Engineering Notes
University of Wisconsin Sea Grant Advisory Services

#2 Infiltration Intakes for Very Large Water Supplies: Feasible?

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DRAFTED FEBRUARY 1992, REVISED JUNE 1992 — These notes provide an overview of how engineering judgments about using infiltration intakes for very large water supply systems have developed over the past two decades. 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.

Reports of Infiltration Intakes for Very Large Water Supplies

The literature on infiltration intakes for large water supply systems appears to consist of four sources published in the 1970s. In 1973, the University of California published a feasibility study of using sand filter intakes to screen aquatic organisms while withdrawing water during water diversion projects (De Vries 1973). In 1976, the U.S. Environmental Protection Agency (EPA) published two reports. The first was a "development document for best technology" on cooling water intakes for minimizing adverse environmental impact (U.S. EPA 1976). The second was a state-of-the-art report on intake technologies (Ray et al. 1976). In 1978, Argonne National Laboratory published the proceedings of a Larval Exclusion Systems Workshop held the same year (Sharma and Palmer 1978).

The 1978 Larval Exclusion Systems Workshop was co-sponsored by the Argonne National Laboratory, the Electric Power Research Institute (EPRI, which provided most of the funding) and the Southern California Edison Company. Workshop participants addressed the problem of entrainment of larval, juvenile and adult fish in power plant intakes.

The evaluations of technical and economic feasibility, then, were made from the perspective of protecting aquatic organisms from harm in water supply systems. Now, however, the problem with zebra mussels is just the reverse: how to protect the water supply systems from harm by aquatic organisms.

The concerns raised nearly 20 years ago are just as valid today, but economic considerations and risks are very different. Therefore, careful investigation of specific sites is needed to assess engineering judgments that were made 20 years ago about large sand filter intakes.

The U.S. EPA (1976) report did not mention infiltration intakes in a discussion of control strategies to limit impacts on aquatic organisms. However, the report did consider infiltration as an intake technique and referred to filter beds and radial wells as "non-conventional intakes." A diagram of five types of intakes includes a "deep intake (infiltration)," consisting of a buried field of horizontal pipes, which is similar in concept to the Ludington, Mich., infiltration bed intake.

Further, the U.S. EPA (1976) report stated that filter type intakes: (1) draw water through sand and stone filter media, (2) had been developed on an experimental basis and installed at relatively small-scale power plants, and (3) "can be effective in eliminating damage even to small fish. Planktonic organisms can also be protected to some extent." The U.S. EPA (1976) report concluded that while filter intakes appear ideal from an environmental point of view, there are many disadvantages. The foremost is clogging. Turbid waters rule out the use of filter intakes, and even in relatively clear water, backwashing is needed, which can temporarily raise downstream turbidity in excess of permit regulations.

Ray et al. (1976) reviewed state-of-the-art intake technologies, with particular reference to the problem of fish entrainment. In the review, radial well intakes were mentioned as being reliable in service for more than 35 years. Ray et al. (1976) considered radial wells feasible for small-capacity intakes, given permeable aquifer materials and clean water, because operating costs were often lower and constructions costs were competitive with the costs of conventional intakes. However, Ray et al. considered radial wells unsuitable for large water supply systems, requiring several wells, because construction costs could exceed the costs of conventional intakes. The authors did not cite cost information to support this opinion.

"Other possible intakes capable of larval fish protection include low-velocity, filtration-type structures (infiltration beds and slotted or perforated conduit)." Ray et al. (1976) also stated that passive screening through a permeable substrate with a low intake velocity of less than 15.0 cm/sec (29.7 ft/min or 0.5 ft/sec) would allow larval fish to swim away. "In the design of new power plants, particularly lower volume intakes of less than 8.5 cubic meters per second (18003 gpm or 26 MGD), physical screens are available that offer substantial reductions in fish losses over conventional vertical screens." Such physical screens include infiltration beds and dikes requiring clean substrate, low velocity and backflushing provisions (perforated pipe and circular well screens). Ray et al. included infiltration beds in a list of mechanical screens offering the greatest protection for the smallest size fish.

Sharma and Palmer (1978) summarized the proceedings of a workshop held to determine the engineering feasibility and biological effectiveness of various concepts for screening larval fish at power plant cooling water intakes. The following excerpts were based on papers presented at the workshop and discussions among participants as well as follow-up comments submitted in writing thereafter:

> "To date no large-scale filter system has been developed and proved reliable in operation. The cost of such a system will be substantially higher than for a comparable conventional screen facility."

Not surprisingly, filter beds were not included in cost tables and curves. The basic conclusion on intake design:

> "No generally viable alternative to the conventional traveling water screen is available at the present time."

Sharma and Palmer (1978) recommendations included the following:

- Given present knowledge, no sound arguments on an ecological basis can be forwarded to screen fish larval forms at all power plants. If economics are favorable, or if cost:benefit analyses dictate, technological options should be investigated.
- Geologic and hydrologic factors permitting, the subsurface collector concept is the most effective for larval exclusion.
- Biological effectiveness of porous dikes is unknown at this time. Field demonstrations are essential prior to any long-term commitments to develop this technology.
- Further research and development of artificial filter beds is not warranted because of operational and maintenance problems.

FILTER INTAKE BUILT IN THE SUSQUEHANNA RIVER, PENNSYLVANIA

The U.S. EPA (1976) report shows a drawing of the original stone filter built for a large Northeast power plant (No. 4222) in 1971:

> FILTER BED — in a 13- to 14-ft deep excavated pit, 33 ft wide by more than 160 ft long at the base with 1:1 side slopes. Three, 48-inch diameter perforated pipes, each 160-ft long, were placed on a 2.25-ft thick layer of sand and backfilled with a 6.75- to 7.75-ft thick layer of 4.0-inch size stone, overlaid with a 4.00-ft thick layer of stone, 1.5-inch maximum size.
>
> FLOW CAPACITY — 15,700 gpm (22.6 MGD).
>
> INFILTRATION RATE (per filter bed area of 35 ft by 170 ft) — 2.64 gpm/ft^2 of filter area.

The intent was to expand the pumping rate to 33,000 gpm (47.5 MGD) and the infiltration rate to 5.55 gpm/ft^2 of filter area. The intake was modified several times to improve performance but had a tendency to clog and was not considered reliable.

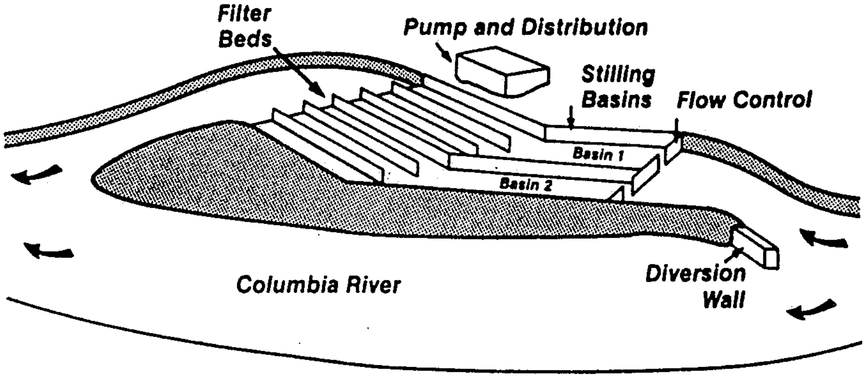
This appears to be the same intake mentioned by Richards (1978): An artificial filter designed for 33,000 gpm flow was placed on the west branch of the Susquehanna River to draw make-up water for the Montour Steam Electric Station of the Pennsylvania Power and Light Company. Several field modifications were made in the original design. However, clogging at a rate considered unacceptable could not be prevented, and the intake was subsequently abandoned.

Other large intakes considered in De Vries (1973), U.S. EPA (1976), Ray et al. (1976), and Sharma and Palmer (1978) were all designed but never built. The design features provide some clues to the decisions not to build.

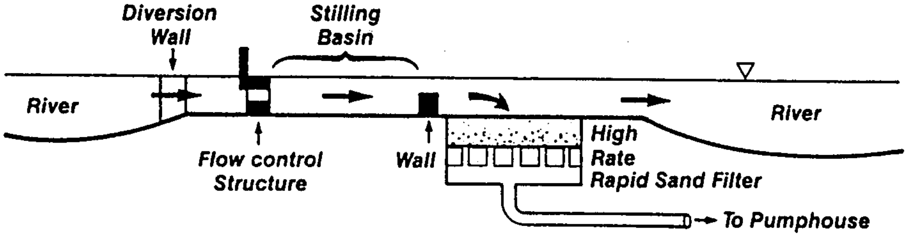
FILTER INTAKE DESIGN CONSIDERED FOR THE COLUMBIA RIVER, WASHINGTON

Richards (1978) mentioned a number of intake filter designs considered for the make-up water system at Nuclear Project No. 2 of the Washington Public Power Supply System (WPPSS) on the Columbia River. The maximum flow rate needed was 25,000 gpm (36 MGD).

Concepts studied included an infiltration gallery in the river bank, a filter in the river bed and a filter in the bed of an artificial off-stream channel. The latter concept was considered most seriously, and a design was prepared in 1972. Some design details are available in U.S. EPA (1976) and Richards (1978).



Above: perspective view of conceptual design for Columbia River sand filter intake — below: elevation view.



The intake was designed for 25,000 gpm (36 MGD) flow with five cells in operation and two cells backwashing at any time. Air and water backwash were provided. The drawing in U.S. EPA (1976) shows a filter bed of seven cells, totaling 133 ft wide by 30 ft long. This agrees with Richards (1978) description of each filter bed being 19 ft by 30 ft in size. With five cells in use, the filter bed area in use would be 95 ft by 30 ft, or 2,850 ft^2. Infiltration rate would be 25,000 gpm/2,850 ft^2, or 8.8 gpm/ft^2 of filter bed area. In each cell, three, 18-inch diameter perforated pipes were to be placed on 6-ft centers on a 2-ft thick graded stone base and covered with a 4-ft thick layer of graded stone.

Richards (1978) added more details. The filter bed design included a wall to divert river water into a channel leading to a flow control structure. The water then flowed to two stilling basins, across the filter bed and into a discharge channel leading to the river. The stilling basins were designed for worst case river turbidity, allowing for sedimentation before the water reached the filter beds. One of the stilling basins could be closed off and dredged while the other was in operation. There was no storage capacity at the power plant site except in the cooling tower basins, which were about 3 mi from the river.

WPPSS engineers concluded that the filter concept could be developed successfully, but major research would be required for a final design. The filter concept was set aside in favor of a modified perforated-pipe intake design.

Richards (1978) concluded from his analysis that the WPPSS filter concept would have been a very complex system as designed and could have become even more complex if proposed model and field tests had dictated design changes:

> "We can see from this discussion [of the design] how the simple filter concept ... can grow into a relatively monstrous project from an engineering standpoint ... if the intake is to have the high degree of reliability required of a power plant installation, the engineering of an acceptable artificial filter system will continue to be difficult and costly."

Richards (1978) conclusions can be understood by considering the purpose of the intake (to prevent harm to aquatic organisms) and by examining the list of design requirements, discussion of the design details and list of research needs.

Design Requirements

RELIABILITY — The facility must be capable of functioning at full output for the life of the plant.

OPERABILITY — Operation must be possible with reasonable operator attention.

MAINTAINABILITY — There must be duplicate filters to permit backwash, and there must be accessibility for maintaining the filter beds (periodic replacement or rebuilding). Also implied is the necessity for providing a facility that does not require excessive maintenance.

ENVIRONMENTAL ACCEPTABILITY — The facility must be environmentally acceptable. For example, the turbidity during backwash could have to meet certain stringent standards.

REASONABLE COST — This could be a sensitive subject where the environment is involved, but it is nonetheless an important factor that ultimately will determine whether the filter system is to be used.

Design Problems and Research Needs

RIVER DIVERSION WALL — It needs to divert a sufficient quantity of water into the channel for proper performance of the intake and backwash systems. Model tests would be required.

FLOW CONTROL STRUCTURE — This limits inflow to proper rates for intake and backwash and allows diversion of flow to either or both stilling basins. No special design problems were mentioned.

STILLING BASIN — The Columbia River is "relatively clean" but "even modest seasonal sediment could be a major factor ruling out the use of such an artificial filter." However, in the design, the length of the stilling basins and the flow-through velocities were determined by the settling rate of sediment to be removed under worst river conditions. Dikes protect basins from flooding during high river-level periods.

FILTER BEDS — Fine- and coarse-textured filters were studied in detail, and a design was developed as far as possible. The implication is that the filters need final model and prototype field tests. Water and air piping is complex.

DISTRIBUTION STRUCTURE — This would be required to isolate the seven filter sections for operation, backwash and maintenance.

BACKWASH — The major problem is maintaining enough water flow across the filter to carry away backwashed material and not exceed the regulatory requirement limiting turbidity increase to 5 JTU above the natural river turbidity at any river stage. The normal river turbidity is about 6 JTU. Richards (1978) says the backwash is achieved by air flow, but the schematic shows both air and water backwash.

AUXILIARY FACILITIES — A road system would be needed to permit access of trucks, cranes, dredges and other maintenance equipment. These facilities would add considerably to the cost of the filter intake facility.

RETURN CHANNEL — There were no comments on any problems.

Richards (1978) called for the following research, per the WPPSS project engineers, needed to finalize design details of a filter system like that proposed for the Columbia River power plant, including "a major model and field testing program" possibly costing several hundreds of thousands of dollars:

- An on-site laboratory test of one or more short sections of the filter bed to develop a suitable gradation of filter material, to test the rate of clogging and to perfect the backwash system.
- An extended field test of a prototype filter section in the river, located such that representative characteristics would duplicate those of the final installation." Run the test for all river stages.
- A reduced-scale laboratory model test of the entire filter complex and of the adjoining Columbia River. Determine optimum angle and location of the diversion wall and approach channel; refine detail of the gate structure. Use results of extensive field work to determine river's physical and flow characteristics for accurate modeling.

[Author Comments: In Richards (1978), the list of design requirements, discussion of the proposed system and the list of research needs do not seem to justify describing the Columbia River infiltration bed as a "relatively monstrous project," requiring engineering that would be "difficult and costly." The statement is probably justifiable in comparison to the engineering of an intake crib, but relative to other aspects of power plant design, the engineering seems to be straightforward.]

FILTER INTAKE DESIGN CONSIDERED FOR PUGET SOUND, WASHINGTON

The U.S. EPA (1976) report and Richards (1978) mentioned a preliminary filter design that was developed for the entire circulating water flow to serve a major power plant in the Northwest. The intake design had 1,500 cfs (969 MGD) flow and consisted of precast concrete filter modules in seven separate filter sections. Each section could be isolated for maintenance. The entire filter in plan view was 450 ft by 260 ft. This description fits a design evaluation reported by Stober et al. (1974).

Stober et al. (1974) described the pilot study for a large capacity sand filter for a thermal power plant cooling water intake on Puget Sound. A prototype filter was constructed on a barge and operated for several months in Similk Bay, Wash. A filtration rate of 6 gpm/ft^2 was maintained on a filter consisting of four different media combinations in the first year (1971):

- 24-inch thick bed of sand (0.45-0.55 mm) over four gravel grades.
- 20-inch thick bed of anthracite (0.6-0.8 mm) over 4 inch of 1 mm sand over four gravel grades.
- 12-inch thick bed of anthracite (3/32-3/16 inch) over 4 inch of 2-mm sand over four gravel grades.
- 12-inch thick bed of anthracite (5/16 by 9/16 inch) over two gravel grades.

A 12-inch thick bed of anthracite (3/16 by 5/16 inch) over four gravel grades was selected and tested in the second year. The use of fine media (0.6-0.8 mm) would result in filter runs too short to be acceptable from an operating standpoint. The optimum size for the anthracite filtration media was 3/32-5/16 inch. The proportion of each type of filtration media and depths could be optimized. Anthracite was selected to allow for greater particle penetration and to minimize rapid surface cake formation. Coarse filter media allows a higher rate of filtration and longer runs but also requires a higher velocity of backwash water for bed expansion and cleaning. This was the limiting parameter.

At 12 gpm/ft^2, the model filter was not adequately backwashed. Backwash velocities needed to be increased by at least a factor of 2.8 to properly expand the filter media.

It was not found practical to remove plankton because of unrealistically short run times. Silt had the greatest short-term effect in reducing filter performance, but marine fouling was expected to cause the most serious long-term operational difficulty. A filamentous alga and a diatom colonized the anthracite surface 16 days after operation started. Barnacles were first observed on the anthracite and large gravel 47 days after filtration was started.

The most effective anti-fouling techniques tested were daily chlorination, backwashing with heated sea water and anoxia. Model tests over one annual cycle were recommended to provide operating experience prior to final design.

An engineering feasibility study, based on the model results reported by Stober et al. (1974) indicated the Puget Sound sand filter intake was economically feasible. Computations of filter bed expansion and backwash rate yielded an intermediate grade (1/8-1/4 inch) of anthracite for the filter design, based on filtering sea water at a temperature of 10°C (50°F); a salinity of 25 g/l; a density of 19.198 (units unspecified); and a raw water turbidity of 5 JTU in spring, 8 JTU in summer.

Design Features

DESIGN OUTPUT — 1,500 cfs (675,000 gpm, 969 MGD)

REQUIRED ACTIVE FILTER AREA — 90,000 ft^2 (2.1 acre)

TOTAL FILTER AREA — 452 ft by 260 ft (117,520 ft^2, 2.7 acre)

FILTER RATE (based on use of heated effluent for backwash) —

normal, seven units in service	7.50 gpm/ft^2
one unit on backwash	8.75 gpm/ft^2
plus one unit out of service	10.50 gpm/ft^2

BACKWASH RATE — 17.5 gpm/ft^2

DURATION OF BACKWASH — 10-20 min

RATE OF FLOW DURING BACKWASH OF A FILTER SECTION — 225,000 gpm

TIDAL FLOW DURING BACKWASH — 1.47 ft/sec

DURATION OF FILTER RUNS —

maximum, period of low turbidity	480 hr
normal	168 hr
minimum, period of high turbidity	24 hr

Backwash was to be timed to coincide with the maximum velocity of tidal flow across the filter to obtain the maximum removal and dispersion of solids released from the filter. Most of the filter burden would thus be released in the first 2 min of backwash. Resultant high turbidity was expected to be rapidly reduced by mixing and settling to near-ambient levels.

The design was for a filter bed made up of seven filter sections. Each section would contain 50 filter units. Each unit would be 5 ft wide by 60 ft long, containing a 15-inch thick layer of 1/8- to 1/4-inch crushed and graded anthracite, supported on graded gravel. The number of grades and grading of the gravel would be determined by a prototype test to optimize the design. The top of the filter units was to be set 5 ft below the extreme low water level.

The design included provisions for crane access to remove deadheads and other debris. A traveling gate would be used to close off a filter section for dewatering and maintenance.

An order of magnitude estimate of the cost of construction, operation and maintenance was based on the conceptual design without design detail and performance optimization. Costs, in 1972 dollars, did not include interest during construction. Costs were estimated to be:

■ construction of the filter and control system	$8,578,000
■ annual debt service (based on amortization in 30 years with interest at 6%)	$625,000
■ annual maintenance and operation	$188,000

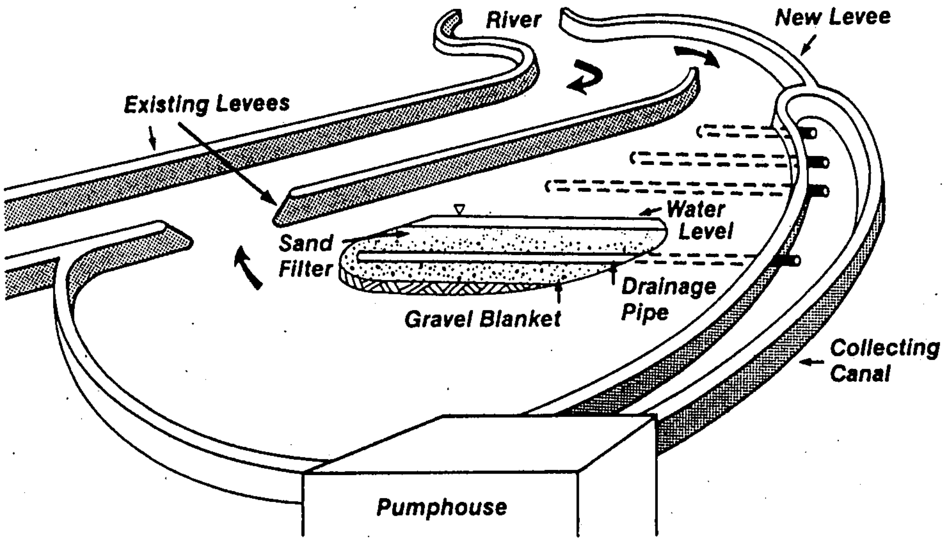
Total annual cost would be $813,000 or approximately 0.12 mill/kWh over a 30-yr life while serving a 1,100-MW nuclear plant with a 30-year average capacity factor of 0.70.

Unlike Richards (1978), Stober (1978) draws some hopeful conclusions about the potential value of large sand filter intakes like the one proposed for the Puget Sound power plant. After mentioning that the concept of using a filter intake system to prevent entrainment of aquatic organisms had been evaluated more frequently in river environments, Stober (1978) concluded:

> "Filter intake systems could be a very attractive and effective technology for the exclusion of pelagic eggs and larval fishes. However, the present technology is not sufficiently developed to allow reliable design and operation. Extensive biological and engineering research and development programs designed to meet site-specific criteria are needed if this technology is to be feasible. Application of alternate technologies may be more cost-effective in the short term."

FILTER INTAKE CONSIDERED FOR THE SACRAMENTO RIVER, CALIFORNIA

De Vries (1973) did a feasibility study for constructing a large-scale (3,230-1,2920 MGD) rapid sand filter adjacent to the Sacramento River to screen diverted water, preventing fish, fish eggs and larvae from being drawn into the intakes. The filter was designed to exclude the aquatic organisms by having openings smaller than 0.5 mm, but silt particles smaller than 0.05 mm (50 microns) would pass through the filter to minimize clogging.



De Vries (1973) used then-current theories of filtration to calculate that a 12- to 18-inch thick layer of uniform sand 1-2 mm in size should be used for the filter matrix. The flow rate into the filter bed would have to be about 4.9 gpm/ft^2. For a total flow of 5,000 cfs (3,230 MGD), a minimum filter area of about 10.5 acre would be needed. For a total flow of 20,000 cfs (12,920 MGD), an area of about 42.0 acre would be needed.

Horizontal velocities of flow over the filter bed would have to be less than 4.5 ft/sec to avoid movement of the filter material. Further information was needed on the minimum horizontal velocities required for the filter to be self-cleaning. Measurements of light transmission in the river indicated that water depths of 8 ft or more would be needed to reduce sunlight to levels sufficient to discourage algal growth. De Vries (1973) included calculations for a gravel blanket under the filter and for collector pipes within the gravel blanket.

Commentary

Following are excerpts from Sharma and Palmer (1978), which synthesize the conclusions of a workshop held to determine the engineering feasibility and biological effectiveness of various concepts for screening larval fish at power plant cooling water intakes. These excerpts represent papers presented at the workshop and discussions among participants as well as follow-up comments submitted in writing thereafter:

RADIAL WELL (RANNEY) COLLECTORS

"A reliable concept in design and operation ... Relatively maintenance free ... Geological and hydrological considerations are critical in siting ... Substrate must have adequate permeability ... This system has been used for small water demands comparable to closed-cycle make-up water requirements ... The feasibility of meeting water demands for a once-through cooling system has not been determined ... Geologic and hydrologic factors permitting, should be preferable to all other systems for larval screening."

ARTIFICIAL FILTER BEDS

"Artificial filter beds have been used extensively for the filtration of municipal water supplies for a considerable time. Their design is proven, and operation is reliable. However, the problems associated with this concept — clogging and biofouling due to operation, silting and decreased water quality due to maintenance backwash — make it unattractive for use at power plant intakes ... Although this concept appears to have high screening effectiveness and all fish eggs and larvae can be expected to be filtered, it was the consensus of the participants that the operational problems noted in the previous paragraph discourage further research and development of this concept for use at power plant intakes."

POROUS DIKES

"The design and operation of such dikes appear reliable. Whether or not maintenance is a problem depends on the extent of biofouling and clogging by debris, which is determined by the size of the pores in the dike ... Backflushing is not feasible at a dike installation ... Biological effectiveness of screening of fish larvae is not established ... Porous dikes are suitable for closed-cycle make-up water as well as for once-through cooling. Presence of currents past the dike is an important positive factor."

Author Comments

It is curious that all three types of infiltration intakes are described as "reliable" but only the porous dike was considered suitable for both make-up water and once-through cooling water in power plants. The link between observations and conclusions is not clear in Sharma and Palmer (1978). Following is my analysis of the workshop participants' negative views of large subsurface collector systems and large infiltration beds:

- Negative experience with the high-rate, gravel infiltration bed at the Susquehanna River plant of the Montour Steam Electric Station in the early 1970s cast a dark cloud over the feasibility of using such beds for large power plant water supplies. However, this was the only experience the power industry had with a large capacity infiltration bed at the time the workshop was held.

- It is clear from the workshop proceedings that infiltration intake systems considered reliable for municipal water supplies were not considered reliable for power plants. Municipal water systems have storage capacity and can handle relatively short interruptions due to temporary intake clogging. However, power plants do not have water storage capacity to handle such interruptions. The possibilities of adding such storage capacity were not explored at the workshop.

- Workshop participants considered aquatic organisms as passive victims of entrainment, not as causes of power plant impairment. They did not weigh the risks of power plant shutdown due to clogging by aquatic organisms (like zebra mussels) against the risks of shutdown due to an infiltration intake clogging by suspended material. If they had made such a comparison, they would have considered the qualitative differences between the two modes of clogging: the relatively slow process of shutdown and entering the system to remove aquatic organisms vs. the relatively fast process of backflushing or scraping the infiltration bed surface.

- The only infiltration beds considered were designs patterned after rapid sand filter beds used in water treatment plants. Workshop participants did not consider designs similar to the Ludington, Mich., infiltration bed.

- Workshop participants did not consider the possibility of large water supplies furnished by many subsurface collectors.

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