Detroit Water and Sewerage Department

Wastewater Master Plan

DWSD Project No. CS-1314

Review of Large Treatment and Collection Systems

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Appendix B- Wastewater Collection Systems Surveys
Please reference the CD for file named: Wastewater Collection Systems Surveys.pdf

Review of Large Treatment and Collection Systems

1. Introduction

The Detroit WWTP ranks as the largest facility in the world based on Peak Flow capacity. Table 1 ranks the top 20 WWTP s in the world. The Wastewater Master Plan project includes analysis of critical current and future facilities needs through review and development of criteria and a program for maintenance, renewal, or replacement of such facilities. Included in these critical facilities are both trunk/interceptor sewers and wastewater treatment plant (WWTP) facilities. This work task was designed to address the following concerns:

- ***The concept of economy of scale in wastewater treatment*—**Detroit now has one of the largest WWTPs in the world. There appears to be need to treat more flow; but the DWSD is concerned that expanding the plant may not be the appropriate solution, and that the master planning study should consider other sites to build a new plant(s). However, there may be good reasons to consider expanding the current plant. This task includes a review of large WWTP economics and other issues related to managerial effectiveness in the United States. Information on large WWTP facilities outside of the U.S. was obtained from sources with CDM International and WRc (the Water Resource center in Swinden, England). CDM and WRc are familiar with the specific international utilities included.

- ***Service Life of Detroit's Sewers and Interceptors*—**Detroit has over 3,300 miles of sewers, most of which will be 120 to 150 years old by 2050. The Wastewater Master Plan needs to identify a program for rehabilitation and replacement of the sewers. The DWSD has sewer inspection records, and some limited inspection was performed in 2001 and 2002. For this task, additional background information was needed on the Midwest and other areas, with a focus on large combined sewer rehabilitation experience in other cities.

Table 1. 20 Largest WWTPs in the World

City/Name	Plant Size (mgd)			
	Average Daily	Max Monthly	Max Day	Peak
Detroit	724	885		1700
Montreal/Montreal	570	853		1618
Acheres/Acheres 1-4	713			1598
Chicago/Stickney	800		1200	1440
Sau Paulo/Barueri	159			1438
Los Angeles/Hyperion WWTP	450			1100/1400
Hong Kong	347			913
Washington DC	370			900
Mexico City/lago de Texcoco	304			799
London/Beckton	277			730
Massachusetts/Deer Island	360			500-700
Beijing/Gaobeidian	264			695
Emscher/'Emscher Mouth'	368			684
Minn.-St. Paul/Metropolitan	251		450	650
Rio de Janeiro	243			639
Athens/Psyttalia Island	185			616
Chicago/Northside			333	450
Chicago/Calumet	220		354	430
Simmering, Vienna/Main	145			410
Tokyo/Morigasaki	322			406
NEORSD/Southerly	175			400

Note: Plants with in the US are normally sized based on peak treatment Capacity. Plants outside the US are reported based on peak daily flow.

An initial draft of a Wastewater Treatment Plant Questionnaire for U.S. communities was prepared and reviewed with senior study management. Potential candidates were identified through AMSA (Association of Metropolitan Sewerage Agencies) listings of communities with large WWTPs and communities with large service areas and multiple WWTPs. Similarly, a sewer system questionnaire was developed to address the issues of concern. Review of potential candidate communities and identification of points of contact were accomplished through CDM's network of offices.

Over a period of two months, the questionnaires were distributed to a number of communities by fax, e-mail, and by direct telephone solicitation. The results of individual interviews have provided a level of insight into the programs and the "economy of scale" processes of various other communities. The following section provides a summary of findings, with the questionnaires included in Appendix A.

2. Questionnaire Results

2.1 Wastewater Treatment Plants

The U.S. communities included in the survey were large cities with a variety of WWTP assets, ranging from a single WWTP serving the urban service area for the Massachusetts Water Resources Authority (MWRA) to multiple plants for communities such as New York City, the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) and Northeast Ohio Regional Sewer District (NEORSD). Other communities providing information included Milwaukee, Washington, D.C., Los Angeles, Minneapolis/St. Paul, Dallas, and Houston.

Additionally, information on international locations was obtained from the CDM and WRc staffs who were involved in a number of these programs. Responses indicated a preference for serving the large cities with multiple WWTPs for a variety of reasons (as noted in Table 2), although the island nation of Singapore is consolidating their five to six facilities into two larger treatment plants in order to reclaim the land for new development.

2.2 Wastewater Collection Systems

The collection systems of communities surveyed were similar in most respects to that of DWSD. However, many included multiple plants for communities such as New York City, Chicago, Boston, and Cincinnati (Metropolitan sewer District of Greater Cincinnati (MSDGC)). Detailed descriptions are provided in section 4.1

Each community has a program of wastewater collection system maintenance including internal inspection, rehabilitation, and replacement. The individual programs vary widely from Boston's "opportunistic" approach based on intensive reconstruction of infrastructure concurrent with redevelopment of the downtown area, to Cincinnati MSD's aggressive scheduled program for internal inspection and rehabilitation. It seems clear that each of these communities has established a program consistent with their own local financial and political considerations.

2.3 Summary of Results

Analysis of the questionnaire responses revealed a wide variety in approach and opinion on the issue of "economy of scale" in wastewater treatment. Much of the differentiation can be attributed to local conditions. Wastewater collection variations were more difficult to identify in similar communities; the programs appear to be individually oriented to local conditions.

3. U.S. Wastewater Treatment Facilities

During the survey, the number and capacity of treatment facilities owned by each community were reviewed, without regard for the type of treatment required. (The exceptions are discussed separately.) In most communities, the wastewater treatment facilities configuration is the result of a master planning effort. Typically, larger communities have several WWTPs serving individual drainage areas. Table 2 also shows that U.S. communities with populations similar to Detroit typically rely on a large wastewater treatment plant (MWRDGC-Stickney; Los Angeles-Hyperion; and MWRA-Deer Island), although New York City has a total of 14 WWTPs, with two in excess of 250 mgd. The reasons given for each community's approach includes a perceived economy of scale appropriate for their community, although most cities did not have clearly defined bases for their view.

Table 2. Summary of Questionnaires – Wastewater Treatment Facilities

City/Agency	Population Served (in Millions)	No. of WWTPs	No. >400mgd	No. >200mgd	No. >100 mgd	No. >50mgd	No. <50mgd	Remarks
Chicago (Metropolitan Water Reclamatation District of Greater Chicago)	5.1	7	1	2		1	3	Industrial population is equivalent to another 5 million.
Dallas	1.3	2			2			
District of Columbia, Water and Sewer Authority	2.0	1		1				Non-residential population is indeterminate. Note peak flow is approximately 900 mgd.
Houston	1.8	40		1		1	38	
Los Angeles	4	4	1			1	2	2 WWTPs are designed for reclaimed water production.
Massachusetts Water Resources Authority	2.6	2	1			1		
Metropolitan Council (Minneapolis/St. Paul)	2.5	8		1			7	Developed as regional system.
Milwaukee	1.25	2		1	1			Operating contractor provided limited information.
New York	8	14		3	4	2	5	Non-residential population indeterminate.
Northeast Ohio Regional Sewer District	1.14	3			3			

The following subsections highlight the essential points raised by each community in the interview/questionnaire process:

3.1 New York City

The City of New York has looked informally at the issue of economy of scale vs. "manageability," although no written analysis has been performed by the City's upper management staff.

While no "hard" data are available, their consensus is that the WWTPs in the 100- to 150-mgd (ADF) range accomplish "economy of scale" and are also "manageable." This refers to the ability of staff to accomplish all routine maintenance and housekeeping tasks in an efficient and effective manner. Their impression of larger plants is that small things are not getting done, and that the WWTPs in the 100- to 150-mgd range represent an optimum size for their utility. New York reported four WWTPs in the range of 100 to 160 mgd; three additional WWTPs in the 200-to 310-mgd range; and seven WWTPs in the <80-mgd size range, for comparison. They serve a total residential population of 8 million, with an unknown number of visitors, etc.

3.2 Metropolitan Water Reclamation District of Greater Chicago (MWRDGC)

This utility has evaluated the issue of economy of scale to a degree that few other utilities have reported. In the Chicago area, budgeting for operations and maintenance (O&M) is established by individual WWTP. The district's seven WWTPs range in size from the 800-mgd Stickney WWTP to their smallest WWTP, the Lamont facility at 3.4 mgd. To the MWRDGC management, there is little doubt that economy of scale occurs with their larger WWTPs (in addition to Stickney, MWRDGC also operates two other large WWTPs in excess of 200 mgd at Calumet and Northside). Budgeted costs (liquid treatment costs only) for 2001 for the WWTPs is included in Appendix A. MWRDGC is convinced that despite some variances with individual WWTPs, the cost of treatment for the larger plants is significantly less than for the smaller plants; however, they do not perceive significant cost savings between the largest WWTP (Stickney) and the other two large WWTPs. There is no thought given to further consolidation of the larger facilities because each facility serves a separate drainage basin, and transporting the flows from one basin to another is considered expensive. Recently, the District had the opportunity to study the cost effectiveness of eliminating the smallest (Lamont) WWTP and redirecting the flow to the Stickney WWTP. However, the cost of transportation to Stickney overshadowed the O&M savings, and despite their preference to eliminate the Lamont WWTP, the District will most likely expand the small facility. The district serves a population of 5 million with another 5.1 million population equivalents for industrial flows.

3.3 Massachusetts Water Resources Authority (MWRA)

This agency has two WWTPs serving a 2.6-million population—the large (360-mgd) Deer Island WWTP and a small (1.2-mgd) WWTP serving a remote area. The Deer Island WWTP is considered to be operating with true economy of scale, based on the consolidation of the Nutt Island WWTP to the Deer Island site. The operations manager for the WWTP cites the reduction in staff from the two WWTPs to the single facility at Deer Island resulting from the Nutt Island conversion to pretreatment with

liquid and biosolids processing at Deer Island. Not only is there a reduction in staffing, the manager indicates that there has also been a reduction in the use of electricity and chemicals with a single larger WWTP. Combined sewer flow management will also center on the Deer Island facility to provide a primary capacity of 1200 mgd and a secondary capacity of up to 700 mgd during wet weather events; other components will include storage and separate combined sewer overflow treatment.

3.4 District of Columbia Water and Sewer Authority (DCWASA)

The District of Columbia and portions of four surrounding counties in Maryland and Virginia (totaling approximately two million residents) are served by a single regional WWTP. The Blue Plains facility serves the older combined sewer areas of Washington D.C. and the separate sewer areas of the surrounding communities. The advanced wastewater treatment facilities provide treatment for 370 mgd average daily flow (over 900 mgd wet weather peak). The facility is considered to be operating with economy of scale because of the ability to centralize maintenance and operation staff and support services in one location. The higher cost to maintain larger equipment is a negative aspect along with the more difficult to operate complex facilities needed to meet stringent effluent standards. Projects to enhance the controls within the plant are expected to address the difficulties associated with manual operations of this large complex facility. In addition, a new maintenance management system and staff training to comfortably use these new tools are expected to further enhance the benefits of economy of scale.

3.5 City of Los Angeles

This community of 4 million is served by a major WWTP (Hyperion WWTP at 450-mgd average daily flow) and a second WWTP at Terminal Island, with a capacity of 18 mgd. In addition, the City operates two additional water reclamation facilities, with a design based on recovering water for irrigation purposes. These are the Tillman (80 mgd) and LA/Glendale (20 mgd) water reclamation facilities constructed upstream of the Hyperion WWTP along the trunk sewer system. The issue of economy of scale has been considered by the City with the Hyperion and Terminal Island WWTPs; the Hyperion WWTP is less expensive to operate than Terminal Island.

The issue of cost of operation for the reclamation facilities is more complex because these facilities provide a higher degree of treatment (partial Total N removal) than the secondary treatment provided at Hyperion. These facilities are therefore more expensive to operate, even considering that sludge from the reclamation plants is sent to the Hyperion WWTP for processing. The City has recently commissioned a facilities plan for the wastewater system, with one goal addressing the cost of treatment. The future cost of treatment is expected to be influenced significantly by the requirements of the LA Regional Water Resource Board for quantity and quality of additional reclaimed water. Future expansion of the Hyperion WWTP by another 100 mgd can be accommodated on the existing site and will be the preferred option for additional capacity.

3.6 Northeast Ohio Regional Sewer District (NEORSD)

The 1.14-million customers of the City of Cleveland and much of the surrounding area are served by three major WWTPs (Southerly at 175 mgd, Easterly at 155 mgd, and Westerly at 100 mgd) and one small WWTP operated by the NEORSD. These facilities were planned to serve the Cleveland area from the earliest plan for wastewater in the early 1900s. The NEORSD believes it has attained economy of scale with the three existing WWTPs, based on a comparison of their rates with other local communities. Treatment costs are cited as typical. As a result, some of the local communities have joined the district and have been connected to the wastewater treatment plants through trunk sewer extensions. The staffing of the WWTPs has been optimized over the past several years to obtain this economy of scale. The optimization has included staff reductions through attrition from 700 to 550 and a program of cross-training and aggressive conversion to automation and supervisory control and data acquisition (SCADA).

3.7 Metropolitan Council

The region around Minneapolis/St. Paul is governed by a regional agency established by the state and encompasses a total of 104 communities. The wastewater treatment facilities have been developed based on a plan developed in the late 1960s to address pollution problems caused by wastewater discharges into the lakes in the region. The plan resulted in regionalization of wastewater treatment from a total of 35 WWTPs to 8 at present. The largest of these is the Metropolitan WWTP at 251 mgd with two others at 38 mgd each. Regarding economy of scale, the Metro WWTP may be too big for their community to allow staff to build enthusiasm for their teams and locations. Regional plants in the 20 to 30 mgd are believed to offer reasonable economy of scale, while enhancing team enthusiasm to aid in effective management of the facilities. Sludge processing is provided on a more regional basis, with only Metro and three other dispersed WWTPs equipped with sludge processing facilities. Metropolitan Council management believes recent optimization projects have significantly improved the economy of scale benefits at the Metro WWTP. Further centralization would encounter a number of environmental, socio–economic and political hurdles.

3.8 City of Dallas

The City is served by two wastewater treatment plants—the Central and Southside WWTPs. The Central WWTP is a 179-mgd ADF capacity WWTP, which is located at a site selected in 1912. When the population growth shifted to the south in the 1960s, the City elected to construct a new Southside WWTP at the furthest south extremity of the anticipated service area. This 110-mgd plant now serves approximately 450,000 of the total population of 1.3 million. The issue of economy of scale has not been fully investigated; the second WWTP was constructed based on the need to serve a growth

area without use of a large number of pumping stations. At present, there is only one major pump station, and it discharges to one of the treatment trains at the Central WWTP.

Because of the unique nature of the Central WWTP (there are actually two separate WWTPs on the same site), true economy of scale is not being realized with the present configuration of the WWTPs. The City believes, however, they are achieving economy of scale with the centralized bio-solids management complex located at the Southside WWTP. This existing facility will soon be enhanced by eliminating old digesters at the Central WWTP and pumping raw sludge to an expanded centralized sludge management complex; however, no further consolidation of the liquid stream is being contemplated.

The existing collection system allows for diversion of a portion of the service area flow (approximately 20 percent) to either of the two WWTPs. This is a feature that the City likes about having multiple facilities. As a matter of convenience, the City wastewater planning staff would prefer to have another treatment plant further upstream in the collection system; but that is considered unfeasible because of the politics of siting a new WWTP in existing built-up areas. The advantages cited by the City staff for this additional facility include elimination of expensive, large, conveyance piping networks (the City notes that their service area is extremely spread-out, with low densities of 4,200 people per square mile or 6.5 people per acre.)

3.9 City of Houston

The City of Houston has grown to a population to 1.8 million, with a corresponding growth in total area. With annexations, the City often found that they had acquired additional small WWTPs serving the annexed areas. Because of the widespread area and the flat topography, the City also operates a total of 58 pumping stations, in addition to the 40 WWTPs. These WWTPs range in size from the 200-mgd 69th Street, down to a number of WWTPs of less than 1 mgd. The City has eliminated 39 WWTPs over the past 15 years and has been able to eliminate many of their smallest facilities. Based on studies undertaken for Houston, the City believes that economy of scale begins to be realized in the 5-mgd range. Their long-term objective is to consolidate to only a few large WWTPs to optimize the operation and maintenance, and to improve reliability. This has not been formalized into a comprehensive master plan; rather it is more of an *ad hoc* plan developed by management at the City.

Houston has incorporated existing small WWTPs into their larger plants, where possible, and will continue this approach. The City has a consolidated sludge management system, with dewatering and drying implemented on an around-the-clock basis at two of their facilities, and sludge management using other technologies practiced on a regional basis for a number of other facilities. Staffing is only one shift for all but the two WWTPs. Heat drying processes and use of SCADA to monitor WWTP operations during off-hours is common.

The City is unlikely to ever abandon the multiple WWTP concept, since the cost involved in transporting the flows to a centralized WWTP would be too great and there is insufficient space at the 69th street WWTP to handle any significant plant expansion. The City also believes that excessive costs are incorporated with spare facilities and equipment for very large WWTPs.

Their reasoning is that the large equipment required for very large WWTPs is not readily available "off-the-shelf" and is needed to be stored in reserve by the facility or risk long lead times to acquire equipment spare parts. Their concerns with larger plants having more complex equipment repair needs are mitigated by the use of multiple trains, with standby capacity in the larger facilities.

3.10 Milwaukee Metropolitan Sewerage District

Two WWTPs serve this 430 square mile area with a municipal and industrial population of 1.25 million. The Jones Island WWTP is rated at 150 mgd, and the South Shore WWTP is rated at 110 mgd. These facilities evolved with shifting populations being accommodated by the construction of the second WWTP. There was no assessment of the efficiency or economy of scale benefits for these two WWTPs, which are now being operated by a private contract operations firm.

4. Wastewater Treatment Facilities Outside the U.S.

4.1 North America

The city of Montreal currently operates a single large WWTP (570 mgd ADF/1618 mgd peak). The decision to construct the plant was based on a legal obligation to discharge all wastewater from the island towards the riviere de prairie district. Mexico City has four WWTPs that are planned for construction, two of which details are known. The total volume of wastewater from Mexico City was estimated to be 912 mgd in dry season, 1824 mgd in rainy season. In 1996, 75% of this was used for irrigation without treatment, and 752 mgd treatment capacity was provided by 32 small WWTPs. Disposal is via 3 manmade outlets.

4.2 South America

In Brazil two WWTPs are noteworthy. The plant in Rio de Janeiro (243 mgd ADF, 639 mgd peak) provides preliminary treatment, then discharges to the sea. The Barueri plant (planned expansion to 649 mgd ADF/2462 mgd peak), located in Sao Paulo, has the need to treat 469 mgd by 2005. The plant has one module, built in 1997, with the capacity to treat 159 mgd, and operated efficiently for its first 5 years. Starting in April 1995, treatment objectives were not met for 4 consecutive months, a problem thought to have been caused by a series of toxic shocks.

4.3 Africa

The first of 3 modules is near completion in Cairo, Egypt. As part of the Greater Cairo Wastewater Project, the WWTP will perform non-nitrifying ASP and sludge treatment. Stage II is currently in preliminary design stages, and when fully completed the plant will be situated to provide for the use of treated wastewater for irrigation.

4.4 Asia

Six cities within Asia are served by major wastewater treatment facilities. The following sections discuss these WWTPs.

4.4.1 Singapore

The city/nation of Singapore is consolidating their existing six WWTPs into two larger regional facilities in order to reclaim the land for other purposes that the extra facilities would require. Consolidation is coupled with a Deep Tunnel wastewater collection system that will allow the flows to be readily diverted to the future consolidated treatment plants. The schedule for constructing the future consolidated WWTPs is long-term; the first of two plants is under design (initial capacity is 800,000 cmd (211 mgd) at peak flow rate. The second facility will be sized when design commences in about 10 years. Existing WWTPs range from 40 to 95 mg, (total combined capacity is over 400 mgd), so the consolidation will provide for two WWTPs of comparable size. For Singapore, the economy of consolidation is focused on the land commitment of multiple WWTPs with their redundant support and other facilities at each WWTP, rather than specifically the efficiency of the WWTP.

4.4.2 Bangkok

Bangkok is in the process of constructing five WWTPs to serve the capitol of Thailand. These WWTPs are typically in the range of 250,000 to 300,000 cmd (66 to 80 mgd), with more planned to serve the remaining areas of the city of 10 million. In the areas surrounding the city, three WWTPs are planned, with one constructed—the Samut Prakam WWTP designed by CDM, at 525,000 cmd (138 mgd). Decisions to site this number of WWTPs had nothing to do with the issue of trying to achieve enhanced economy of scale; rather, the decision was based on staged funding, which allowed for more of the smaller WWTPs and combined collection systems.

4.4.3 Tokyo

Four WWTPs, the Shinmachi, Morigasaki, Shin-Kawagishi, and Shibura serve the Tokyo, Japan area. The population density served by the Shinmachi plant is extremely high and land values are correspondingly high. Therefore the local authorities prefer to extend the existing WWTP on the land they already own. Problems with the Morigasaki are known to have caused local flooding near Tokyo airport.

4.4.4 Beijing

In the late 1980's Beijing was served by only one secondary sewage treatment plant with an annual capacity of 500,000 tons. The Gaobedian plant, commissioned in the early 1990's treats about 30% of all Beijing's sewage.
Nineteen new WWTPs are currently in the design/planning stages, such that eventually 90% of sewage will be treated.

4.4.5 Seoul

The city of Seoul, South Korea is served by an activated sludge plant. Gayang was constructed during a major Waste Water Treatment Works program in the 1980's, after rapid population increase, economic development and industrialization caused pollution in the 1960's. Treatment at the plant met legal influent criteria, but since 1996 these criteria have become more rigorous. Hence, additional facilities will be needed.

4.4.6 Hong Kong

Hong Kong's population of 7 million people is served by a number of facilities. Many of these have been recently constructed or upgraded to address the severe pollution problems of near shore water. A series of preliminary treatment facilities on Hong Kong Island are connected by tunnel to the largest WWTP on Stonecutter Island. This plant provides treatment for 347 mgd above average day flow with capacity for up to 913 mgd. Other new facilities are currently under design and construction.

4.5 Europe

The following sections provide an overview of major WWTPs located in Europe.

4.5.1 London, England

In England London, served by the Beckton WWTP (277 mgd ADF/730 mgd peak) located at the outfall of the interceptor sewer built in the 19th century along the North Bank of the Thames in London. The outfall is within the tidal reaches of the Thames Estuary and the effluent has a 60-day retention within the river before clearing to the sea. This resulted in severe pollution prior to extension and upgrading of Beckton since the 1960's.

4.5.2 Vienna, Austria

The Main WWTP in Simmering, Vienna was commissioned in 1980 and expanded around 1992. The existing plant was enlarged to provide sufficient capacity for the forecast growth in population to 2015, and includes primary, intermediate, and final sedimentation, with aeration and sludge thickening.

4.5.3 Emscher, Germany

The plant in Emscher was under construction from 1966 to 1977, and is used to treat domestic and industrial effluent flowing out of a 744 square kilometer area. The plant was expanded to meet requirements of nitrogen and phosphorus removal. Decentralization of the plant is planned and will reduce treatment from 5.0 million Population Equivalent (PE) to 1.3 million PE.

4.5.4 Hamburg Germany

Hamburg is served by two plants operated in series. The Kohlbrandhoft plant was constructed in 1961 and extended in 1973. In 1988, Dradenau, located 2.3 km from Kohlbrandhoft, was linked by pipeline to provide further treatment (nitrification, denitrification, and phosphate removal). The plant currently removes an average of 70% of influent nitrogen. Closure of another WWTP will result in treatment of an additional 0.25 million PE.

4.5.5 Turin, Italy

The Azienda Po-Sangone in Turin treats 30% industrial, and 70% municipal effluent, providing primary sedimentation, secondary treatment, activated sludge, secondary clarification, and phosphate removal, as well as filtration.

4.5.6 Rome Italy

The Rome South plant has shown that the economics of scale are advantageous. The unit cost was found to be greater for smaller works even if cake conc. is similar. Costs of personnel and amortization show proportional savings with increased treatment capacity.

4.5.7 Istanbul, Turkey

The Riva WWTP in Istanbul, Turkey is located on the Black Sea coast and is designed as a two-stage step feeding system. Currently, Istanbul is the major polluter of the Marmara Sea.

4.5.8. Ankara, Turkey

The Ankara Central Wastewater Treatment Plant is a conventional facility comprised of preliminary treatment, primary and secondary sedimentation, and aeration facilities. The plant has a population equivalent hydraulic treatment capacity of over 750 mgd.

4.5.9 Paris

The fourth and most recent stage of the Acheres WWTP in Paris, France serves a population equivalent of 2.5 M alone. The reasons for the construction of this plant are both historical and topographical. The sewer system of Paris was laid out in the 19th century as gravity fed. The shape of the basin means that the five major sewers drain to the Acheres Plain and an outfall into the River Seine. Some of the wastewater is diverted to other works to relieve the load entering the Seine at this point.

4.5.10 Athens

Athens, Greece is served by the Psyttalia Island plant, constructed under 2 phases (the second to be complete in 2002). Phase A commissioned in 1994 provides preliminary and primary treatment and disposal to a sea outfall. Phase B is being built to comply with the EU Urban Waste Water Directive, and will provide biological and sludge treatment.

4.6 Summary of WWTPs outside the U.S.

Typical large cities with multiple WWTPs include Sydney (Bondi at 42 mgd, Malabar at 169 mgd, and North Head at 86 mgd) and Paris, which has several WWTPs, including one in excess of 500 mgd. In many of the older and/or rapidly growing cities, the issue of land appears to be a major concern. For example, Hong Kong has a large WWTP (Stonecutter at 455 mgd), along with several smaller WWTPs and is studying how to upgrade the WWTPs to secondary treatment while conserving space. Results of this study are not yet available, and Hong Kong's decision is unclear.

Results of inquiries made through WRc indicate similar results to the CDM responses. The number of large cities with a single large wastewater treatment works of more than 200 mgd ADF is limited. These include Montreal, Sao Paulo, Rio de Janeiro, and a new facility planned for St. Petersburg to serve a 4.8-million population.

In contrast, Tokyo is served by four facilities ranging from 112 mgd ADF/282 mgd peak to 322-mgd/406 mgd, and Beijing will be served by approximately 20 treatment works with one at 264-mgd/695 mgd. Mexico City will have multiple facilities and Emscher (Germany) is decentralizing their 368 mgd/684 mgd and the existing large facility is being down graded. Rome has several treatment works, but uses centralized facilities for treatment of sludge.

5. Wastewater Treatment Facilities Summary

The majority of the communities surveyed operate multiple WWTPs, and they expressed a range of opinions on the economy of scale issues, ranging from a general opinion that the larger plants were more cost effective, to the explicit cost data from the Metropolitan District of Greater Chicago Stickney WWTP, which is significantly more cost efficient to operate than the smaller WWTPs. One point, however, that most of the communities with multiple WWTPs cited as a benefit is the existing or potential capability to divert flows from one service area to another to address wet-weather flow issues. Another frequent concern of many communities is the difficulties that

would be encountered in attempting to site a new major WWTP within existing built-up service areas, were frequent comment from many communities. New York City's observation that facilities in the 150- to 200-mgd range appeared to be the most effectively managed indicates that costs are not the exclusive determinant in selecting an optimum facility mix for the individual community. Of other note were the comments from MWRA regarding handling wet weather flows at separate locations, rather than in their Deer Island facility. Other communities made similar comments about the need to assess the cost of transportation i.e., new sewers, and the cost of expanded facilities compared to the cost of new facilities.

Another comment worth noting was one from the Director of Maintenance services at the District of Columbia Blue Plains WWTP. The notion that systems can be installed in large WWTPs to enhance the operability and maintenance of these works is well accepted; however, the efficacy of those systems is entirely reliant on staff understanding how to use them and having a comfort level with these enhancements. The Metropolitan Council experience is that their facilities are achieving a measure of economy of scale while meeting environmental and local concerns and allowing staff to build team enthusiasm necessary for successful operations.

Throughout the comments received, the uniqueness of each community's economic, geographical, and political circumstances was emphasized. Appendix A contains copies of the questionnaires completed for these communities.

For the international cities, the cost issues appear to be a significant factor in how each community develops their wastewater treatment works, and none reported a problem with operating a large facility. However, many of these communities have multiple treatment works, which are often the result of sewers constructed to serve drainage basins.

It is observed that multiple facilities do seem to be more popular than single large facilities; however, many communities with multiple facilities do have a single large facility in excess of 500 mgd (Paris has multiple facilities including the Acheres works at 713 mgd/1598 mgd.)

6. Wastewater Collection Systems

Fewer U.S. communities were contacted because of the limitations placed on the contacts: namely, communities with similar age of sewers, preferably Midwestern, and with experience with combined sewers. Copies of the completed questionnaires are located in Appendix B. A survey of collection systems information for communities outside the U.S. was not available. Table 3 at the end of this section presents a summary of questionnaire information.

6.1 Boston

BWSC has not focused on the issue of life expectancy of their sewers, other than to assume a life expectancy of 60 years, based on pipe manufacturer's estimates. The staff understands that longer life is often realized, but that the actual life of the sewers

is affected to a great extent by the conditions established when the pipe was installed; especially the type and care given to the bedding of the sewers. The most troubling sewer line material has been vitrified clay pipe (VCP) because of the sensitivity to proper bedding and the joint materials. Both issues have led to problems with high inflow/infiltration (I/I) rates and root intrusion.

The City has a great deal of ongoing redevelopment, and the current approach of the BWSC is to be "opportunistic" in replacing the sewers in the areas where others have paid for the excavation. This is tied to a "guarantee" that the City provides to the citizens, that the streets will not be disturbed by planned projects for a 5-year period after completion of a project. Therefore, it is advantageous to replace the aging sewers in the areas of the City where redevelopment occurs. Problems associated with this approach include the following:

- The City does not yet have a model of the entire system, so necessary changes in sewer sizes may be unknown.

- The Combined Sewer Long-Term Control Plan is calling for sewer separation in large areas of the community, so the extent of areas to be disturbed at one time will be greatly increased with this planned construction program.

Maintenance and rehabilitation processes are in place, with maintenance or repair typically performed by City crews on an as-needed basis, in response to a problem. This approach is a result of the amount of reconstruction associated with new construction, including the Central Artery Project (which has focused a great deal of funding and attention on the relocation of utilities associated with that multi-year project).

Similarly, sewer inspections using CCTV have been mostly in response to problems. City CCTV crews have produced a large volume of tapes of much of the sewer system; however, no systematic cataloging of the tapes and no database of inspection reports for this information have been implemented.

Data management is not well defined for the sewer system mapping at this time. Manholes and pipes are shown on a GIS mapping system, but the attribute data are not included as yet; and some staff members prefer the old atlases for sewer information.

Other means of visual inspection, including sonar to detect debris buildup, have been used with limited success. In addition, manhole inspections and "lamping" of the sewers between manholes continues as a crude means of identifying the condition of the sewers.

Rehabilitation techniques used include cured in place lining, slip lining on a limited basis, and pipe bursting. Although rehabilitation of the sewers has been ongoing, City staff believes that more time is needed to determine the impact of such methods on the life of the collection system.

6.2 City of Chicago

The City of Chicago considers sewers to have a highly variable life expectancy. They know that some of their brick sewers are over 100 years in age (although records are limited to identify when some of the sewers were actually installed, because of records lost in the Great Chicago fire). Sewer mapping data is currently displayed on atlases, but a pilot GIS project is underway.

Their experience indicates that soil conditions and quality of initial installation have a tremendous bearing on the life expectancy of the sewers. Records are being updated to include all information on a GIS system, with a pilot program currently underway. Exactly how the attribute data (including age of sewers) from the atlases and record drawings will be incorporated into the GIS system is not yet determined.

In Chicago, the VCP pipe has resisted collapse, but is prone to I/I and susceptible to root intrusion. Respondents expressed concern that the collapse of old single-course brick sewers was possible even though they are newer than some other sewers. Typical materials of newer construction are VCP for sewers up to 24 inches in diameter and RCP above that size. In response to problems with some sewers, the City has undertaken a $30 million per year replacement sewer program to address water in basement (WIB) problems. These replacement projects are typically in response to customer complaints and are also typically "spread around" to be sure that the problem is being addressed in all parts of the City. The City handles all point repairs with in-house staff and equipment. In addition to the replacement program, the City reports that they are actively rehabilitating sewers with cured-in-place lining. The program started out with a budget of $1 million per year, and now up to $6 million per year of work is allocated.

With increased competition in this type of service, the cost of the rehabilitation work is actually decreasing. Using cured-in-place lining, the City reports good success with solving their problems with the single-course, 24-inch brick sewers; although the repairs have not been in place long enough to assess the long-term impact on sewer life expectancy.

In addition to the program for capital improvements for sewer replacement, the City is also undertaking a number of other measures for extending the life of their sewer infrastructure, such as sewer cleaning and TV inspection. Cleaning includes both the

sewers and the catch basins/inlets. Typically, catch basins are scheduled to be cleaned once every 4 years. In addition, there are sewer-cleaning contracts with multiple local contractors, who provide cleaning in response to problems and also support the sewer CCTV efforts. Typically, Chicago awards multiple contracts for cleaning based on sizes of sewers to be cleaned (8 to 21 inches; 24 to 36 inches; and >36 inches). This approach works well for Chicago in assuring competition, and they also have a comprehensive set of specifications defining expectations for time to complete work and control of the work of the contractors.

Chicago also uses private contractors for all sewer CCTV work. The City originally used City crews, but found the private contractors more efficient and less expensive. Currently, the City has three contracts for CCTV based on geographic areas, with a total of 370,000 feet of CCTV work annually. This is 1.6 percent of the collection system. It was noted that as part of the advance work for the Democratic National Convention held in Chicago, all of the sewers in the entire downtown area required CCTV inspection, on a special-event basis.

6.3 Cincinnati Metropolitan Sewer District (MSD)

MSD reports a variety of materials of sewer construction and has established a typical life expectancy of 100 years, except for PVC, which they are estimating at 50 years. Specific factors that appear to affect the life expectancy of sewers are primarily the quality of the original installation, especially the bedding. Another factor is the selection of materials of construction for corrosion resistance. For that reason, MSD has found VCP to be an excellent material, because of its resistance to corrosive environments. MSD is willing to accept that there will be leakage at joints (cited as not a problem in their combined sewer areas.) Problems cited with other materials include leaky joints in World War II era concrete pipes (which didn't have O-ring gaskets), and brick sewers with thick mortar joints experiencing problems with mortar corrosion (tighter joints have better experience). Based on their experience and success in dealing with these different problems, the management staff estimates the above cited life expectancies.

To extend the life of the existing sewers, many of which are already over 100 years in age, the MSD has developed a proactive program. An integral part of their approach is a comprehensive GIS mapping of the sewers with an attached Oracle database containing the attribute data for the sewers. A second part of the program is a maintenance program designed to achieve cleaning and CCTV coverage of the complete sewer system on a 10-year cycle. As a result, they estimate that less than 10 percent of their cleaning is now in response to problems. Cleaning of sewers is done with in-house staff (2/3), and with contractors (1/3). All CCTV is done in-house. MSD has focused on accessibility issues, since many of their sewers are located along steep ravines; they have installed several CCTV systems and flusher equipment on John Deere tractor frames to access sewers off-road.

In addition to CCTV, manholes are visually inspected, and sonar has been used in conjunction with CCTV to locate problems on large sewers. CCTV provides images of above-liquid level, and sonar can identify roots or holes in the sewers below liquid level. Plans include use of sonar in all large-diameter sewers during the next several years. Based on the internal inspection experience and anticipated CMOM requirements, the focus on preventive maintenance (PM) is expected to extend the life of the sewers.

Repairs are generally handled by 12 in-house crews, with contractors on call. Annually, MSD spends about $2.5 million on contract work. Most repairs occur on house lateral connections in the public ROW. Scheduled rehabilitation includes cured-in-place lining of sewers (up to 42-inch diameter), at a rate of about $6 million per year, using three separate contractors on an as-needed basis. This provides about 6 miles per year of relining (note that a backlog of 20 miles of needed relining work is estimated). Based on manufacturer's claims and success to date, it is estimated relining will add 50 years to the life of the sewers being lined. Experience with slip lining using HDPE/PVC has convinced MSD to discontinue that approach. Stretching of the slip liner during installation has been experienced (with shrinkage back to the original dimensions within a few years, resulting in blockages of laterals and effective loss of use of sewer). Root intrusion has also been found to continue within the annular space around the liner when grouting was not performed, or with deterioration of grout over time. Other trenchless technologies, such as pipe bursting, have been successful for sewers up to 18 inches in diameter. These approaches are typically used in special cases only.

MSD has concluded that they save money by focusing on a preventive maintenance approach to sewer maintenance as opposed to reacting to problems. A key part of their philosophy was described as establishing performance standards for the MSD crews (linear feet of sewer per day for cleaning/CCTV crews.) If all crews met the performance standards, then the standards were considered too low and revised. Similarly, MSD determined their cleaning goals were too high and reduced them to allow time for cutting roots after cleaning and before CCTV work. MSD management has provided a copy of their internal budget planning documentation as an example of how they approach the maintenance of the collection system.

6.4 Milwaukee Metropolitan Sewerage District

Representatives of the operating contractor for Milwaukee reported better than expected life for the collection system (without specifics). This contractor provides cleaning for both emergency and scheduled maintenance, with their own crews used for CCTV. The contractor reported using cured-in-place lining for up to 42-inch diameter sewers and also slip lining of sewers. The results are reported to be extending the life of the sewers (without specific data).

6.5 New York Department of Environmental Protection (NYDEP)

This community reported an expected life for their sewers of at least 100 years, with a variety of factors impacting that value--including: pipe materials, extent of surcharging of the sewers, traffic loading, utility interferences, and construction practices, such as tap-in procedures and bedding. They reported that many sewers installed in the 1850s are still in service. The City observed that VCP, properly installed, "lasts indefinitely," whereas un-reinforced concrete pipe usually fails within 40 years. The City representative also noted that combined sewers seemed to pose the most critical maintenance problems--more so than separate sanitary or storm sewers.

Rehabilitation practices found to be effective by NYDEP include gunite and lining. Their practice is to repair the sewer, while the cracks and deficiencies are still small, using lining. They have yet to experience a structural failure of any of these liners and, therefore, have no lower estimate of the impact of these processes on life expectancy of sewers. The goal of the lining program is to avoid structural collapse of the sewer, which requires point repairs. In those cases where point repairs are required, the City has in-house staff and equipment to perform manhole/catch basin and shallow sewer repairs.

Deeper sewers are referred to an on-call contractor, who perform the work on a time-and-material basis. Contractors repairing concrete or VCP pipe perform those services on a unit price ($/lf) basis.

The sewers are visually inspected on a scheduled basis by City staff using CCTV. This is being supplemented by newly purchased digital cameras mounted on poles and small snake-type cameras furnished to maintenance crews. These high-tech tools allow maintenance crews to make instantaneous assessments and eliminate the need for follow-up CCTV schedules. As a result, house connection problems can usually be resolved sooner.

The City sewer records are currently in the process of being converted to GIS. In addition, the atlas information is being converted, but the attribute data are not well managed.

7. Wastewater Collection System Summary

Each community has an individual approach to maintenance and replacement ranging from Boston's "opportunistic" approach to the structured approaches of Chicago and Cincinnati. There is also a wide array of opinions on life expectancy (although many communities did cite initial installation as a major factor affecting life experienced for a sewer). Table 3 provides a summary of some of the items outlined in the questionnaires.

Table 3. Summary of Questionnaires - Wastewater Collection Systems

COMMUNITY	Boston	Chicago	Cincinnati (Metropolitan Sewer District of Greater Cincinnati)	Milwaukee	New York City
Length of Sewers (in Miles)	NA	4,400	2,900	NA	6,600+
Life Expectancy in years	60	100 (2)	100	50-75	100 (5)
GIS	Yes w/Oracle database	Pilot underway	Yes w/Oracle database		Pilot Underway
Sewer Materials					
VCP	Y	Y	Y		Y
RCP	Y	Y	Y	Y	Y
NRCP		Y	Y		Y
Brick	Y	Y	Y	Y	Y
Others	Y		Y	Y	
Cleaning Crews					
City	Y		Y		Y
Contractor	AN	Y	Y	Y	AN
Cycle		4 years (1)	10 years	AN	AN
CCTV Crews					
City	Y	N	Y		Y
Contractor	AN	Y	N	Y	Y
Cycle		60 years	10 years	AN	AN
Replacement Program	AN	Y (3)	Y (4)		AN

Notes:
(1)- Cleaning cycle is for catch basins only.
(2)- Life expectancy varies based on variety of factors.
(3)- Lining is $6M/yr and replacement is $30M/yr.
(4)- Lining is $6M/yr and replacement is separate.
(5)- Life expectancy varies from 40 yrs for non-reinforced concrete to indefinite for properly installed VCP.
NA-Not Available
AN- As Needed