Engineering Notes

University of Wisconsin Sea Grant Advisory Services

#1 Case Studies of Constructed Filter Bed Intakes

by Philip Keillor, Coastal Engineer. University of Wisconsin Sea Grant

DRAFTED AUGUST 1990, REVISED JUNE 1992 — These notes provide an overview of features and experience with infiltration type intakes in the western Great Lakes. 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

- **gpm** — gallons per minute.

- **horizontal wells** — can be either the Ranney type of well or a horizontal pipe with a wellscreen at the end, laid in a trench and surrounded by filter gravel and sand. The latter type is also known as an infiltration gallery. Superior, Wis., has a 100-year-old Great Lakes prototype of a lakebed infiltration gallery.

- **infiltration gallery** — an ancient and still-used method of withdrawing water from waterbodies by digging a trench in porous soils adjacent to the shore or in the shallow lakebed nearshore.

- **MG** — million gallons.

- **MGD** — million gallons per day. 1 MGD = 694 gpm.

- **NTU** — nephelometric turbidity units

- **Ranney wells** (pronounced "ran-ee") — are also known as radial collector wells. A Ranney well is constructed by sinking an open-bottomed, reinforced concrete caisson in soil adjacent to a waterbody. Horizontal collector pipes (laterals) are extended from the caisson into permeable, water-bearing soil. The laterals are installed using a method of horizontal screen projection whereby fine materials in the soil are removed and coarser materials in the soil form a natural gravel pack around the slotted screen laterals. Groundwater drains into the lateral collector pipes and then into the caisson, from which it is pumped into a water supply system. The water is withdrawn at very low rates, for example, water in a 40-ft thick porous soil layer can take a year to travel 1,000 ft. Systems have been constructed with capacities as low as 232 gpm and as high as 70 MGD.

- **sand filter infiltration beds** — the Great Lakes prototype is at Ludington, Mich., on Lake Michigan. The filter bed is a pit dug into the lakebed and partially backfilled with a layer of filter gravel. A grid of plastic perforated pipe and non-perforated collector pipe is laid on the gravel layer and covered with more filter gravel, a layer of finer gravel and a top layer of sand to completely fill the pit. Water is drawn from the lake and lakebed soil (if permeable) into the collector pipes.

Case Studies

SUPERIOR, WIS. — **INFILTRATION GALLERY**

The City of Superior draws water from 80 vertical and horizontal wells along the beach on Minnesota Point. First constructed in 1890-91, the system has had additions as recently as 1975 and is still in operation.

DESCRIPTION — the horizontal wells are under the lake. The vertical wells are on land, some 50 ft from the water's edge. Water is obtained by pump suction on header pipes connecting the wells. The vertical wells are approximately 45 ft deep and 8-12 inches in diameter with wellscreens 20 ft long. The horizontal wells are either 12 or 24 inches in diameter. A typical horizontal well has 275 ft of steel pipe with 30 ft of wellscreen at the end. Some of the oldest pipe is probably iron. The horizontal well pipe was laid in trenches, about 12 ft deep at the screen and about 4 ft deep at the beach. Horizontal pipes tie into a 24-inch header. The newest header has three, 12-inch diameter horizontal wells tied to it. All wells are connected to the suction headers. A 1990 flow test provided 2.5 MGD through the three new horizontal wells.

INFILTRATION AREA — unknown.

INFILTRATION RATE — unknown.

PUMPING RATE— 4 MGD in summer.

BACKFLUSHING RATE — no way to tell; Superior Light and Power Company just shuts down and lets water wash back through the screens.

METHOD OF CONSTRUCTION — horizontal well pipe was laid in a trench dug by dragline in the winter, working on the ice. All screens were set in a bed of buckshot-sized gravel. About 100 yd of gravel was placed around each screen and backfilled with lakebed sand.

RAW WATER TURBIDITY — 0.3 NTU (typical).

PROBLEMS — once or twice a year the intake must be backflushed to loosen clay that has settled into the lakebed. During high runoff periods, high turbidity in the lake (over 0.7 NTU) comes through the system, mostly through the horizontal wells. In February and March under ice cover, there is trouble holding a vacuum on the system because of saturated oxygen conditions in the water being pulled through the lakebed.

PUMPING CAPACITY LIMITATIONS — permeability of the bottom of the lake. After a storm, permeability improves. To some extent, the area can also have migrating sandbars, but these don't appear to cause a problem by increasing hydraulic resistance or reducing permeability.

OTHER INTAKE STRUCTURES — a surface intake about 2 mi off Minnesota Point in Lake Superior is in about 70 ft of water. This intake principally serves Cloquet, Minn. The intake has a 48-inch diameter main. Superior purchases some of its water supply from this intake. Cloquet uses about 10-12 MGD from this intake on the lakebed surface.

FOR FURTHER INFORMATION — on system design and operational experience, contact: Ron Evans, Operations and Maintenance Supervisor. Superior Water, Light and Power Company, 1230 Tower Avenue, P.O. Box 519, Superior, WI 54880. Phone: 715-394-2320.

LUDINGTON, MICH. — SAND INFILTRATION BED INTAKE

Installed in 1969-70 (Newhof 1992), this system was built to replace an old surface intake crib (which still is used to provide the turbidity needed to make the clarifiers work). The newer, buried intake is located about 900 ft offshore in about 10-15 ft of water.

DESCRIPTION — the infiltration bed is buried 15 ft under the lakebed in a deep sand deposit (Prein and Newhof 1988b). At the end of the 36-inch diameter intake main, about 280 ft of 24-inch diameter header pipe extends north at right angles to the 36-inch main (Prein and Newhof 1988a). Extending westerly from the 24-inch header are 10 perforated pipes, each 200 ft long. Each 8-inch diameter, Sched. 80 PVC pipe has 3/16-inch wide by 4-inch long slots cut in the bottom. The pipes are located 20 ft apart. The total length of slotted pipe is 2,000 ft. The pipe is surrounded by gravel with a thickness of 6 ft. Then, 2 ft of coarse, graded sand was placed on top of the gravel and about 8 ft of beach sand was placed on top of the coarse sand (Prein and Newhof 1988a).

INFILTRATION AREA — 44,000 ft^2 (Prein and Newhof 1988b).

INFILTRATION RATE — (calculated at the elevation of the pipe grid) 0.12 gpm/ft^2 (Prein and Newhof 1988b) or 250 ft of collector/MGD or 2.8 gpm/ft. of collector (Newhof 1992).

PUMPING RATE— over 4,000 gpm, 6-8 MGD capacity (Newhof 1992). An average of 2.75 MGD is produced, with a maximum day demand of 4.5 MGD. A test of the intake was conducted on December 17, 1987. With the water temperature at 43°F, the pumped rate was 6,100 gpm, and the intake pump suction pressure was 1.25 psi. Some sand came through the raw water main, but it was not clear whether this sand came from the new intake or the old surface intake, which had been shut off for the test (Prein and Newhof 1988a).

BACKFLUSHING RATE — unknown.

METHOD OF CONSTRUCTION — approximately 36,000 yd^3 of lakebed sand was removed by dredging. Then, 5,400 yd^3 of coarse filter gravel was laid in the pit, the pipe field was laid, an additional 5,400 yd^3 of coarse filter gravel was laid, 4,600 yd^3 of fine filter gravel was laid and, finally, 21,000 yd^3 of beach sand was laid as the top cover.

RAW WATER TURBIDITY — 0.1 NTU, when only the infiltration bed intake was being used in March 1985 because of high turbidity (7.4 NTU) in the old surface intake. Water drawn through the new infiltration bed intake is 0.12-0.15 NTU (Prein and Newhof 1988a).

PROBLEMS — on two occasions the capacity of the infiltration bed intake was reduced. Once was during the summer when lake currents moved a sand bar over the intake and the capacity dropped off. After four or five days, the wind shifted, the sand bar washed away and the capacity was restored. On another occasion, during construction of the Consumers Power Pumped Storage Plant about 5 mi south of the intake, a clay material was transported northward and settled on the lakebed over the intake. This material was scraped off by a crane operating on a barge over the intake (Prein and Newhof 1988a). Another problem is that turbidity of water from the buried intake is too low for proper settling and clarification.

PUMPING CAPACITY LIMITATIONS — capacity of the water treatment plant processes, not the intake field.

OTHER INTAKE STRUCTURES — older, conventional crib-type surface water intake.

ENGINEER — Tom Newhof. Prein and Newhof, 3355 Evergreen Drive, N.E., Grand Rapids, MI 49505. Phone: 616-364-8491. Fax: 616-364-6955.

FOR FURTHER INFORMATION — on operational experience, contact: Bill Swan or Bruce Lemire, Assistant Superintendents, or Jerry Kolaski, Superintendent of the Water Plant. Ludington Department of Public Works. Phone: 616-843-8830.

A series of three Ranney wells were installed in 1951 along the beach near the harbor entrance.

DESCRIPTION — each of the wells is a 13-ft (inside diameter) caisson sunk to 30 ft below the lakebed at the lakeshore. Lateral screen collector pipes (laterals) extend outward from the caissons at 22 ft, 25 ft and several other depths below the lakebed (Prein and Newhof 1988b).

It is uncertain how much total length of active laterals are now in this system. Seven new laterals were installed in the spring of 1989. The Ranney Division of Hydro Group, Inc., in a 1989 test report, reported 1,114.5 ft of total old lateral collector pipe length plus 1,004.0 ft of total new lateral collector pipe length. The combined total of lateral collector pipe is 2,118.5 ft. The total lateral collector screen length is 2,018.5 ft.

INFILTRATION AREA — unknown.

INFILTRATION RATE — the infiltration rate/ft of lateral collector pipe was 4.4 gpm or 158 ft of lateral collector pipe/MGD (Prein and Newhof 1988b). New laterals have been added since then. Newhof (1992) reports 6 MGD capacity, 225 ft of laterals/MGD of capacity and 4.4 gpm/ft of lateral.

PUMPING RATE — Well No. 1 has one pump at 1,100 gpm and one pump at 1,800 gpm. Well No. 2 has one pump at 1,000 gpm and one pump at 1,600 gpm. Well No. 3 has one pump at 900 gpm and one pump at 1,200 gpm. The maximum combined pump capacity is 7,700 gpm (10.9 MGD). Actual pumping capacities were 5.66 MGD at 72°F in summer and 3.21 MGD at 35°F in winter, based on 1987 data (Prein and Newhof 1988b). Sand accretion on the lakebed above the laterals field accounted for the reduced capacity.

BACKFLUSHING RATE — unknown.

METHOD OF CONSTRUCTION — caissons were sunk by excavation under and inside the caissons. Laterals were jetted outward hydraulically into the lakebed through valves in the caisson walls, to the point of refusal.

RAW WATER TURBIDITY — less than 0.20 NTU up to 0.50 NTU after backwash or storm. Prein and Newhof (1988b) show a table with a maximum of 1.00 NTU, a minimum of 0.10 NTU, and averages of 0.29 NTU and 0.25 NTU, respectively, for 1977 and 1978.

PROBLEMS — in the spring of 1987, the Corps of Engineers did a beach nourishment project near these wells, and the shore moved lakeward about 50-100 ft (Prein and Newhof 1988a). In recent years, lake levels dropped. The combined result: in 1990, Well No. 2 had 200 ft of sand beach in front and none of the radial collector pipes were under the lake. The summertime capacity of the Ranney collectors has dropped to about 3.5-4.0 MGD at 60°F (Prein and Newhof 1988a). There is more, harder, water from groundwater and less water infiltrating from the lake. Since the 1950s, the laterals have required cleaning once (in 1982) because of plugging with iron and calcium deposits. Growth of iron bacteria in the laterals is a continuing and common problem, reducing capacity. The city uses an 18-inch long nozzle that fits inside the laterals to backwash one short section of lateral at a time (Prein and Newhof 1988a). Capacity is also limited by the shallow depth and fine sediments. A better aquifer is located south of Grand Haven.

TOTAL HARDNESS — 156 mg/l in summer, 200 mg/l in winter when the lake surface is frozen (Prein and Newhof 1988a).

OTHER INTAKE STRUCTURES — a crow's foot infiltration gallery and a new infiltration bed intake.

FOR FURTHER INFORMATION — on design, contact: James French. Ranney Division; Hydro Group, Inc.; 2 North State Street; P.O. Box 729; Westerville, Ohio 43081. Phone: 614-882-3104. Also, for further information on operational experience, contact: Terry Velik, Supervisor, or Bob Hoffer, Director. Grand Haven Water Plant, Grand Haven City Hall, 519 Washington Street, Grand Haven, MI 49417-1486. Phone: 616-847-3488 and 616-847-3487, respectively. Fax: 616-842-0085.

GRAND HAVEN, MICH. — "CROW'S FOOT" INFILTRATION GALLERY

This infiltration gallery was installed in 1960.

DESCRIPTION — an 18-inch diameter steel pipe extends about 500 ft offshore (Prein and Newhof 1988a). The pipe branches to three 12-inch diameter, perforated steel pipes, each 100 ft long with 1/4-inch diameter holes at 1-inch spacing all around the pipe diameter and extending the entire pipe length (Prein and Newhof, 1988a). One pipe extends straight out from shore. The other two extend at 45° angles to the north and to the south of the center pipe.

INFILTRATION AREA — 3,000 ft^2 (Prein and Newhof 1988b).

INFILTRATION RATE — 1.4 gpm/ft^2 pumped, 0.46 gpm/ft^2 design (Prein and Newhof 1988b; Newhof 1992).

PUMPING RATE — 3 MGD was the design capacity, but 6 MGD was pumped. Newhof (1992) gives the original design capacity at 2 MGD and the intake being pumped currently at 6 MGD. In 1990, this system was cut back to 500 gpm for maintenance of a clean pipe. According to Prein and Newhof (1988a), the pumping capacity was 6 MGD at 60°F in summer and about 3.5-4.0 MGD at 40°F in winter. A Corps of Engineers beach nourishment project is believed to have caused a drop in summer capacity from 6 to 4 MGD and winter capacity from 4 to 2 MGD.

BACKFLUSHING RATE — unknown.

PUMPING RATE — 14 MGD (Newhof 1992). The intake system performed adequately at a pumping rate of about 15,000 gpm, about 50% greater than the design capacity of 10,000 gpm (Newhof 1992).

BACKFLUSHING RATE — unknown.

METHOD OF CONSTRUCTION — a 2-acre pit was hydraulically dredged and left open over winter. In the spring of 1990, the gravel, pipe grid and sand layers were installed and the pit was backfilled. Little infilling occurred over winter, according to the contractor.

RAW WATER TURBIDITY — 0.4 NTU initially. During the first year of operation, turbidity averaged 0.5 NTU in raw water being pumped to the treatment plant (Newhof 1992).

PROBLEMS — in the summer of 1991, pumping capacity was cut in half. This problem and the various methods that were attempted to solve it are described in Newhof (1992). An investigation with divers suggested that the intake flow had drawn to the filter bed surface a large quantity of fine clays and silts from dredged material placed on the nearby beach by the Corps of Engineers. The clay formed a layer 1/16-1/8 inches thick over the filter bed. A contractor was hired to drag a huge I-beam across the filterbed. The I-beam was suspended from a barge, and the barge was towed by tug across the site. This activity re-suspended the fine particulates temporarily. The process was repeated several times. Eventually, a summer storm moved the fine sediments off the intake and along the coast, clearing the intake.

ENGINEER — Tom Newhof. Prein and Newhof. 3355 Evergreen Drive N.E., Grand Rapids, MI 49505. Phone: 616-364-8491. Fax: 616-364-6955.

CONTRACTOR — Andrie, Inc. Muskegon, Mich.

FOR FURTHER INFORMATION — on operational experience, contact: Terry Velik, Supervisor, or Bob Hoffer, Director. Grand Haven Water Plant, Grand Haven City Hall, 519 Washington Street, Grand Haven, MI 49417-1486. Phone: 616-847-3488 and 616-847-3487, respectively. Fax: 616-842-0085.

CHARLEVOIX, MICH. — "CROW'S FOOT" INFILTRATION GALLERY

The intake was installed in March 1987.

DESCRIPTION — a 24-inch diameter PVC pipe was laid in a trench 5 ft below the lakebed and runs 1,00 ft from shore. Near the lakeward end of the pipe, two tees extend out from the main. Each tee is connected to a valve and another tee. From each of the second tees, two, 25-ft long by 14-inch diameter stainless steel wellscreens extend, one on each branch of the tee. (See diagram in Prein and Newhof 1988a.) An elbow takes a vertical capped riser to about 3 ft above the lakebed. If the wellscreen plugs, divers can remove the cap for an emergency supply of water. The total length of 14-inch diameter wellscreen is 100 ft.

METHOD OF CONSTRUCTION — trenches were dug with a dredge. Perforated pipe was laid in the trenches, 14-15 ft below the surface of the lakebed. Gravel was placed beneath, around and above the pipes. The trenches were then backfilled with lakebed sand. The water depth is 10-15 ft over this buried gallery (Prein and Newhof 1988b; Newhof 1992).

RAW WATER TURBIDITY — 0.2-0.3 NTU, less than 0.2 up to 0.5 NTU after backwash (Prein and Newhof 1988a). Prein and Newhof (1988b) show a maximum 0.71, a minimum 0.10, and averages 0.25 and 0.20 NTU, respectively, for 1977 and 1978.

PROBLEMS — currently the system is infested with iron bacteria (too close to an iron seawall) and not used much. Because each lateral cannot be backwashed separately, washwater distribution could vary. Sand enters the intake, filtering through the gravel pack. The iron bacteria problem could be due to excavation of the intake through an organic sediment layer but more likely is due to iron in the groundwater, since the Ranney collectors have the same problem. Occasionally during calm weather, the intake will plug and capacity will be reduced (Prein and Newhof 1988a).

PUMPING CAPACITY LIMITATIONS — none. It was overpumped.

FOR FURTHER INFORMATION — on operational experience, contact: Terry Velik, Supervisor, or Bob Hoffer, Director. Grand Haven Water Plant, Grand Haven City Hall, 519 Washington Street, Grand Haven, MI 49417-1486. Phone: 616-847-3488 and 616-847-3487, respectively. Fax: 616-842-0085.

GRAND HAVEN, MICH. — SAND INFILTRATION BED INTAKE

Installation of a new infiltration bed intake (patterned after the Ludington design) was completed in June 1990.

DESCRIPTION — a 1-acre grid of 26 slotted pipes off a 30-inch diameter header pipe connected to a 30-inch diameter main that extends 1,200 ft offshore at 15 ft water depth. The total collector length is 3,380 ft (Prein and Newhof 1988b; Newhof 1992). The slotted pipes are each 130 ft long, Schedule 80, 8-inch diameter PVC with slits on the bottom surfaces; each 4 inches long by 3/16 inches wide and 13/16 inches apart. The slotted pipe centerlines are 11.5 ft below the lakebed (Newhof 1992). A 6 ft thick coarse aggregate filter gravel layer covers 2 ft and 2 inches below the pipes and 3 ft and 2 inches above the pipes. Two ft of #2 NS fine aggregate overlay the coarse aggregate layer and, finally, 6 ft of lakebed sand was placed over the fine aggregate to complete the backfilling of the bed pit. A cross-sectional sketch of the filter bed is shown in Newhof (1992).

INFILTRATION AREA — 72,800 ft^2 (Prein and Newhof 1988b; Newhof 1992).

INFILTRATION RATE — (calculated at the elevation of the pipe grid) 0.13 gpm/ft^2 (Prein and Newhof 1988b) or 241 ft of collector pipe/MGD or 2.9 gpm/ft of collector pipe (Newhof 1992).

Infiltration Area — unknown.

Infiltration Rate — (design) 21 gpm/ft of wellscreen.

Pumping Rate — 4 MGD. According to Prein and Newhof (1988a), this system has a design capacity of 3 MGD with a summer maximum demand of 2.1 MGD and an average day demand of 0.5 MGD in winter.

Backflushing Rate — 4,000 gpm from three pumps, which are high service pumps rated at 2,000 gpm, 1,000 gpm and 1,000 gpm (Prein and Newhof 1988a).

Method of Construction — a clamshell crane on a barge was used to dig the trench for the main and a pit at the end of the trench for the wellscreen. Digging took place in loose material: sand, shale and gravel lakebed materials. The lakebed soil is dense, light brown, fine to medium sand with a trace of coarse sand and fine gravel (Prein and Newhof 1988a). A single grade of filter gravel was laid in the pit. Backfill around the gravel was sand passing No. 10-20 mesh screen and having an effective size of 0.036-0.040 inches.

Raw Water Turbidity — 0.15 to 0.50 NTU.

Problems — this intake began experiencing severe plugging problems during the summer of 1987. Prior to June 1987, one branch of the intake system had been closed since only half of the system was needed to provide the necessary capacity. During June 1987, the other half of the intake was opened because of problems with reduced capacity. Plugging problems continued. When the lake is rough, the intake filter bed plugs and pumping drops to 1.5 MGD. At first, backflushing worked after storms. Now after backflushing, water hardness is reduced only to 160 parts. The problem seems to be getting progressively worse.

Pumping Capacity Limitations — plugging temporarily drops the pumping rate. Corrective action involves backwashing the system with treated water from the 1 MG treated water storage reservoir at the treatment plant. During August through November 1987, a total of 102 MG of water was abstracted from the lake. A total of 3.8 MG was used as backwash water. Backwash totals show a decline from month to month: 2.2 MG, 0.84 MG, 0.60 MG, 0.16 MG. In mid-November 1987, a diver inspected the intake before and during backwashing. He observed 4-6 inches of fine sand over the coarse media that surrounds the intake screen.

For Further Information — on operational experience, contact: Mike Reinhart, Supervisor. Water Plant, Charlevoix, MI 49720. Phone: 616-547-3256.

Charlevoix, Mich. — **Sand Infiltration Bed Intake**

A new intake was constructed 30 ft from the existing 24 inch diameter intake main in 16-18 ft water depths. The new intake is in operation in the summer of 1992. The design is similar to the Ludington infiltration bed design.

Description — the 160 by 172 ft bed was excavated 5 ft and 8 inches below the existing lake bottom. Side slopes on the excavation are estimated at 1:3 (vertical:horizontal). The collector pipes consist of 16 8-inch diameter slotted PVC pipes that branch off at right angles from each side of a 24-inch diameter header pipe. These slotted pipes are spaced 10 ft apart on centers and are 81 ft long. The pipes are placed on a bed of coarse aggregate (MDOT 28B), 1 ft thick that is covered with a layer of the same aggregate, 2 ft and 8 inches thick. A layer of natural lakebottom sand, 2 ft thick is placed on top of the coarse aggregate.

Infiltration Area — (at the level of the collector pipes) 27,500 ft^2.

Infiltration Rate — 0.08 gpm/ft^2 (design).

Pumping Rate — 3 MGD (design).

Backflushing Rate — there are no provisions for backwashing the new infiltration bed. Where the 24-inch diameter header pipe joins the intake main, there is a 24-inch butterfly valve and a tee that allows the collector pipe grid to be isolated and bypassed in the event the infiltration bed becomes clogged.

Method of Construction — the same method that was used to excavate the infiltration gallery. The pit was excavated in an area of sandy, gravelly lakebed sediments, and nearby clay lakebed areas were avoided.

Engineer — John Adams, Project Manager. Macnamee, Porter and Seely, Engineers, Ann Arbor, Mich. Phone: 313-665-6000.

For Further Information — on operational experience, contact: Mike Reinhart, Supervisor. Water Plant, Charlevoix, MI 49720. Phone: 616-547-3256.

Manitowoc, Wis. — Ranney Wells

A program of groundwater exploration and aquifer testing began in 1945. This effort identified 65-70 ft of permeable sand and gravel deposits and a potential groundwater supply of up to 15 MGD. A series of three Ranney wells were installed along the Lake Michigan shoreline. Two wells were installed in 1945, one about 100 ft offshore and the other about 100 ft inland. The third well was installed in 1958.

Description — the three Ranney wells are each 13 ft in diameter and 80 ft deep, constructed of reinforced concrete caissons. Each of the three wells has a 2 MGD pump and a 4 MGD pump. The wells do not feed water to the filtration plant, but directly into the distribution system with pre-chlorination as the only treatment. Water from the wells needs no alum, settling or filtration. In 1965, a radial recharge well was constructed adjacent to Ranney well Collector B, but this well was removed from operation in 1987.

Infiltration Area — unknown.

Infiltration Rate — unknown.

Pumping Rate — 5-6 MGD/well.

Backflushing Rate — unknown.

Method of Construction — same as the Grand Haven, Mich., system.

Raw Water Turbidity — unknown.

Problems — about 1957, there were reports of reduced well capacity from Collector B, which had been installed in 1945, 100 ft inland. It was determined that wellscreen plugging or excessive encrustation had not occurred. It appeared that the problem was a change in lakebed permeability. Nearshore test drilling indicated that the thickness of the sand and gravel zone diminished greatly offshore and eventually pinched off. The problem was solved by installing a recharge well in 1965. One of the wells discontinued operations in 1990 because of some questions about water quality.

Other Intake Structures — by 1970, demand for water exceeded available groundwater supply from the Ranney wells, requiring the construction of a surface water intake system. The city constructed a surface intake, 10,000 ft offshore in 30 ft of water, with a 48-inch diameter intake pipe. The new intake was installed in 1970 and has a 20-25 MGD capacity (26 MGD peak).

For Further Information — contact: Nilaksh Kothari. Manitowoc Public Utilities. Phone: 414-683-4601.

Tilbury, Ont. — Sand Infiltration Bed Intake

The Tilbury, Ont., Thames River water treatment plant has a new infiltration bed intake buried in sand on the lakebed of Lake St. Clair. The treatment plant has an initial design capacity of 3.0 MGD. Construction began in June 1991. The design is patterned after the Ludington and Grand Haven designs of Tom Newhof. Lake St. Clair is a large, shallow lake between Lake Huron and Lake Erie. Zebra mussels were first found in North America in Lake St. Clair, in 1988.

Description — this filter bed is located in 9-10 ft water depths. The filter bed is about 8 ft deep below the lakebed. Polyethylene slotted pipe, 8 inches in diameter, was placed on coarse gravel bed and backfilled with fine gravel. An additional backfill layer is mostly sand. The lakebed is packed sand and clayey silt with little or no rock. A new low lift pumping system has been installed with two 3 MGD capacity pumps.

Infiltration Area — approximately 1 acre (200 by 200 ft).

Infiltration Rate — 0.05 gpm/ft^2 of filter area at 3 MGD.

Pumping Rate — initial plant design capacity is 3 MGD, but the bed is sized for 4.5 MGD. The bed could be increased to 12 MGD capacity.

Backflushing Rate — 3,000-4,000 gpm.

Raw Water Turbidity — maximum of 500-1,000 JTU in raw water coming through the old conventional intake. Water coming through the new filter bed intake is typically 10-25 JTU, and sometimes 50 JTU, depending upon the wind conditions.

Problems — in 1992 during ice break-up, a strong westerly wind re-suspended fine clay sediments in the water of this shallow lake and caused clogging. While frazil ice could cause clogging, that was not likely. The intake flow rate dropped from 1,500 gpm to 100-200 gpm. Coring of the clogged bed showed that clay was only in the surface sand layer and had not penetrated to the center of the filter bed. The backwash pumping rate was inadequate to re-suspend the clay on the filter bed. A large tug with a draft of 5.5 ft was brought in to blow the clay layer off the bed. The engineer is investigating a surface wash system using pressure jets and vacuum removal of the re-suspended clay, and several other options.

Pumping Capacity Limitations — new low lift system with two 3 MGD pumps.

Engineer — Jerry Chevalier. Chevalier Engineering, 5349 Outer Drive, RR 1, Windsor, Ontario N9A 6J3 Canada. Phone: 519-737-7042. Fax: 519-737-7045.

Contractor — Boris Zaitz. Zaitz Construction and Marine, Collingwood, Ont.

For Further Information — contact: G. Bouillon, Tilbury Water Treatment Plant, Stoney Point, Ontario N0R 1N0 Canada. Phone: 519-682-0330.

Caseville, Mich. — Sand Infiltration Bed Intake

This the first (to my knowledge) sand infiltration bed intake that has been constructed on a stiff clay lakebed with only a 2-4 ft thick layer of sand. The design was chosen as an alternative to a costly pipeline running a long distance to a surface intake in deep water. This intake is also unique in that the bed is surrounded by a sheetpile cofferdam, constructed at the insistence of the state health department in order to cut off the intake from groundwater. The cofferdam also provided some protection from storms during construction. The intake is protected by a harbor breakwater about 400 ft away.

Description — the intake area is 154 by 154 ft at the lakebed surface and roughly 130 by 130 ft at the pit bottom. The bed is covered with a grid of 8-inch diameter, Class 150 PVC pipe, with 3/16 inches wide by 4 inches long slots on 1 inch centers. Eighteen slotted pipes, each 65 ft long, branch off at right angles from a 16-inch diameter header pipe. The slotted pipes are 15 ft apart, on centers. The header pipe is equipped with a cross and elbow blind flange that will permit divers to bolt on a wellscreen in case the sand filter bed plugs.

Infiltration Area — 23,716 ft^2 at the lakebed surface.

Infiltration Rate — 0.32 gpm/ft^2, test; 0.035 gpm/ft^2, normal operations.

Pumping Rate — 10.5-11.0 MGD, test; 1.2 MGD, in operation.

Backflushing Rate — unknown.

Method of Construction — the pit was dug by using a backhoe on a barge to excavate the stiff clay. The contractor made straps, anchored by concrete, to hold the pipe on pedestals. The slotted pipe grid was laid on a bed of coarse No. 17A filter gravel and backfilled with the same gravel to a total depth of 4-5 ft. Over the coarse gravel was placed a 2-ft thick layer of fine gravel (2 NS modified gradation). The fine gravel was then covered with a layer of clean beach and lakebed sand that had been excavated from the site.

Raw Water Turbidity — an average of 0.3 NTU raw water turbidity through the new filter bed intake. The turbidity is less than 1 NTU 99% of the time and only peaks at that high of a level for half an hour or less.

Pumping Capacity Limitations — 1.2 MGD rated capacity of the existing water treatment system.

Other Intake Structures — none. The previous water supply had been obtained from wells.

Engineer — Harold Baar. Wolverine Engineering and Surveyors, 312 North Street, Mason, MI 48854. Phone: 517-676-9200. Fax: 517-676-9396.

Contractor — Dean King. King Construction, Saugatuck, Mich.

For Further Information — on operational experience, contact: Robert H. Peter, Superintendent. Public Utilities, 6767 Main Street, Caseville, MI 48725. Phone: 517-856-4407.

Commentary

From Marine Contractors

- For economy, design infiltration bed pits for excavation by a hydraulic dredge.

- Long, trench-type, infiltration gallery intakes are also feasible, using a clamshell crane on a barge, digging and placing pipe, and backfilling as the job progresses.

- If PVC pipe is used for collector pipes, anchor the pipe immediately after laying it, using screw anchors or concrete anchors to prevent loss or damage from wave action.

- Be realistic on pit elevation tolerances. Accept a 1-2 ft variance in elevation due to detritus.

- Buried boulders are not a serious problem.

- A large trench-type infiltration gallery intake, 11 ft wide, 12-17 ft deep and 8-16 mi long would be an unusual Great Lakes marine construction job but possible with current equipment and expertise. Contractors have experience with laying 4-5 mi or more of pipeline and burying it in the lakebed.

- A 12-acre infiltration bed would be an unusually large excavation pit but can be constructed.

FROM ENGINEERS

- European experience indicates that zebra mussel veligers do not pass through high rate sand filter beds in water treatment plants where the filters have 2-3 ft of sand.

- Plan to scarify the filter bed surface and have a blind flange connection for divers to bolt on an emergency surface intake, in case of plugging.

- If concerned about ice piling over the intake and damaging the filter bed, try to locate the intake where ice ridges do not form and scour the lakebed. Scour tracks formed by moving "ice islands" are a possibility in the Great Lakes.

- Zebra mussels have been found in Europe at water depths of 30 m (100 ft). Cleveland, Ohio, has had zebra mussel infestation at its Lake Erie water intake in 50 ft of water.

- The largest infiltration bed intake in the Great Lakes for which a preliminary design has been prepared (as of 1991): A 20-acre bed with a 85 MGD capacity and 0.13 gpm/ft^2 infiltration rate. For details, contact: Tom Newhof. Prein and Newhof, 3355 Evergreen Drive, N.E., Grand Rapids, MI 49505. Phone: 616-364-8491. Fax: 616-364-6955.

- Where fine sand is dominant on the lakebed, a maximum infiltration rate can be on the order of 0.2 gpm/ft^2 of filter area. (No one has yet related infiltration intake performance to the raw water turbidity history of these intakes).

- The infiltration galleries at Charlevoix and Grand Haven, which have had more frequent plugging problems, have infiltration rates more than 10 times the 0.12 gpm/ft^2 rate of the infiltration bed intake at Ludington, which has had few plugging problems. (Infiltration rate is not the only difference between the intakes).

- Large infiltration beds should be oversized and designed in multiple sections such that one section at a time can be backflushed with enough water capacity to get adequate flushing rates.

- Larger infiltration rates (larger than 0.12 gpm/ft^2) could be feasible in a sand filter intake by using a coarser grade of sand to cover the infiltration bed than is found on the adjacent lakebed.

Summary Examples

Location	Type	Size (1,000 ft^2)	Present Capacity (MGD)	Lakebed Infiltration (gpm/ft^2)
Intakes on the Bed of the Great Lakes				
Ludington, Mich.	sand/gravel	44.0	6.0	0.120
Grand Haven, Mich.	sand/gravel	72.8	14.0	0.130
Tilbury, Ont.	sand/gravel	40.0	3.0	0.050
Caseville, Mich.	sand/gravel	23.7	1.2	0.035
Charlevoix, Mich.	sand/gravel	27.5	3.0	0.080
Treatment Plant Filters (for comparison)				
Rapid sand filters	multi media	—	—	2.000 - 8.000
Slow sand filters	sand/gravel	—	—	0.040 - 0.080

References

Prein and Newhof. 1988a. *Preliminary design, Lake Michigan filtration plant and transmission main for the City of Grand Rapids, Michigan.* Grand Rapids, Mich.: Prein and Newhof.

Prein and Newhof. 1988b. *Preliminary design, Lake Michigan water intake and pumping station for Northwest Ottawa County.* Grand Rapids, Mich.: Prein and Newhof.

Newhof, Thomas. 1992. Design and construction of an infiltration bed intake in Lake Michigan. Paper presented at Second International Zebra Mussel Conference, 21 February, at Toronto, Ontario, Canada.

Acknowledgments

The information in these notes was provided by the operators and engineers mentioned in the text. Tom Newhof and James French reviewed several drafts and provided much written information. Additional information was provided by Philip and Stanley Andrie, Andrie Inc. of Muskegon, Mich.; Karl Luedtke, Luedtke Engineering Company of Frankfort, Mich.; Michael Auger, Ontario Ministry of the Environment;

Edward Fedak, Brown and Root Company of Houston, Texas; and Richard Zirbel, the Gillen Company of Milwaukee, Wis. Thanks to these people for their assistance. Thanks also to Kendra Nelson, Science Editor at the University of Wisconsin Sea Grant Institute, for editing and reorganizing this information into a readable format.

This work was funded by the University of Wisconsin Sea Grant Institute under grants from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and from the State of Wisconsin. Federal grants NA 16RG0273 and NA90AA-D-SG469; projects A/AS-2 and A/AS-28.