Design of the Deer Island Treatment Plant

Confined space, meeting effluent quality goals, maintaining existing plant operations and providing a cost-effective facility while keeping to a strict schedule can complicate design.

JOHN A. LAGER, DAVID P. BOVA, ROBERT M. OTOSKI & GERARD L. GALLINARO

The Massachusetts Water Resources Authority's (MWRA) new Deer Island wastewater treatment facilities are designed to meet secondary treatment standards for deep water discharge into Massachusetts Bay. With design flow requirements of 480 million gallons per day (mgd) average and 1,270 mgd peak, the plant will be one of the largest in the United States. The facilities fully utilize the available land on Deer Island owned by the MWRA, which is centrally located in Boston Harbor (see Figure 1).

The need for the plant was highlighted in 1986, pursuant to the findings of the U.S. District Court upon litigation brought by the U.S. Environmental Protection Agency (USEPA) against the Metropolitan District Commission (predecessor agency to the MWRA), combined with a separate action by the Conservation Law Foundation, for violations of the Clean Water Act. The conceptual design commenced in August 1988 and as of May 1994 the final design is 93 percent complete, and the construction is 48 percent complete on awarded construction contracts totaling in excess of $2 billion. The facilities include 16 digesters, 48 primary clarifiers, 12 oxygen reactors, 72 secondary clarifiers, control facilities, power plant, pump stations, gas handling facilities, and many more associated structures (see Figure 2). The startup of portions of the new plant (including the renovation of the North System pump station, the North System headworks, primary batteries A and B, primary sludge thickening and digestion, interim disinfection and appurtenance works) is scheduled for November 1994.

Flow Conveyance

Wastewater, including a substantial combined sewer component, from two system areas (North and South) is conveyed to Deer Island through three major tunnels (97 percent) and one surface interceptor (3 percent). On Deer Island all flow is pumped an average lift of 80 to 120 feet (static) to provide gravity flow through the treatment plant and outfall system and to be capable of discharging against a 100-year storm condition. The peak design flow is based on the theoretical hydraulic capacity of the headworks and feeder conveyance system and it exceeds the peak recorded flows at the combined existing plants by a wide margin

FIGURE 1. Construction on Deer Island, January 1993, looking toward downtown Boston on the left. (Photo courtesy of Kevin Kirwin, RVA.)

(greater than 20 percent). This margin is being reduced continuously by "fast-track" projects designed to remove bottlenecks and strengthen the reliability of the present system (see Figure 3). These fast-track projects were designed and constructed from 1986 to 1992 to repair or replace critical pumping and treatment components of the existing facilities to ensure their survivability and improve their performance until the new program could be implemented. Figure 3 illustrates a progressive increase in peak flow captured from an average of 400 mgd in 1988 to 700 mgd in 1992. The wet weather flows that are not treated discharge directly to the harbor as combined sewer overflows (CSOs) and, as a result, are a major contributor to harbor pollution (see "Combined Sewer Overflow Abatement in Boston Harbor," which begins on page 83 for a more detailed discussion on CSOs).

North System. The North System accounts for approximately two-thirds of the total flow and virtually all of the combined sewer flow. The North System pumping stations (North Main serving the Main Drainage and North Metro Relief tunnels and Winthrop Terminal serving the North Metro Interceptor) are being electrified and upgraded in two stages. The first stage meets the immediate needs of the fast-track upgrade to maximize treatment through the existing Deer Island plant. The second provides the higher lift and increased surge protection required for the replacement plant.

The first, "thumb-in-the-dike" improvements have been completed and work on the long-term pump replacements has started. When completed, the North Main Station will have ten pumping units, each rated for 78,400 gallons per minute (gpm) and powered by 3,500-horsepower (hp) motors with variable frequency drives. Similarly, the Winthrop Terminal will have six pumps, each rated at 22,200 gpm and powered by 600-hp motors with variable frequency drives. The variable frequency drives are essential due to the small "wet well" capacities and the need to match inflows to maintain unrestricted flow conditions at each of the headworks. The design capacities of the upgraded stations will be 790 mgd and 120 mgd, respectively.

Replacing the existing diesel and diesel/ electric drives with electric pump drives has introduced new requirements for power reliability, redundancy, water hammer and surge controls. Under the existing system, failures are incremental, as a consequence of multiple independent drives, and surges are relatively inconsequential. For the proposed facilities, transfer from primary to backup power will take from 10 to 30 minutes. Thus, surge containment and control are provided both between the pumps and the plant and between the pumps and the headworks.

To maintain existing plant operations, North System pump replacements are scheduled on a carefully structured program to provide for continuous discharge to the existing plant until the new plant is tested and on line. At the critical plant changeover point in late 1994, 50 percent of the pumping capacity in each pump station will be dedicated to the existing plant and 50 percent to the new plant. The split was facilitated by the foresight of the original station designers who linked all odd and all even numbered pumps to separate forcemains. This level of redundancy is carried forward into the new design. Once the new plant is accepted for operation, the existing plant will be demolished to clear space for construction of the remaining two secondary treatment batteries.

South System. The South System flows are presently treated at the Nut Island primary treatment plant and discharged to Quincy Bay. Under the Boston Harbor Project, this plant will be replaced by a new, fully enclosed headworks for grit and screenings removal. From the headworks the flow is dropped through a shaft to the new 4.5-mile inter-island tunnel to Deer Island. At Deer Island, a new South System pump station (SSPS) lifts the flow for primary and secondary treatment and outfall discharge. Startup is scheduled for mid-1995, coinciding with the startup of new primary batteries C and D and the outfall tunnel.

The SSPS will be equipped with eight raw sewage pumps, each with a capacity of 46,300 gpm and powered by 1,250-hp motors equipped with variable frequency drives. Six operating units will provide a firm pumping capacity of 400 mgd. Since the wastewater will have been pre-screened and de-gritted at Nut Island, the flows will be combined with the North System flows in a mixing/distribution chamber immediately downstream of the North System grit facility. Provisions are incorporated in the design to maintain separation between North System and South System flows should this be desirable. Separate treatment of South System flows could be justified by treatability tests demonstrating cost benefits, by sludge characteristics (enhanced marketability) and to control/limit process upsets through segregation. To effect this flexibility the SSPS can discharge either to a central mixing chamber or directly to an isolated primary clarifier battery D.

Accommodating Storm Flows. Consolidating wastewater treatment into a single facility offers more than economic advantages. The MWRA's collection system is plagued by excess wet weather and high groundwater flows. The single plant concept allows treatment capacity to be allocated (north or south or by headworks) to optimize benefits whether they be water quality, flood protection or equipment oriented. This prioritization is accomplished by implementing pump allocation scenarios, since each of the 24 influent pumps on Deer Island can be operated to draw from only one tunnel or interceptor. Also, the differentiation between the sources of excess flows is significant in that high groundwater flows are seasonally biased (highest in the spring); whereas storm related flows are comparatively evenly distributed throughout the year. The result is increased capacity available for storm flow intercept and treatment in the summer and fall months when base flows are at their seasonal lows.

Similar to the provisions made for isolating South System flows, primary battery D is also designed to facilitate the separate treatment of CSOs (new separate CSO flow conveyance to Deer Island would be required) or to provide split flow treatment (secondaries are bypassed for that increment of peak flow that exceeds the available two-, three- or four-battery secondary process flow limit). Pilot studies are underway to assess the advantages and disadvantages of enhancing the treatment of less than secondary treated flows by chemical addition. These stud-

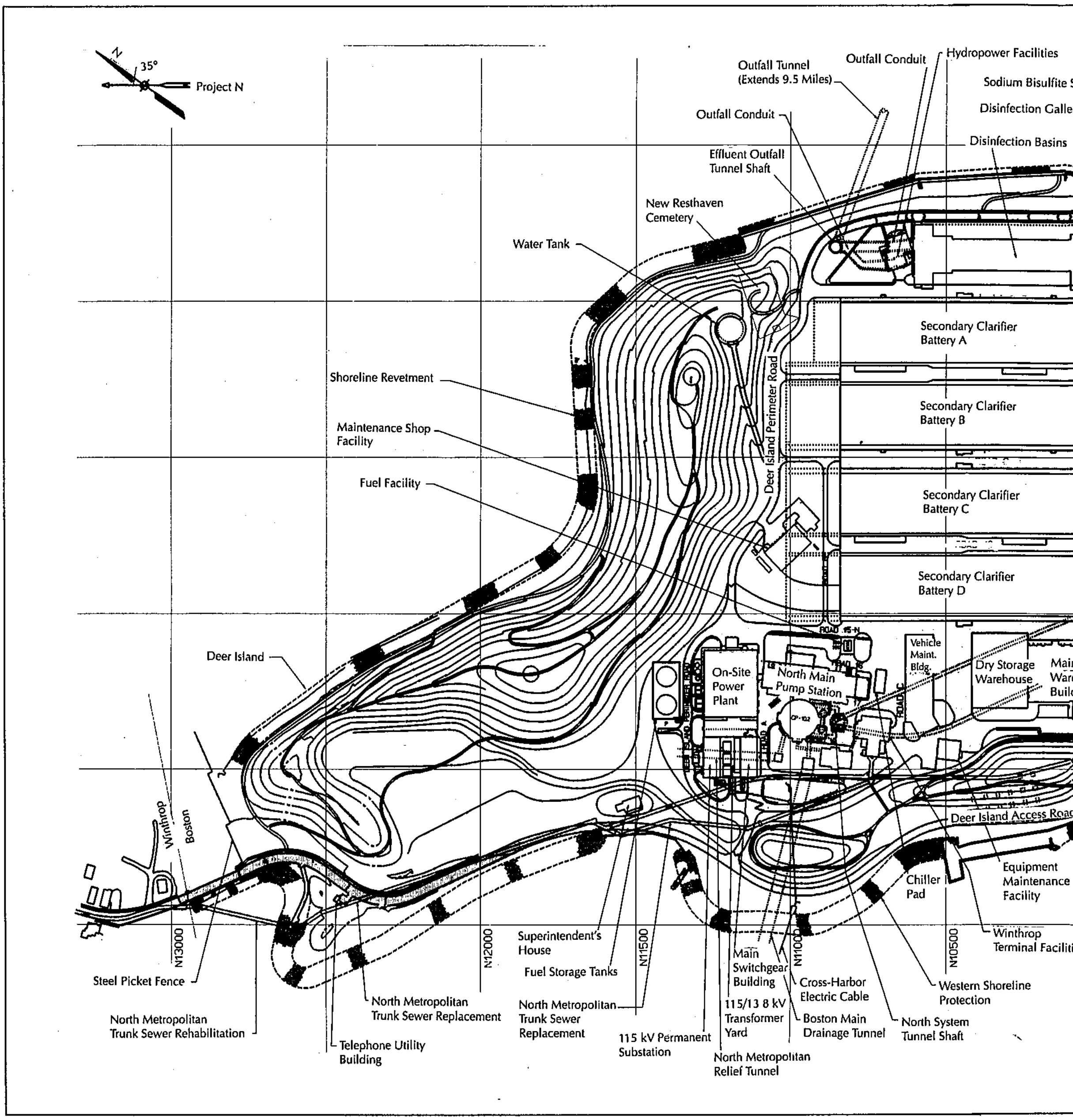


FIGURE 2. A schematic of the final Deer Island wastewater treatment facilities.

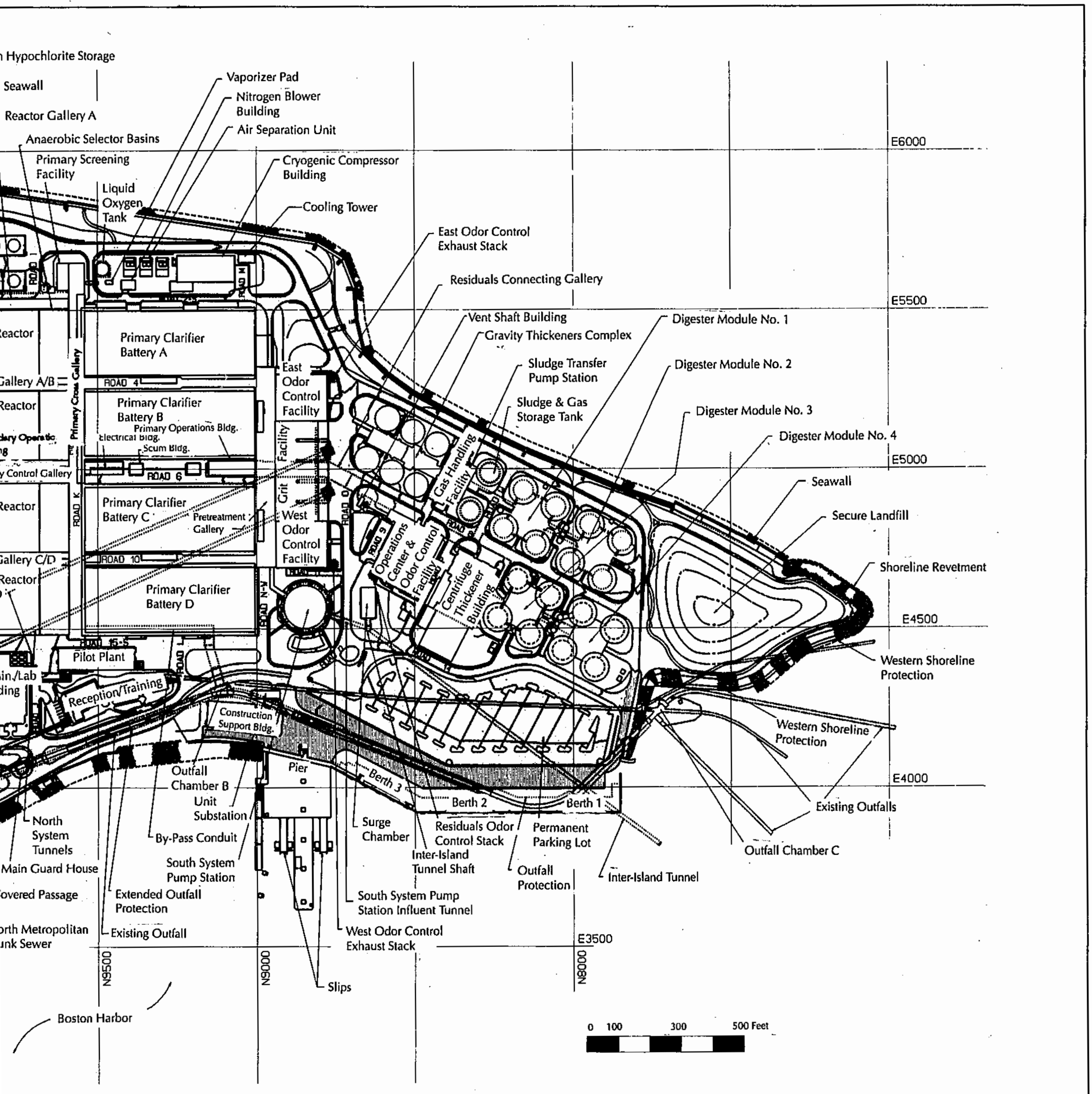
ies are being conducted in a two-mgd research/training pilot plant facility that was recently constructed on Deer Island.

Liquid Unit Processes

Overriding design considerations for the liquid process train are:

- Limited land area;
- Mitigation agreements;
- Maintenance of existing operations; and,
- A compressed design and construction schedule.

Furthermore, the generally poor condition of the existing facilities (resulting from decades of marginal maintenance budgets and evidenced by excessive equipment down times and fail-



Note: Portions of the center of this figure overlap.

ures) dictate that, on the whole, they be replaced, rather than incorporated into the new construction.

Layout. Because of the large size of the facility, the high peak-to-average flow variability, considerations for separating treatment trains, and the mandate for early construction and startup, the plant is laid out in four parallel primary/secondary trains. Each train, or battery, is sized to process up to 25 percent of the peak design flow while maintaining a unit redundancy of no less than ten percent for routine maintenance (*e.g.*, tank re-chaining, weir adjustments, *etc.*). The combined primaries have a capacity of 1,270 mgd, equal to the aggregate capacity of the feeder conveyance systems. The secondaries are restricted to a peak flow of 1,080 mgd (85 percent of the primaries' peak) to avoid excessive solids loss through washout. Larger secondaries would further constrain on-site construction and "buffer zones" and could not be economically justified

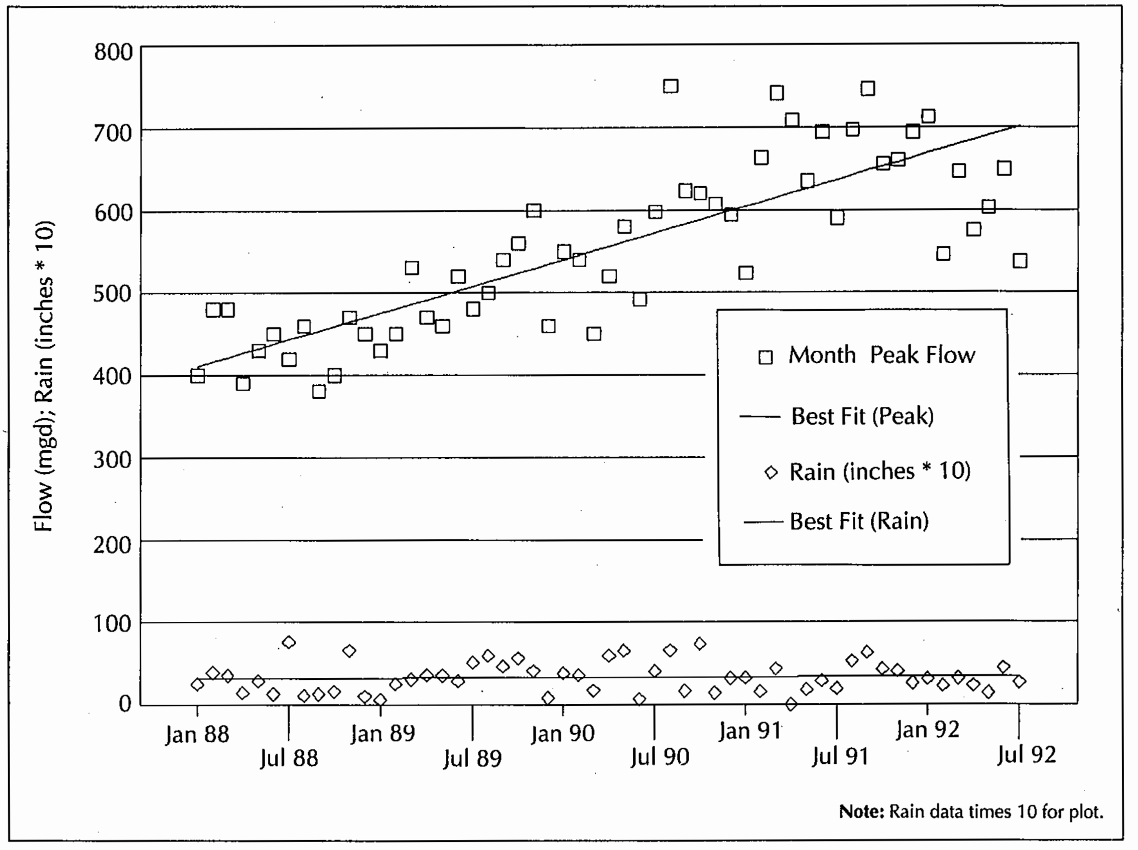


FIGURE 3. Deer Island monthly peak flows versus time.

based on the expected rare (less than 1.5 percent of the time) flow excursions in excess of this rate.

The batteries are virtually identical, with each pair sharing a common (north-south) gallery that houses the majority of the process pumps, piping and controls (see Figure 2). The galleries are completely enclosed and provide:

- Worker protection from the harsh environment;
- Protection for instrumentation sensors, readouts and controls;
- Safety devices; and,
- All-weather, all-hour service and repair capabilities.

East-west pretreatment and primary and secondary cross-galleries provide a fully protected, subterranean grid access system to complement a similar surface road and deck network.[1]

To conserve space and cost, common-wall construction is used throughout the plant. This requires near perfect site control, highly detailed and skilled interface planning, and very tight construction scheduling. The lead design engineer (LDE) is providing the necessary design oversight through development of a detailed conceptual design, project specific design manuals, programmed progress reviews, and a common GDS computer-aided design and drafting (CADD) system. All project design engineers (PDEs) are required to comply with these standards and procedures.

To facilitate centralized operations and maintenance, the support facilities — consisting of administration, laboratories, training, maintenance, operations, and warehousing — are grouped into a central complex with direct protected access to the gallery system and to one another (see Figures 4 and 5). Plant staffing will provide continuous, three-shift, seven days per week operation with an aggregate

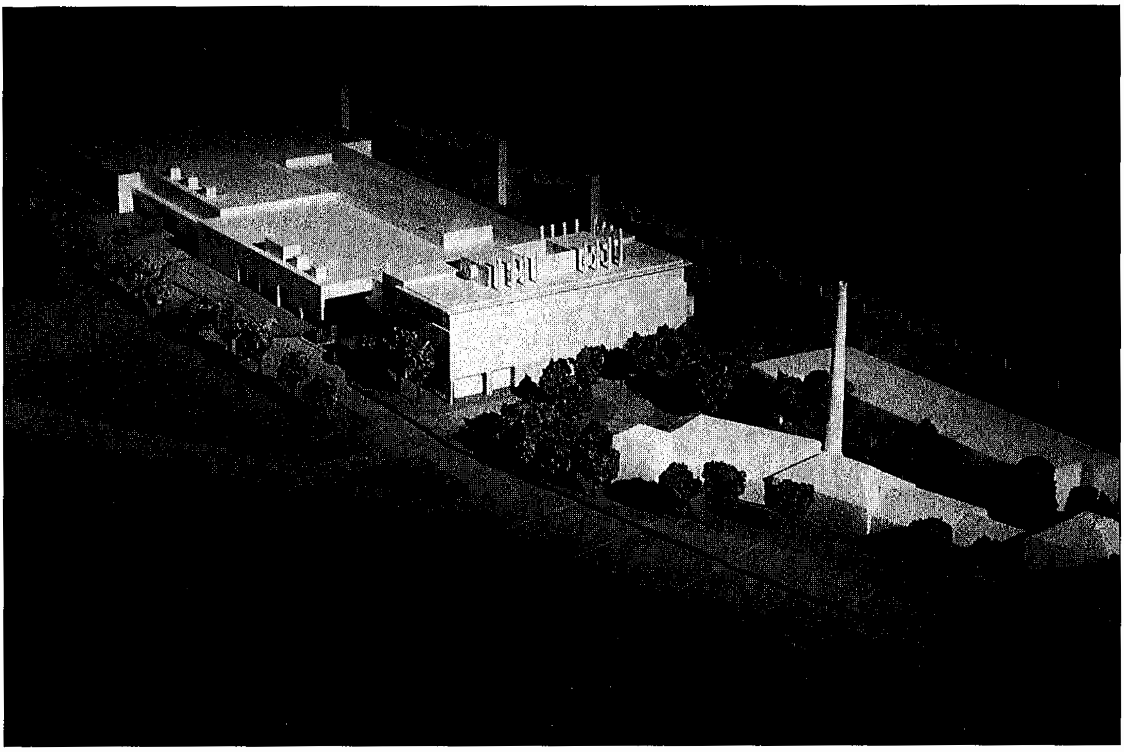


FIGURE 4. A model of the central control complex for the Deer Island wastewater treatment plant. To the left are maintenance and warehouse facilities. In the center are quarters for administrative offices and a laboratory. In the right front area are located reception and training facilities. The two-mgd research/training pilot plant is located to the right rear. (Model courtesy of Tsoi-Kobus & Associates.)

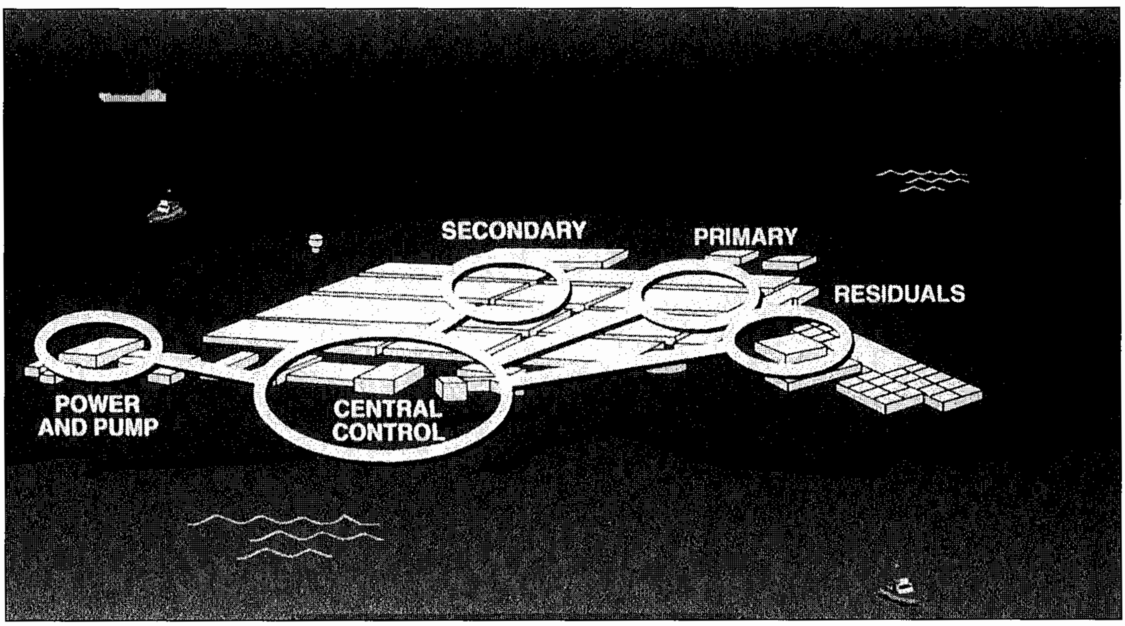


FIGURE 5. A representation of the plant operation distribution control network. (Drawing courtesy of Metcalf & Eddy.)

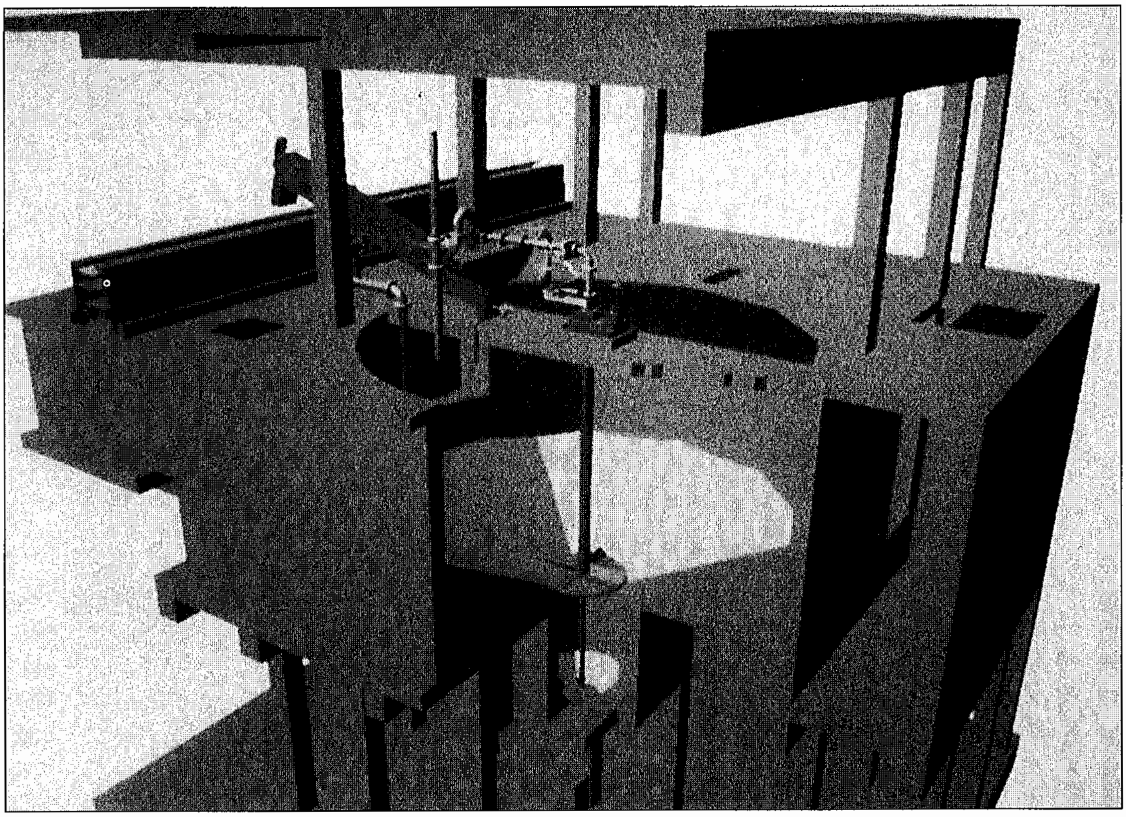


FIGURE 6. CADD representation of the vortex grit separator. (Drawing courtesy of Metcalf & Eddy.)

staff of 400 to 500 operators, technicians and managers. Distributed process control centers are provided in each of the major process areas: power and pumping, primary, secondary, and residuals. Each has extensive computer control capabilities and support facilities consistent with its functional requirement.

Pretreatment. On-site pretreatment is provided for the North System flows only at the Deer Island plant, since pretreatment for South System flows is accomplished at the new Nut Island headworks. The latter decision was made not only to conserve space on Deer Island but also to reduce the potential for solids deposition in the long inter-island tunnel.

The vortex grit separators were selected on the basis of their broad range flow capabilities, low maintenance and small footprint (see Figure 6). Sixteen separators, each 24 feet in diameter with an average water depth of about four feet, are located on Deer Island; another six are situated on Nut Island. Each separator has a rated capacity of approximately 70 mgd, thus providing a 20 percent redundancy for maintenance and operating flexibility. Removed grit is washed by grit classifiers to return excess organic material to the main plant flow to control odors. Conveyors are provided to transfer the washed grit to covered trucks for removal to off-site landfills. All loading and processing areas are fully enclosed. The exhaust air is processed using wet scrubbers and/or activated carbon for odor and volatile organic compound (VOC) control. Since both the North System and South System flows are screened at their respective remote headworks, no raw sewage screening is provided on-island other than at Winthrop Terminal.

To take full advantage of Winthrop Terminal screening, available capacity and lower lift requirements (Winthrop Terminal pumps only from the comparatively shallow North Metro Trunk Sewer), all sanitary wastewater and tank drainage generated on-island is routed back to

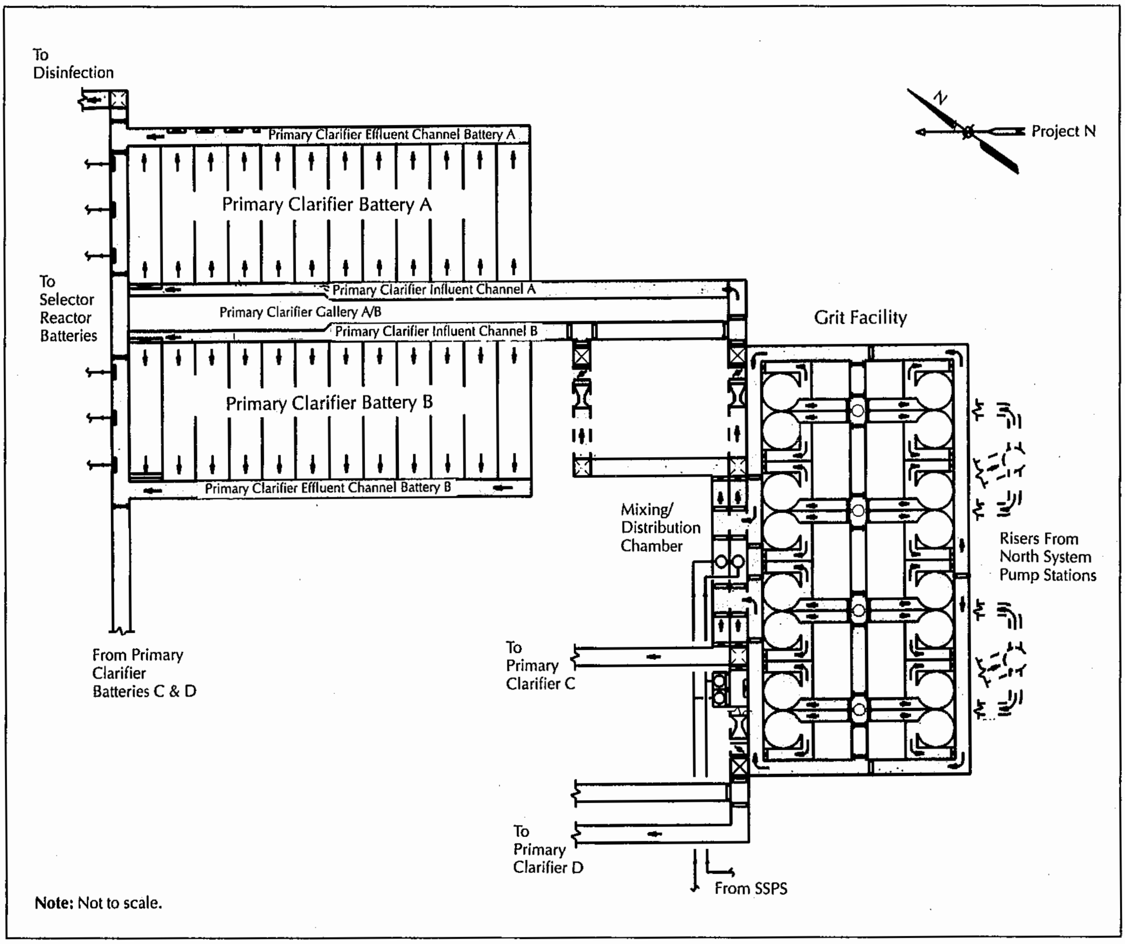


FIGURE 7. Partial wastewater flow schematic.

Winthrop Terminal for screening and pumping to the North System headworks.

In the event CSO flows are conveyed independently to Deer Island in the future, isolation gates are positioned to dedicate five of the 16 grit separators for this service during storms to maintain the "technical" separation of flows and to facilitate post-storm cleanup.

Flow Control. Following grit removal, flows converge into a mixing chamber where, under normal operations, North System and South System flows are blended prior to splitting to each of the four batteries for primary treatment (see Figure 7). Flow splitting is accomplished through rate controllers (combinations of very large Venturi flow meters with integrated butterfly control valves) for programmable distribution to each of the batteries. Each meter offers a capacity range of 75 to 360 mgd, with a specified accuracy above 150 mgd of 0.5 percent. These meters furnish the principal flow control mechanism in the plant. The four Venturi meter readings are automatically summed for measurements of instantaneous plant flow and totalized for the daily logs.

Recycle flows from residuals treatment are blended after passing through meters if programmed for primary treatment, or directed to the four primary *effluent* channels if programmed for secondary feed only. The normal flow control algorithm is to divide all influent flow equally among the four batteries.

Primary Treatment. Each primary treatment battery consists of twelve two-pass, double-decked (stacked) clarifiers (see Figures 8 and 9). Sludge and scum are removed by four longitudinal, conventional chain and flight collectors per tank. Flights (bay widths) are 20.5 feet wide

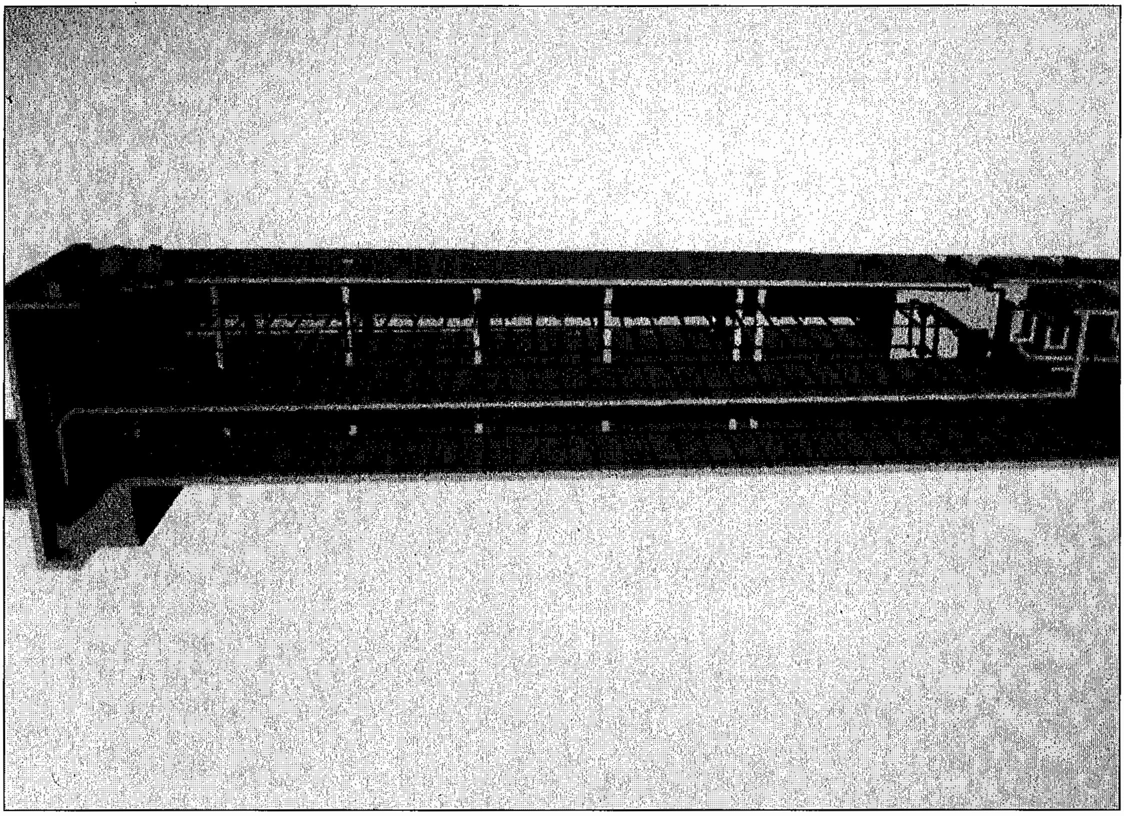


FIGURE 8. CADD representation of a stacked clarifier. (Drawing courtesy of Metcalf & Eddy.)

and the effective lengths of the top and bottom bays are 181 and 191 feet, respectively. The design overflow rate at peak flow (based on one clarifier per battery out of service) is nominally 2,000 gallons per day per square foot (gpd/sf) with a detention time of 1.09 hours. The minimum sidewater depth of both upper and lower tanks is 12 feet. Because of the restricted inspection and repair access to the lower tanks, the potential for high solids accumulations (first flush) during CSO events and concern over elongation, all chains are proposed to be constructed of stainless steel.

Scum is removed using tipping skimmers (timer or manually operated) at the effluent end of the tanks and sludge is plowed to and pumped from the inlet end. Top and bottom tanks share a common water surface and a common sludge hopper. Chain and flight cross collectors are used in the sludge hoppers to move the sludge to the sludge pump suction pipes.

Flow distribution to the primary clarifiers in a single battery is through an aerated, tapered, 525-foot long influent channel. Equalized flow distribution into the tanks is maintained by relatively high headloss (compared to the channel) inlet ports. Eight inlet ports feed each clarifier, two to each bay. The maximum flow differential between the first and last tanks is less than seven percent.

The use of stacked clarifiers at Deer Island will be only the second such application of this technology in the United States (the first application was operational in 1993). The technology was developed beginning in the 1970s in "landshort" Japan. The Boston Harbor Project facilities planners toured several Japanese plants and concluded that the process would be suitable for Boston.[2]

Stacking (which yields a 40 percent savings in footprint) is required to fit the complete primary and secondary treatment plants within the limited land available on Deer Island. Conventional (unstacked) primary and secondary clarifiers would have required filling portions of Boston Harbor and/or encroachment into

FIGURE 9. A view of the primary clarifiers batteries A and B in June 1992. (Photo courtesy of Kevin Kirwin, RVA.)

the buffer zone that separates the plant from the town of Winthrop, two options deemed unacceptable.

The LDE and the MWRA concurred in the adoption of this technology and commissioned hydraulic physical model tests (with a prototype to model scale of 9:1) to develop inlet and outlet designs to optimize performance (see Figure 10).[3] The principal concern was the lack of operating data for secondary stacked clarifiers at overflow rates in excess of 800 gpd/sf. The two-mgd Deer Island pilot plant which has replica stacked clarifiers for both primary and secondary treatment is providing insights into performance expectations and maintenance requirements since it commenced operation in the fall of 1993, six to twelve months prior to the startup of primary batteries A and B. The pilot is designed to facilitate inlet and outlet zone modifications, should this prove desirable for potential future upgrades to the prototype.

Another advantage of the stacked clarifier concept is that it halves the cost of covering tank areas that is required at Deer Island in order to meet mitigation agreements for odor and VOC control. All headspace gasses from the concrete-decked, primary clarifiers and channels are exhausted through air emissions control facilities for treatment before being released through tall stacks to the atmosphere.[4,5]

Finally, the MWRA has also contracted for bench scale research on the potentials for chemically enhanced primary treatment as an adjunct to its long-term program. The bench tests, completed in the summer of 1993, are being phased into full pilot confirmation work as new needs and means become identified. Of particular interest are the performance enhancement at low dose chemical and polymer additions (typically 15 milligrams per liter [mg/l] $FeCL_3$ plus 0.5 mg/l anionic polymer) and the effectiveness in treating excess wet-weather flows, which because of their unpre-

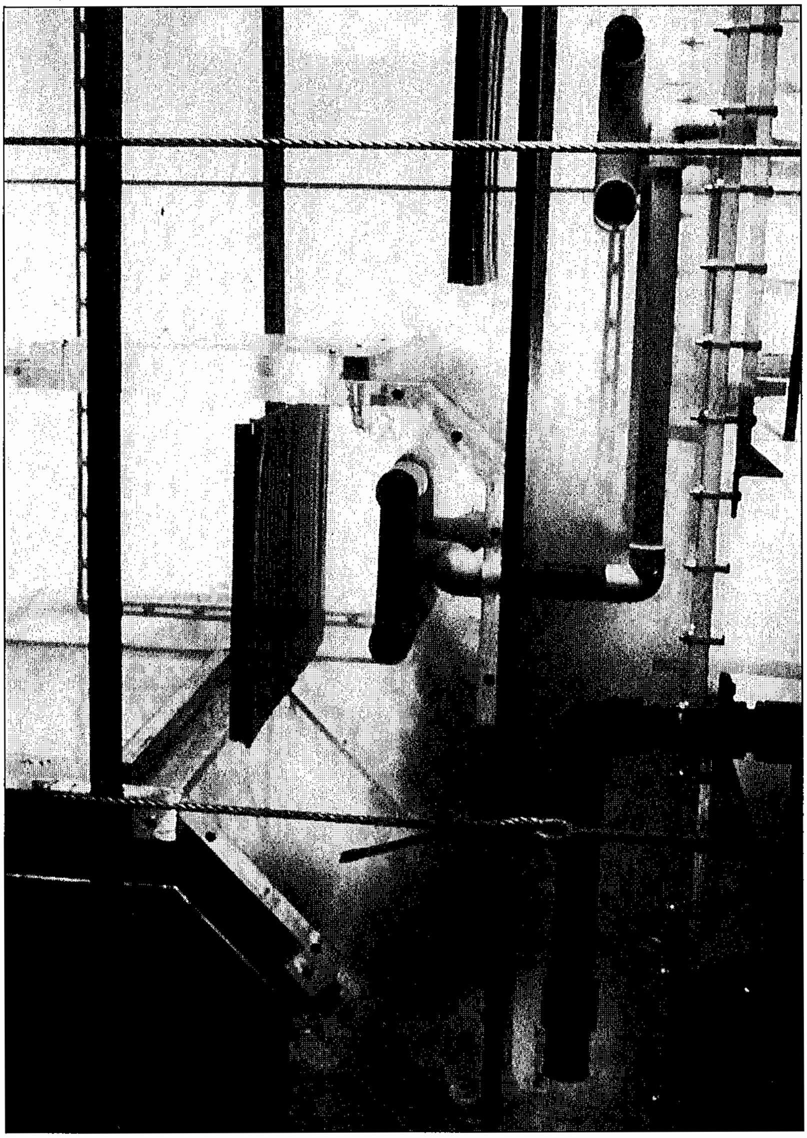


FIGURE 10. Model testing for the stacked clarifier inlet design. (Photo courtesy of Alden Research Laboratory.)

other major factor was that the decked construction and enclosed atmosphere of the oxygen reactors would produce only two percent of the vent gas quantity as the equivalent air activated sludge system; thus, the control facilities for air toxic emissions and odor would be greatly reduced.

In keeping with state-of-the-art developments, anaerobic selectors were designed ahead of the reactors to further improve process stability and reliability, to potentially reduce oxygen requirements and to produce a better settling sludge.[6,7] The latter factor is most important considering the performance reservations for stacked secondary clarifiers that have no operating track record in this country and their criticality in overall system performance. In Japan, stacked secondary clarifiers are typically limited to nominal, peak overflow rates of 800 gpd/sf; whereas the Deer Island design will extend peak operations to 1,200 gpd/sf or higher. As a contingency, space has been reserved for a 20 percent expansion of secondary clarifier capacity should field performance fall short of expectations.

In 1989, a 26-week pilot study of secondary treatment was conducted using an oxygen activated sludge system with and without anaerobic selectors.[8] The testing was performed on Deer Island by the LDE using the existing plant primary effluent as the feed to a 10,000-gpd pilot facility located in a 40-foot trailer (see Figure 11). The trailer pilot plant consisted of a

dictability and short duration are ill-suited for conventional secondary treatment.

Secondary Treatment. The facilities planners evaluated 12 potentially viable secondary treatment processes before selecting three systems — oxygen activated sludge, air activated sludge and coupled (fixed film packed tower followed by activated sludge) — for detailed evaluation.[2] The oxygen activated sludge process was recommended on the basis of cost, operational stability under the expected varying flows and loads, and small footprint. An-

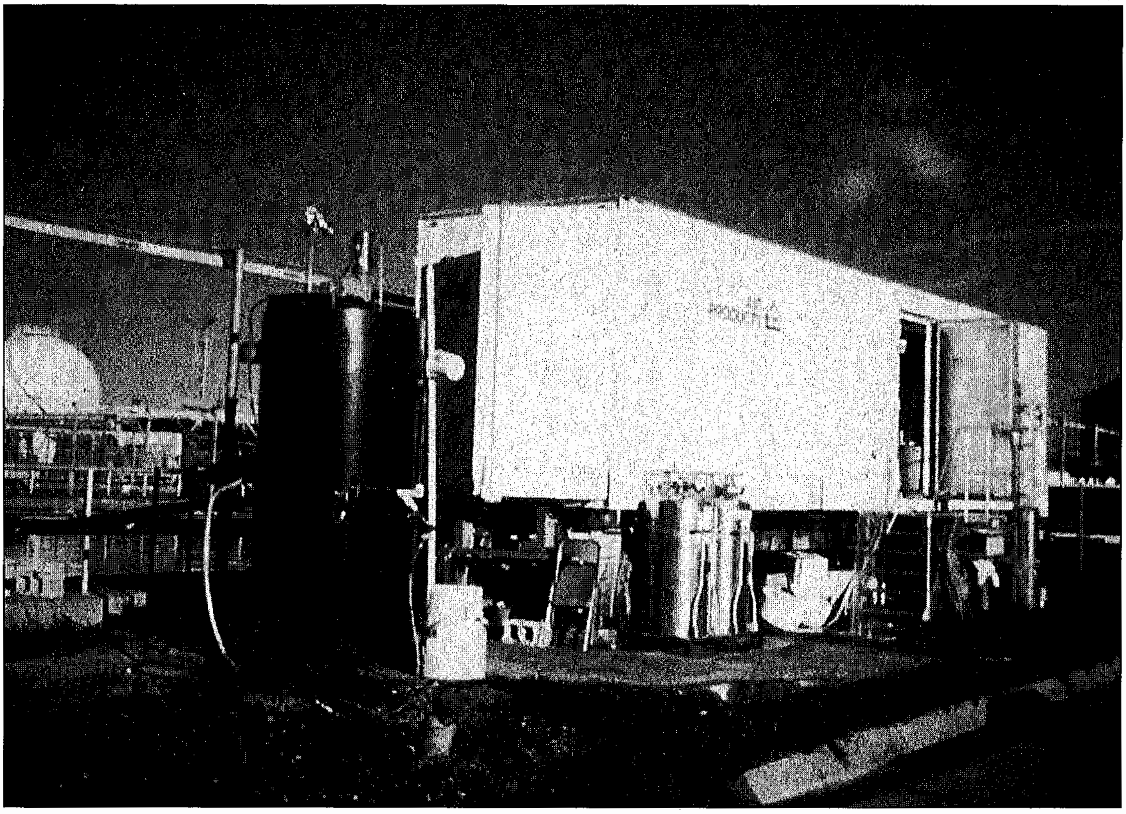


FIGURE 11. A view of the trailer-mounted pilot plant for high purity oxygen (HPO) secondary treatment. The unit includes optional anaerobic selectors and an external secondary clarifier. (Photo courtesy of Metcalf & Eddy.)

two-stage anaerobic selector, a four-stage pure oxygen reactor, a secondary clarifier and a field laboratory. Each process modification was examined in sequential tests under spring and summer flow as well as temperature conditions.

Performance with and without the anaerobic selectors was excellent with typical effluent BOD concentrations of less than 10 mg/l, total suspended solids (TSS) less than 15 mg/l and total Kjeldahl nitrogen (TKN) less than 15 mg/l. The train with the anaerobic selector produced a denser sludge with lower sludge volume indexes and higher settling velocities than the conventional system. The anaerobic selector also improved process stability and resistance to stress loadings.

The Deer Island plant includes four secondary batteries, each containing a three-stage anaerobic selector followed by a four-stage high purity oxygen reactor. The selectors are capable of operating in either an anaerobic or oxygen feed mode to provide flexibility for future operations. The selectors and reactors are 24.5 feet deep and have aggregate (full plant) volumes of 12.7 and 41.3 mg, respectively. These volumes correspond to high groundwater table (HWT) average flow detention times, excluding return activated sludge (RAS), of 0.45 and 1.5 hours, respectively. Corresponding low groundwater table (LWT) detention times are 0.77 and 2.5 hours. The system is designed assuming a mixed liquor suspended solids (MLSS) concentration of 2,000 mg/l and a corresponding food to mass ratio in the reactors of 0.57 under HWT average conditions.

Oxygen for the activated sludge process will be generated on-site using three cryogenic oxygen systems, each capable of producing 150 tons of 95 percent pure oxygen per day. This sizing with turndown will permit the operation of one, two, three or four batteries to meet the requirements for the phased startup of secondary treatment. The first secondary construction contract was awarded in November 1992 (two months ahead of the mandated court schedule). A 1,000-ton liquid oxygen (LOX) storage tank is provided for redundancy and peak oxygen demand equalization.

Each secondary battery contains 18 two-pass, double-decked (stacked) clarifiers to separate the RAS from the MLSS. The minimum side water depth for both upper and lower tanks is 13 feet. The upper tank surface is uncovered. Two sets of transverse launders are provided for each tank to reduce weir loading rates and approach velocities that would otherwise contribute to solids washout. Design overflow rates are approximately 440 gpd/sf at LWT, 750 gpd/sf at HWT average flows and 1,200 gpd/sf at peak. Other features are similar to those described earlier for the primary clarifiers. Two clarifiers in each battery are redundant to facilitate maintenance and to provide additional flexibility.

RAS pumping capacities range from 15 to 75 percent of the influent flow. The RAS is returned to the first stage of the anaerobic selector basins for blending with incoming primary effluent. Waste sludge is diverted to the residuals area from the RAS lines. While each secondary battery is designed to operate independently, crossover connections are provided for flexibility and redundancy. Secondary scum may be pumped to the primary influent channels or directly to the residuals processing area.

As part of on-going efforts to minimize program costs and in view of accumulating documentation of significantly reduced high groundwater flows, the MWRA has advised the U.S. District Court of its intent to reassess the need to fully build out secondary batteries C and D in their present form. This reassessment is continuing to allow for process input from the new two-mgd pilot plant.

Disinfection. Effluent disinfection is provided by adding sodium hypochlorite to the plant effluent and through flash mixers. Two contact basins are sized for ten minutes of detention at peak flow (15 minutes or greater for flows up to 850 mgd) on the surface followed by five additional minutes within the outfall shaft and tunnel system. This configuration will thereby defer or eliminate $20 million in construction cost associated with the original four-basin plan. The total available travel time in the 9.5-mile long outfall tunnel is 180 minutes at peak flow. Hypochlorite flow is automatically paced based on the selected feed rate (estimated at 10 mg/l for primary effluent and 5.5 mg/l for secondary) and the measured primary influent flow. This feed rate is trimmed based on the chlorine residual measured (directly or via simulation) after a 15-minute contact time.

Dechlorination is provided by the addition of sodium bisulfite after the prescribed minimum 15-minute detention time at peak flow, through pipelines embedded within the first 500 feet of the outfall tunnel system. The chlorine residual analyzer will be located on a looped pipe system designed to simulate travel time to the bisulfite feed location. Redundant bisulfite lines are constructed in the inaccessible tunnel segments as a precaution against blockage or other malfunction. Because the available outfall tunnel travel time is so great, it is hoped that reducing or eliminating the dechlorination chemical addition will be allowed, subject to a yet-to-be-defined *in situ* verification method.

A minimum of 30 days on-site storage for each chemical is provided with permanently installed transfer lines to the pier berthing area for resupply.

Plant Water Systems. To conserve potable water, plant water is used on Deer Island for all process systems where potable water quality is not necessary. Major uses include power plant condenser cooling, gravity thickening dilution, hot water flushing (W4), hot scum flushing water (W5), LOX vaporizer, foam spray, chemical dilution and carrier water, and equipment flushing and washdown. Three separate plant water systems are provided: one low pressure (W3L), one high pressure (W3H) and the third for power plant cooling. All systems draw their supply from the chlorinated effluent at the disinfection basins.

The peak available capacity of the plant water system is 40 mgd, which contrasts markedly with the estimated average potable water consumption of two mgd. All plant water is screened through motorized, self-cleaning strainers to reject any material caught on the 0.0625-inch mesh.

Energy Recovery. A two-megawatt, low head, hydro-electric facility is located on the conduit connecting the disinfection basins to the outfall shaft. This facility serves a dual purpose: one for power generation and the other for hydraulic energy dissipation (to minimize air entrainment and resultant capacity reduction in the outfall system). Since the plant is designed hydraulically to discharge the peak flow of 1,270 mgd by gravity against a 100-year storm tide, normal operations yield approximately 30 feet (within a range of 10 to 38 feet) of excess head that is converted by turbines into electrical power which, in turn, is fed into the plant grid.

Two full bevel gear, bulb turbines are provided, each capable of passing 325 mgd. Wicket gates on the turbines maintain a maximum water surface in the disinfection basin effluent channel to optimize power generation at all flow rates. A parallel bypass conduit and weir system provides a fail-safe bypass around the turbines in the event of equipment malfunction or precautionary shutdown. This instant backup is necessary to avoid damaging surge conditions in the outfall that could result from a sudden cessation of flow. Again, hydraulic physical model testing was performed to improve channel designs to minimize air entrainment.[9]

Normal operation requires both turbines in service. Flows in excess of 650 mgd (which are expected to occur less than 20 percent of the time) automatically overflow to the bypass conduit. The facility payback period under the projected power rate structure is less than 15 years at an annual interest rate of 7.50 percent and a debt service rate of 9.81 percent.

Residuals Management

The Deer Island plant design provides for on-island sludge thickening and anaerobic digestion followed by off-island sludge dewatering, drying and pelletizing. The Fore River sludge processing facilities are located at the former shipbuilding yards in Quincy located 7.6 miles south of Deer Island. Ultimate disposal is through recycling as a soil enhancement or direct disposal to approved landfills. Washed grit is trucked to a landfill in keeping with the present practice. Primary scum is screened, concentrated and blended with the thickened sludge and discharged to the digesters. Screenings are lime conditioned for odor control and disposed of in a landfill with the grit.

Primary Treatment. Eighteen primary sludge pumps, including six standby units, are provided for each battery. These pumps are of the recessed impeller type with friction disc and variable speed drives. Each pump is capable of a 175- to 550-gpm flow range. Pumps transfer sludge from the primary clarifier hoppers to the gravity thickeners located in the residuals processing area. Primary sludge is withdrawn from the clarifiers at a concentration of approximately two percent and thickened to approximately five percent before transfer to the digesters.

Four primary scum pumps, including two standby units, are provided per battery. Pumps are of the recessed impeller type (constant speed, timer or level operated) and rated for a 480 gpm flow rate at 69 feet total dynamic head (TDH). Upon arrival in the residuals area, the scum is rotary screened by four units. Any two of these four units can handle peak flow. After screening, the scum is then blended with primary sludge for thickening and digestion.

A total of six gravity thickeners are provided to receive the blended primary sludge and scum. Optionally, two of these units can be utilized for separate scum processing. All units have self-supporting dome covers and the headspace air is treated through a two-stage wet scrubber system prior to exhausting to the atmosphere. A third stage consisting of a carbon adsorber is provided for polishing, if required. Design loading rates on the thickeners are controlled with W3L dilution water to hydraulic loadings of 600 to 800 gpd/sf. Solids loadings are sized for a maximum day loading of 30 pounds per day per square foot with one unit out of service. Thickener overflow and scum concentrator underflow are pumped back to either the primary influent channels or effluent channels as desired. The thickened primary sludge and scum mixture is pumped to the digester modules for single-stage, complete-mixed, anaerobic digestion.

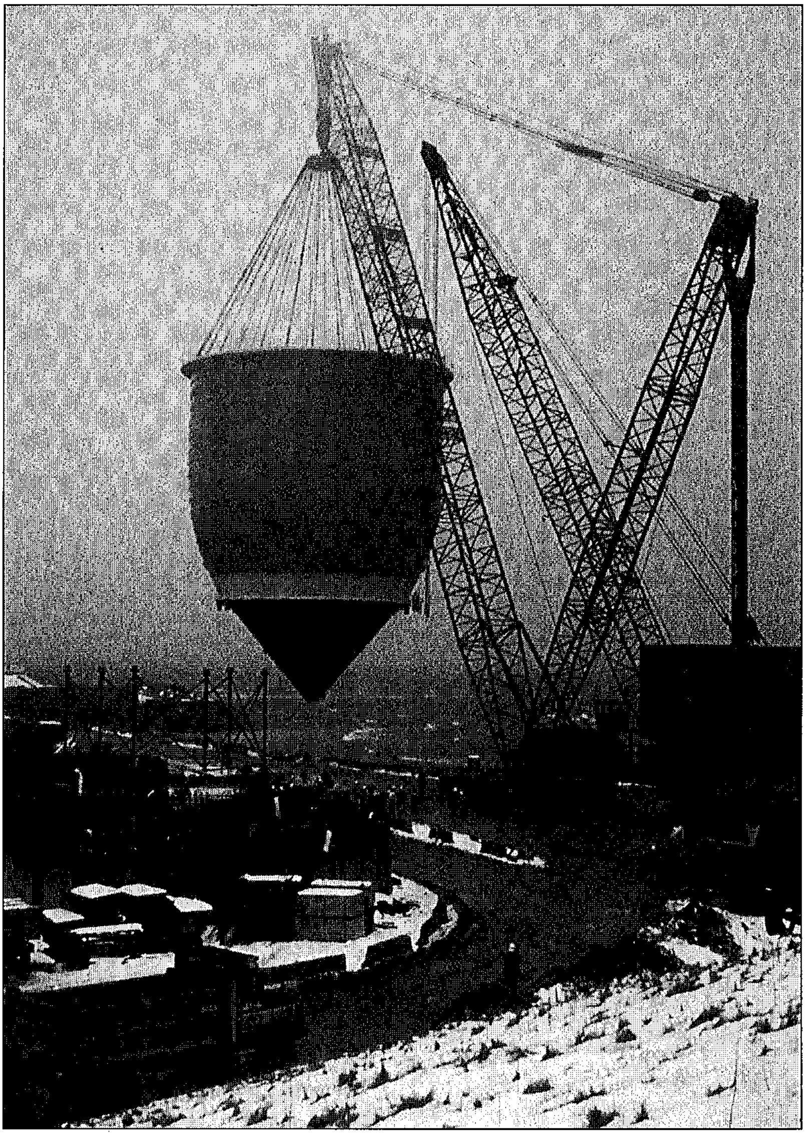


FIGURE 12. A photo of the first egg-shaped digester being installed in March 1993. Prefabricated off-island, these steel assemblies required a lift capacity of up to 700 tons. (Photo courtesy of Kevin Kirwin, RVA.)

Secondary Treatment. Waste activated sludge (WAS) from the secondary process is directed to a feed wet well in the residuals complex from which it is pumped through centrifuges for thickening. A total of 20 horizontal, solid bowl centrifuges (including four standby units) are provided, each with a capacity of 500 to 900 gpm. The average WAS solids content of 0.75 percent is increased to approximately five percent through the centrifuges with the use of polymers. A minimum 85 percent solids capture is specified. Centrate and gravity thickener overflow are returned to either the primary influent or the effluent channels.

Secondary scum, because of its variability, may be handled in any of three ways:

- It may be returned to the primary influent channels, if very dilute, to be removed with the primary scum;
- It may be pumped to the centrifuge feed well to be coprocessed with the WAS; or,
- It may be pumped directly to the gravity thickeners to be processed with the primary sludge and scum.

The latter two options may be required if excessive Nocardia foaming episodes are experienced to avoid inoculating the influent waste.

Egg-Shaped Digesters. Anaerobic digestion of both primary and secondary residuals is accomplished in four digester modules. Each module is similar and has a central equipment/operations building surrounded by four egg-shaped digesters. Each digester has a liquid capacity of three million gallons and a diameter of approximately 90 feet. Central mechanical draft tube mixers are provided in each egg to maintain complete-mixed conditions (minimum of seven turnovers per day). The contents are continuously heated to maintain an operating temperature of 95 degrees Fahrenheit. The unit capacity ranks among the largest presently operating egg-shaped tanks and the concentration of 16 units on a single site will make the Deer Island installation the largest of its type in the world.

The egg-shaped design, developed in Western Europe, was selected on the basis of more efficient mixing and reduced maintenance and because the smaller footprint could be better accommodated within the restricted confines of Deer Island. The disadvantages are a significantly (greater than 25 percent) higher capital cost and greater height (with a top of stair tower elevation of 140 feet above grade, only the water tower will be higher).

The eggs provide a hydraulic residence time of 30 days at average design conditions and 21 days under maximum load. Two of the 16 eggs are normally operated as equalization storage to reduce fluctuations in processing cycles.

Four additional centrifuges are used to rethicken the digested sludge from approximately three to six percent solids to reduce the liquid volume required for barge transport. The average production of thickened, digested sludge is approximately 185 dry tons per day.

Two additional eggs (unheated) are provided for the dual purpose of gas holding and thickened, digested sludge storage (see Figure 12). Initially, the digested sludge will be transported to the Fore River sludge processing facility by barge for final processing and disposal. However, twin pipelines in the inter-island tunnel will facilitate the pumping of sludge in the future. If the latter transport method is implemented, the four post-digestion centrifuges would be then reassigned for waste sludge thickening.

Resource Conservation. The methane gas produced in the digestion process is used as fuel in the boilers for the central plant heating system. This system not only provides the heat input to maintain the digester contents at 95 degrees Fahrenheit, but also provides the heat source for all on-island building and hot plant water needs. Processed excess gas can also be used to fuel the two existing six-megawatt engine generators or the two new 26-megawatt combustion turbines to further reduce the requirements for auxiliary fuel or power purchases. Backup waste gas flares are provided for emergency service.

ACKNOWLEDGMENTS — *The authors wish to acknowledge the dedicated contributions of the core staffs of the Lead Design Engineer Team and the Program Management Division of the MWRA and the timely support of the Sewerage Division of the MWRA, the Construction Manager, the original Facility Planning Team, and the Project Design Engineering firms for making this a unified, professionally rewarding, and technically successful project. Metcalf & Eddy, Inc., served as lead design engineer for the plant. Principal design firms included: Metcalf & Eddy (primary facilities); Malcolm Pirnie (secondary facilities); Black & Veatch (residuals); Camp Dresser & McKee (residuals and facilities planner); Havens & Emerson (Nut Island headworks); Sverdrup Corp. (inter-island tunnel); Parsons Brinckerhoff (outfall tunnel); R.W. Beck & Assoc. (power plant); Tsoi/Kobus & Assoc. (administration/laboratory/maintenance facilities); and, EMA Systems (automation & control).*

NOTES — *The work upon which this paper is based is funded by the MWRA and in part by the USEPA and the Massachusetts Department of Environmental Protection. The comments are the authors' and do not necessarily reflect the policies or views of the funding agencies. Questions or comments on the material presented should be forwarded to: John A. Lager, c/o Metcalf & Eddy, 529 Main Street, Charlestown, MA 02129.*

JOHN A. LAGER *is Vice President and Project Manager with Metcalf & Eddy, Inc. He managed the Boston Harbor Project concept design and has directed the lead design engineer team since 1991. He has a B.S.C.E. from Northeastern Univ., an M.S. in Sanitary Engineering from Harvard Univ., and is a Registered Professional Engineer in seven states.*

DAVID P. BOVA *is the Senior Vice President of wastewater technology at Metcalf & Eddy, Inc. Since receiving his B.S. from Worcester Polytechnic Institute in 1963, he has focused on treatment processes and alternatives and their performance during actual operation. He has played a key role in the*

Boston Harbor Project and is currently working on integrating the design of the new treatment facilities with the combined sewer overflow system.

ROBERT M. OTOSKI *has been with the MWRA since 1986 where he is Senior Design Manager with the Program Management Division. He received his B.S. in Civil Engineering from Merrimack College and an M.S. in Environmental Engineering from Tufts Univ. He is in charge of managing all process-related design packages for the Deer Island plant. He is a Registered Professional Engineer as well as a licensed wastewater treatment plant operator in Massachusetts. Before joining the MWRA he was in private consulting for 11 years.*

GERARD L. GALLINARO *has held a variety of positions within the MWRA since 1990. He is currently in the Program Management Division as Senior Design Manager, Startup Services for the Boston Harbor Project. His section is managing the activities in support of Equipment/System Testing and Plant Startup. Prior to coming to the MWRA, he was employed by Havens and Emerson and General Dynamics. He holds a B.S. in Mechanical Engineering.*

REFERENCES

1. Metcalf & Eddy, Inc., *Boston Harbor Project: Deer Island Related Facilities, Conceptual Design — Task 2.8: Concept Improvements Report*, 1989.

2. Camp Dresser & McKee, *Massachusetts Water Resources Authority — Secondary Treatment Facilities Plan, Volume III: Treatment Plant*, 1988.

3. Alden Research Laboratory, Inc., *Hydraulic Model Study of Stacked Secondary Clarifiers for Deer Island Wastewater Treatment Plant*, 1990.

4. Lager, J.A., *et al.*, *Water Environment Federation — Measurement and Control of Volatile Organic Compounds and Reduced Sulfur Species in Wastewater Treatment Air Emissions*, #AC91-021-001, 1991.

5. Lager, J.A., *et al.*, *Water Environment Federation — Air Emissions Control for Wastewater Treatment Facilities: Boston Harbor Case Study*, #AC92-022-002, 1992.

6. Water Environment Federation, *Design of Municipal Wastewater Treatment Plants, Manual of Practice No. 8*, 1992, p. 543.

7. MWRA Consultants (Albertson, Eckenfelder, and Jenkins) with Camp Dresser & McKee, *MWRA Design Team Technical Review Memoranda*, 1987.

8. Metcalf & Eddy, Inc., *Boston Harbor Project — Deer Island Related Facilities, Task 7.6: Trailer Plant Final Report*, 1990.

9. Alden Research Laboratory, Inc., *Hydraulic Model Study of the Outfall Energy Dissipator for Deer Island Wastewater Treatment Plant*, 1990.