measures."

Ingram (1956) cites observations of a water supply system (which is now incorporated into the Chicago system) on Lake Michigan. Small service pipes in residences became choked with faucet snails. Ingram (1956) tried unsuccessfully, through correspondence with people who were involved in operating Chicago's water supply, to learn what control measures were put into effect to rid the distribution system of the snails.

Asiatic clams were first discovered in the United States in 1938 on the Columbia River in Washington (Smith et al. 1979; Smithson 1981). Since then, the clam has spread to 35 states, reaching as far north as the Michigan shore of Lake Erie, where a small population was discovered in 1980 (Thornton 1989). Control methods commonly stress biocides with modest mention of filtration, screening and straining (Chow and Graham 1983; Smithson 1981; Smith et al. 1979; Weisberg et al. 1986).

Affected Midwestern states are Illinois, Indiana, Ohio and Pennsylvania. The clam has become a maintenance and production problem for many industrial plants using raw river or lake water. Plugging has occurred in valves, nozzles, condensers and heat exchangers. Pump impellers have been broken by shells. After large die-offs, floating clam bodies clog water intake screens. Fire protection systems have been plugged, and fire insurance has become difficult to obtain (Smithson 1981). In most cases, the clams enter water systems in the larval stage and develop to maturity in areas of low water velocity. The shells of dead clams can be carried by the water to areas susceptible to plugging. Live clams have been found in the media of raw-water pressure filters. Nuclear power plants could have plugging problems associated with the shutdown service water and emergency reactor cooling systems (Smithson 1981). In April 1981, the Nuclear Regulatory Commission issued an Inspection and Enforcement Bulletin concerning the flow blockage of cooling water to safety system components by *Corbicula*.

### Comparison of *Corbicula* and *Dreissena*

| FACTOR | *CORBICULA* | *DREISSENA* |
|---|---|---|
| Density of Settled Adults | 20,000/m$^2$ | 114,000/m$^2$ |
| Rate of Veliger Release/Adult | 588/day | — |
| Fecundity | >30,000 veligers | — |
| Size of Released Veliger | 200 microns | 40-70 microns |
| Size within One Year | 25 mm | 10 mm |
| Size at Sexual Maturity | 15 mm | 10 mm |
| Maximum Size | 40-63 mm | 33-42 mm |
| Life Span | — | 4-12 yr |
| Spawning Temperature | 16°C | 12°C |
| Attaches to Hard Substrate? | no | yes |

Sources: Hebert et al. 1989; Smithson 1981; Sinclair 1971; Hoestlandt 1968; Wiktor 1963

## Induced Infiltration Systems

### In Europe and the Middle East

Induced infiltration methods include riverbank filtration, infiltration wells and infiltration galleries. Naturally filtered water has long been prized for its quality as drinking water.

Among the first constructed waterworks were the "Kanats" of Persia/Iran. The tunnel of Negoub was constructed in 800 B.C.; it is one of an extensive system of underground infiltration galleries still employed for Tehran's water supply (Stone 1954).

The Romans could easily have drawn water from the nearby Tevere River. However, they constructed an elaborate waterworks with aqueducts to bring spring water a considerable distance to the city. These waterworks are still used in the municipal water supplies of Rome.

Wilderer et al. (1985) described German experience with riverbank filtration for water supply in the Rhine River Basin. "Based on experiences gained in England, Thiem proposed the application of riverbank filtration in 1877 to cover the increasing water demand in the lower Rhine River Basin. Thiem's proposal, however, was reluctantly accepted on a large-scale basis only when cholera epidemics caused by the direct use of riverwater broke out in German cities, especially Hamburg in 1882. Artificial groundwater recharge and bank filtration gradually became popular and were subsequently used with success."

*Dreissena* had appeared in Germany in the 1830s (Morton 1969), half a century before riverbank filtration was introduced because of cholera.

For a long time, the quality of the German riverbank infiltrate was reportedly excellent (Wilderer et al. 1985). Booming industrial expansion after World War II, however, led to a dramatic increase in riverwater pollution and a decrease in infiltrated water quality and quantity. Some infiltration riverbeds clogged with impermeable layers of organics and trace metals. Dusseldorf, in particular, had such a problem. In the 1960s, waterworks were forced to build sophisticated water treatment facilities because of complaints about bad taste and foul odor as well as problems caused by increased iron and manganese concentrations.

In Germany, from 1960 to 1979, municipal water supply systems experienced a pronounced decrease in the amount and proportion of bank-filtered water and substantial increases in the use of ground water, lakes and impoundments (Wilderer et al. 1985). During the interval, annual withdrawals of bank-filtered water declined from 463 mcm (million cubic meters) (25.0%) to 268 mcm (6.5%).

While the quantity of freshwater withdrawals through riverbank filtration for German industries is much larger than for German public waterworks, such withdrawals are still only a minor source of industrial water supply. In 1978, 612 mcm of water were withdrawn by industries through riverbank filtration, just 2% of the total estimated freshwater withdrawals for industry.

At Dusseldorf, the Municipal Waterworks has a series of riverbank filtration plants along the Rhine River (Wilderer et al. 1985). Their combined capacity of nearly 135 MGD is about the same as the make-up cooling water demands of several large power plants. The plant Auf dem Grind has the largest capacity (up to 8,000 $m^3$/hr or 50.7 MGD). These plants have a combination of old dug wells, vertical filtering wells and horizontal filter wells. Some of these wells are only 50 m from the riverbank.

Problems of major concern in German riverbank infiltration systems are bank filter plugging, the fate of trace organics, heavy metal mobilization and mixing phenomena between the ground water and infiltrated water (Wilderer et al. 1985).

## In North America

- Bank and Bed Infiltration to Wells

Kazmann (1948) proposed methods for determining whether water from a surface source will infiltrate to an adjacent aquifer where wells are pumping. Kazmann (1948) mentioned that infiltration could be prevented by deposits of silt in rivers and lakes or by lenses of clay or cemented materials existing immediately below the stream or lake bed.

Rahn (1968) mentions that published field reports on streambed infiltration wells are few. Cited examples are:

Little Plover River near Stevens Point, Wis.
Kalamazoo River at Kalamazoo, Mich.
Arkansas River near Lamar, Colo.
Collector wells along the Mississippi, Wabash and Ohio rivers
Schenectedy, N.Y. well field along the Mohawk River
University of Connecticut well field adjacent to the Fenton River

- Ranney Collectors

Mikels and Bennett (1978) describe Ranney collector systems designed for capacities up to 340,000 $m^2$/day (89.8 MGD) and costing \$700,000-\$2,200,000/$m^3$/sec developed capacity (1978 dollars) or \$0.78-\$1.54/kW for the capacity range of large nuclear power plant makeup cooling water supplies. Comparison of Mikels and Bennett (1978) cost estimates to EPA cost estimates indicates that Ranney collector systems cost 79%-36% of conventional shoreline intake costs (comparing minimum, maximum costs).

Mikels and Bennett (1978) show a table of 16 collector systems with aquifer depths of 4.4-22.0 m, riverbed infiltration rates of 0.0001-0.0093 cm/sec (average of 0.0023 cm/sec) and velocities through the riverbeds of 0.00036-0.03100 cm/sec (average of 0.00780 cm/sec). They compare infiltration rates with conventional rapid sand filters having infiltration rates of 0.27 cm/sec (0.53 ft/min) and a filter bed thickness of only 1 m.

Typical slow sand filters have a slightly higher filtration rate of 0.1-0.6 m/hr (0.0028-0.0167 cm/sec).

Kazmann (1947) describes a Ranney well system of seven collectors along the bank of the Ohio River about 12 mi north of Louisville, Ky., serving the Indiana Ordnance Works during World War II. The capacity of the well field was about 70 MGD (49,000 gpm). During the period of continuous use (from April 1941 to April 1945), the average pumping rate was 39.7 MGD. Highest monthly pumping rate was 51.2 MGD. For brief periods of a few hours, the field was pumped at more than 60 MGD.

"The well field is on a narrow flood-plain terrace composed mainly of gravel, covered with a layer of silt and top soil...geology similar to a hundred terraces along the Ohio River. The depth of the aquifer to bedrock is about 100 ft. The gravel aquifer is 200-500 ft wide, inland from the river edge. The collector wells are spaced at intervals of 1,300-2,000 ft, within 100 ft of the river edge at normal pool stage. Each well unit has two pumps, each capable of delivering 3,500 gpm; total length of laterals in each well, 1,000-1,200 ft" (Kazmann 1947).

Harmful bacteria from the Ohio River were removed or killed in sands and gravels between the river and the collector. There was no evidence that permanent silting occurred during the period of collector field operation. Production capacity remained unchanged.

Unlike in a sand filter, in the riverine infiltration area of an aquifer, "the principal movement of water is along the river bottom in planes roughly perpendicular to the direction of infiltration. The fines, therefore, do not remain on the surface of the area as they would if raw river water were led to sand beds without prior sedimentation" (Kazmann 1947). Bedload transport in the river removes and replaces fine sediments.

## ■ Infiltration Galleries

Relatively little recent basic engineering information was found in the literature concerning infiltration galleries (Stone 1954; Bennett 1970). Stone (1954) summarized his literature review, correspondence and results of field study as a survey of engineering experience.

According to Stone (1954), the requirements of infiltration galleries include: (1) a shallow aquifer for low cost construction, (2) a plentiful recharge of ground water and (3) collected water of satisfactory chemical quality. Advantages include: (1) infiltration galleries could be the economical and superior option, particularly for small systems where both installation and operating expense are likely to be relatively low, assuming that an infiltration gallery avoids the cost of constructing a chemical treatment plant with conventional rapid filtration, and (2) infiltration galleries employ gravity inflow and do not waste horsepower maintaining a negative pressure head for drawdown.

Some of the types of aquifers developed for infiltration galleries are: springs, rock fissures, shallow ground water stratums, locations adjacent to a stream or lake (Stone 1954). River headwaters, where there is a relatively high velocity of flow, have proven to be the most satisfactory locations with good collection rates possible (Stone 1954). One reason given is that high flow velocities carry away the fine sediment that would reduce the permeability of an aquifer. Wilderer et al. (1985) also mention this as a possible reason why the navigation channel of the Rhine River is not clogged as is the river bed near the bankside of the Dusseldorf infiltration system. Stone (1954) also credits the relatively pure waters in headwaters as well as the coarse porous sand and gravel that enable rapid recharge.

Infiltration galleries appear to operate satisfactorily with 15 ft of permeable material as a cover. The range in soil depth appears to be 2-919 ft above the gallery pipe. Following are some characteristics of eight infiltration galleries.

### Characteristic Infiltration Galleries

| City | Aquifer Media | Cross-Section Area ($ft^2$) | Length (ft) | Depth Below Surface (ft) | Yield Total (MGD) | Yield (MGD / 1,000 ft) |
|---|---|---|---|---|---|---|
| Circleville, Ohio | sand | 3.00 | 650 | 11-19 | 3.00 | 4.6 |
| Des Moines, Iowa | sand & gravel | 4.00 | 18,500 | 10-25 | — | 0.6-1.4 |
| Des Moines, Iowa | coarse sand | 2.10 | 8,480 | — | 14.00 | 1.7 |
| Harrisonburg, Va. | sand & gravel | 1.90 | 758 | 10 | 1.00 | 1.3 |
| Los Angeles, Calif. | sand & gravel | 1.00-15.00 | 1,500 | 2-136 | 6.50-11.50 | 4.3-7.7 |
| South Haven, Mich. | sand & clay | 0.50 | 90 | — | 1.25 | 14.0 |
| Crystal City, Mo. | sand | 0.35 | 65 | 20 | 1.30 | 20.0 |

Source: Stone 1954

In Stone's (1954) list of 33 infiltration galleries worldwide, 11 are abandoned, including the only one mentioned for the Great Lakes: Lake Michigan at South Haven (abandoned in 1902). Surprisingly, Stone (1954) did not mention the Superior, Wis., water system, which has been operating since the 1880s.

Stone (1954) did mention that infiltration galleries had been used in locations such as Los Angeles and Des Moines for over 40 years without reported reduction in the collection rates. He also mentioned Frankfort, Germany, had been reclaiming badly polluted raw water as the water travels 10-1,600 ft through sand and gravel, blending with existing ground water.

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Stone (1954) makes the following recommendations for infiltration galleries:

☐ Infiltration gallery pipe should be perforated and connected by open joints to allow low entrance velocities.

☐ Where flow velocities are less than 2 ft/sec, sand traps and cleanouts should be built for removal of grit.

☐ An expensive backwash is not required for routine operation of most galleries.

☐ Galleries are often laid within a graded gravel and sand cradle and backfilled with the same material.

☐ A properly located gallery within a porous sand and gravel aquifer should average infiltration rates of about 1 MGD/1,000 ft of interceptor length.

☐ Coarse aquifers that are rapidly recharged by fast-flowing ground water could supply higher infiltration rates. Fine sand aquifers can be expected to supply less than 1 MGD/ 1,000 ft of collector length.

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Stone (1954) also lists the following reasons for infiltration gallery failures:

☐ Infiltration galleries located in a water table where dry periods caused drawdown that left the galleries high and dry.

☐ Infiltration galleries improperly located in a poor aquifer with strata containing clay or organic matter, or a sand stratum restricted by hard pan, could prove unsatisfactory.

☐ Permeability reduction caused by the precipitation of minerals with incrustation of the sand and pipe perforations can lead to sealing of galleries. Sealing of three horizontal well screens by introduction of fine clay and other impervious turbidity resulted in the abandonment of horizontal wells at South Haven, Mich., in 1902.

☐ Some infiltration galleries fail because of collapse of the gallery structure.

☐ Some infiltration galleries are closed because of pollution of infiltrated water.

☐ Sometimes not enough infiltration galleries are installed for the large quantity of water supply desired.

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