# Operations and Maintenance Report

MULTI-AGENCY

# Benchmarking Study

December 1999

MULTI-AGENCY BENCHMARKING STUDY

# Operations and Maintenance Report

*Participating Agencies*

Central Contra Costa Sanitation District

City of Los Angeles Bureau of Sanitation

City of Portland Bureau of Environmental Services

East Bay Municipal Utility District

King County Department of Natural Resources

Orange County Sanitation District

Sacramento Regional County Sanitation District

*In Consultation with*

Damon S. Williams Associates, L.L.C.

December 1999

Data and information used to develop this report are from Fiscal Year 1997 (FY1997).

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## TABLES

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## FIGURES

## FIGURES (continued)



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# Introduction

This report documents and compares the Operations and Maintenance (O&M) costs and business practices of the seven agencies participating in the Multi-Agency Benchmarking Study. Areas of potential cost savings or improvements are identified, and a list of best practices is proposed. The report summarizes major findings developed from normalized cost comparisons, process benchmarking surveys, and group workshops. Detailed analyses of each major plant process area and each maintenance function are included.

Cost comparisons are based on normalized values (using flow, tons of solids, or BOD) in order to attain truer comparisons. Conclusions are drawn based on comparing costs with business practices, and recommendations are offered to help the agencies gain efficiencies and reduce costs.

Data and information used to develop this report are from Fiscal Year 1997 (FY1997). Only Operating Budget Expenditures were used to compare costs in this O&M Report; Capital Budget Expenditures were not evaluated.

Considering the sensitivity of the data collected during the project, and adhering to a generally accepted code of conduct for benchmarking, no cost data in the final report refer to any of the seven agencies by name. Instead, the report uses a letter designation for each agency whenever cost information is presented.

## O&M WORK GROUP

The O&M Work Group consists of at least one member from each of the seven agencies, and has a single Group Lead who is responsible for O&M group and consultant oversight. The work group held telephone conference calls, meetings, and technical workshops as necessary to collect, prepare, and disseminate information. A sub-group was formed to assist in the preparation of the final report.

Throughout the study, O&M Work Group meetings were held at plant sites of the participating agencies. Tours of the plants were scheduled at each meeting; the tours provided the opportunity for work group members to observe processes unique to different agencies and learn about a facility’s specific operations and maintenance practices.

The O&M Work Group went through several iterations of data collection. Regular meetings to review and discuss cost allocation allowed each agency the opportunity to research their own costs and allocate them correctly.

Honest and open communications have been crucial to the success of the project. Regular meetings have provided a venue to discuss data collection methods, differences in cost allocations, differences in business operations, and areas of improvement identified by each agency. Discussions of where to distribute the incurred costs have helped identify alternative ways to distribute costs, perform work, and optimize systems. All of the agencies were accountable to each other to participate in and to actively contribute to honest information exchange.

## PERFORMANCE TRACKING SYSTEM

Use of a performance tracking system such as the Access database allows more agencies to be added to the project in the future. Comparisons of normalized cost data can be made more rapidly. Additionally, the database allows single-agency comparisons for multiple years, so individual agencies can track their cost trends. As new cost-saving measures are implemented, the effects of these changes can easily be evaluated using the database. In addition, agencies that participated in past studies can track their performance for FY1997 as well as their performance in previous years.

## DEFINITION OF COSTS

In FY1997, the average cost for the agencies to treat wastewater was $729 per million gallons treated, with the costs ranging between $530 and $976 per million gallons. These costs consist of administration/general costs, technical support costs, and operations and maintenance costs.

Administration/general costs include the costs for overall utility management and clerical functions, human resources, legal services, training, employee benefits, and other functions.

Technical support costs include all laboratory, source control, and other technical support for plant operations.

O&M costs include all costs specific to the plant, including all unit processes, plant clerical support, and other plant O&M functions (e.g., landscape maintenance). The O&M costs are evaluated in this report, and the benchmarking results are presented.

## COST COLLECTION TEMPLATE

The O&M Work Group developed sections of the Multi-Agency Benchmarking Project cost collection template involving the agencies' O&M functions. These sections of the template are organized generally by unit process, allowing collection and evaluation of the costs for each unit process, rather than general costs (which may or may not be applicable to each agency). The goal was to provide the data in discrete units, allowing comparison between agencies that use that specific unit process. The template and definitions used are included in Appendix A, MABS Template and Functional Area Definitions.

## IDENTIFICATION OF POTENTIAL AREAS OF IMPROVEMENT

A major objective of the O&M report is to help the agencies identify potential improvements and prioritize future work. For example, if some agencies discover that their chemical costs for dewatering are higher than other agencies' chemical costs, they might determine that additional study is warranted. Other agencies might want to continue researching their accounting and tracking systems and business practices before determining future actions.

Pooled resources can help make future studies more feasible and cost effective by distributing costs and benefits among participants. For example, several agencies may collaborate and share the costs of evaluating possible treatment alternatives, or discuss how changes in organizational structure and staffing changes have affected a facility.

The O&M Work Group has also identified situations in which group bargaining power may be helpful (e.g., addressing developing regulations that impact the wastewater field).

## AGENCY OVERVIEW

Table 1 provides summary information about the seven participating agencies, including average agency flow in FY1997 and the number of treatment facilities.

| **Table 1<br>Key Agency Facts** | | | |
|---|---|---|---|
| **Agency** | **Number of Wastewater Plants** | **1996-1997 Avg. Annual Influent Flow Rate (mgd*)** | **Governing Organization** |
| Central Contra Costa Sanitary District (CCCSD) | 1 | 49 | Special District |
| City of Los Angeles, Bureau of Sanitation (CLABS) | 4 | 444 | City of Los Angeles |
| City of Portland, Bureau of Environmental Services (CPBES) | 1 | 85 | City of Portland |
| East Bay Municipal Utility District (EBMUD) | 1 | 81 | Special District |
| King County Department of Natural Resources (KCDNR) | 2 | 200 | King County |
| Orange County Sanitation District (OCSD) | 2 | 244 | Special District |
| Sacramento Regional County Sanitation District (SRCSD) | 1 | 152 | Special District |

* mgd = millions of gallons per day

Note: CLABS, KCDNR, SRCSD, and EBMUD operate remote facilities not included in this study.

Table 2 shows the O&M cost centers used in the cost template, and indicates which unit processes are used at the various treatment facilities.

## Table 2
## Summary of O&M Cost Centers

| Agency | Flow (mgd)[1] | Pre- and/or Primary Treatment | | | Secondary Treatment | | | | | | | Residuals Handling | | | | | | | | | Other Plant Processes | | | | | | | | Misc. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Influent pumping | Preliminary treatment | Primary treatment | Pumping to secondary | Aeration basins | Oxygen reactor basins | Oxygen plant | Fixed film reactors | Secondary clarifiers | Other secondary processes | Screenings | Grit | Scum | Sludge thickening | Digestion | Dewatering | Biosolids disposal/reuse | Other residuals handling | Residuals stream odor control | Disinfection | Liquid stream odor control | Effluent pumping/outfall | Auxiliaries/utilities | Automated control systems | Tertiary treatment/reclamation | CMMS | Water Reclamation | Other O&M functions | Plant Supervision | Clerical support |
| CCCSD | 49 | • | • | • | • | • | | | | • | • | • | • | • | • | | • | • | • | • | • | • | • | • | • | | • | • | • | • | • |
| CLABS, Hyperion | 355[2] | | • | • | • | | • | • | | • | • | • | • | • | • | • | • | • | • | • | | • | • | • | • | | • | | • | • | • |
| CLABS, Tillman | 67 | • | • | • | | • | | | | • | • | | | | | | | | | | • | • | | • | • | • | • | • | • | • | • |
| CLABS, Terminal Island | 16 | | • | • | | • | | | | • | | • | • | • | • | • | • | • | | • | | • | • | • | • | • | • | | • | • | • |
| CLABS, LA- Glendale | 20 | • | • | • | | • | | | | • | | | | | | | | | | | • | • | | • | • | • | • | • | • | • | • |
| CPBES | 85 | • | • | • | | • | | | | • | | • | • | • | • | • | • | • | | • | • | • | • | • | • | • | • | | • | • | • |
| EBMUD | 81 | • | • | • | • | | • | • | | • | • | • | • | • | • | • | • | • | • | | • | • | • | • | • | | • | | • | • | • |
| KCDNR, East Plant | 79 | • | • | • | | • | | | | • | | • | • | • | • | • | • | • | | • | • | • | • | • | • | | • | • | • | • | • |
| KCDNR, West Plant | 121 | • | • | • | • | | • | • | | • | • | • | • | • | • | • | • | • | • | • | • | • | • | • | • | | • | • | • | • | • |
| OCSD, Plant 1 | 89 | • | • | • | • | • | | | • | • | • | • | • | | • | • | • | • | • | | | • | • | • | • | | • | | • | • | • |
| OCSD, Plant 2 | 155 | • | • | • | • | | • | • | | • | • | • | • | | • | • | • | • | • | | | • | • | • | • | | • | | • | • | • |
| SRCSD | 152 | • | • | • | | | • | • | | • | | • | • | | • | • | | • | | • | • | • | • | • | • | | • | | • | • | • |

Agency Abbreviations

CCCSD - Central Contra Costa Sanitary District

CLABS- City of Los Angeles Bureau of Sanitation

CPBES- City of Portland Bureau of Environmental Services

EBMUD - East Bay Municipal Utility District

KCDNR - King County Department of Natural Resources

OCSD - Orange County Sanitation District

SRCSD - Sacramento Regional County Sanitation District

1. Average annual flow in FY1997 in million gallons per day (mgd).
2. Wastewater flows through the CLABS Hyperion Plant include 14 mgd residual flows discharged from the Tillman and L.A.-Glendale plants. These discharge flows are reflected in the mgd flow listed here for Hyperion. Thus, although the total of all CLABS flows in this table is 458 mgd, actual flow through the system net of residuals is 444 mgd (458 mgd – 14 mgd = 444 mgd), as indicated in Table 1.1.1 on Page 2. Likewise, the net flow for Hyperion is 341 mgd (355 mgd – 14 mgd = 341 mgd).

Table 3 shows some of the effluent limits for each agency. All plants have other effluent limits, but those given in Table 3 are the most common parameters.

**Table 3**
**FY1997 Effluent Permit Limits**

| Agency | Plant | BOD[1] (mg/l) | TSS[2] (mg/l) | $Cl_2$ Residual (mg/l) | Coliform (MPN/100 ml)[3] | |
|---|---|---|---|---|---|---|
| | | | | | Total | Fecal |
| Central Contra Costa Sanitary District | | 25[4] | 30 | 0.0[5] | N/A[6] | 200 |
| City of Los Angeles Bureau of Sanitation | Hyperion | 190 | 95 | 0.84[5] | N/A | N/A |
| | Tillman | 20 | 15 | 0.1[7] | 2.2[8] | N/A |
| | Terminal Island | 15 | 15 | 0.1[7] | 1,000 | 200 |
| | LA-Glendale | 20 | 15 | 0.1[7] | 2.2[8] | N/A |
| City of Portland Bureau of Environmental Services | | 30 | 30 | 1.0[5] | N/A | 200 |
| East Bay Municipal Utility District | | 30 | 30 | 0.0[5] | 240[9] | N/A |
| King County Department of Natural Resources | East plant | 30 | 30 | 0.66[10] | N/A | 200 |
| | West plant | 30 | 30 | 0.216[10] | N/A | 200 |
| Orange County Sanitation District | Plant 1 | 100 | 60 | 0.001 | N/A | N/A |
| | Plant 2 | 100 | 60 | 0.001 | N/A | N/A |
| Sacramento Regional County Sanitation District | | 30 | 30 | 0.018[11] | 23[12] | N/A |

1 Biochemical oxygen demand (5-day), milligrams per liter – monthly average
2 Total suspended solids, milligram per liter – monthly average
3 Coliform count, most probable number (MPN) per 100 milliliters – monthly average
4 Value is for carbonaceous biochemical oxygen demand, milligrams per liter – monthly average
5 Instantaneous maximum
6 Not applicable
7 Daily maximum
8 7-day moving median
9 Most recent permit limitation is 500 fecal coliform
10 Monthly average
11 Daily average (monthly average is 0.011 mg/l)
12 Monthly median

# Methodology

This subsection describes the collection, organization, and analysis of performance and process benchmarking data. It also discusses presentation of the data in this report.

## DATA COLLECTION

### Performance Benchmarking

A template developed in the first phase of this project was upgraded and refined for this phase of the project. Data were requested for FY1997. Each of the agencies reviewed its expenditures and divided them into the categories presented in the template. The O&M Work Group met regularly to determine the best way to allocate costs to provide the most accurate comparisons. Use of the template brought up inevitable differences in the way each agency allocates costs, and the template was revised accordingly. Appendix A contains the template and definitions used in the study.

Various tools were used for data verification as the project proceeded. Ultimately, each agency compared the costs reported in the study with its actual expenditures for the project year. Additional verification occurred when the O&M Work Group met to compare costs. These meetings promoted more discussion about the different ways the individual agencies performed work or allocated costs. The data were reviewed to determine performance trouble spots and identify areas suitable for discussions about best practices.

The findings from the performance benchmarking efforts are discussed for each unit process in Benchmarking Results. Each unit process has a subsection called Performance Benchmarking in which comparative graphs are discussed and summary cost and labor tables may be presented.

### Process Benchmarking

The O&M Work Group developed Process Benchmarking Surveys designed to gather business practice information about the most important topics affecting its cost centers. The O&M surveys were Laboratory Analysis, New Technology Development, Automation, Energy, Information Management, Transition from Capital Project to Operating System, Predictive Maintenance, Off-shift Staffing, Combined Operation and Maintenance, Workforce Flexibility/Skill-Based Pay, Labor-Management Relations, Biosolids, Y2K, and Fleet services.

Representatives from each agency within each work group were responsible for researching the information and reporting back to the group. The most appropriate people from each agency responded to specific questions in the survey, and tracked the amount of time spent researching the responses. The responses were collated and distributed to the members of the work group to provide a basis for discussion on best practices. The Agencies' responses to these surveys are in Appendix B, Process Benchmarking Surveys.

The findings from the process benchmarking efforts are discussed for each unit process in Benchmarking Results. Each unit process evaluated has a subsection called Process Benchmarking in which information may be presented on unique or distinguishing features of the various facilities' unit process, impact of regulations, public perception, human resources, areas of challenge, areas of efficiency, and impact of capital facilities. The information presented in these sections was gathered from both the process benchmarking questionnaires and from the O&M group meetings.

## DATABASE DEVELOPMENT

The Access database is used as a data collection tool, as well as a method for data presentation after analysis. The structure of the cost collection database (CCD) is based on the data collection template. Each agency received an empty database and was responsible for direct data input at an appropriate level of detail.

Up to seven levels of depth for costs are available, but not all levels are used throughout all cost centers because some cost centers are simpler than others are. Costs are subdivided as far as each agency's accounting system allows, with some agencies able to provide very detailed information on a specific area or a specific unit process.

Sample pages and information on the Master Database are included in Appendix C, Overview of MABS Master Database.

## DATA ANALYSIS

After the raw data were collected from each of the agencies, they were entered into the Project Master Database. The Master Database was designed to accept sets of raw data from the individual agencies, normalize them, and then provide comparative tables and graphs. In order to accommodate the numerous types of analyses that are possible, the Master Database accepts many normalization factors.

Normalization factors are necessary to provide meaningful data comparisons and to reconcile the differences among the agencies by providing a common basis for comparison, such as cost per million gallons treated, rather than simple cost figures. Cost is affected by the size of a facility, and dividing by the amount of wastewater treated normalizes the data to allow straight comparisons. Appropriate normalization values vary with the type of analysis and the type of data desired. Many of the treatment plant processes, for example, can be normalized based on flow.

The normalized performance benchmarking results were compared and analyzed for differences among the agencies in operating costs and values for the same unit process. The process benchmarking results were invaluable in highlighting the defining characteristics between the unit processes at each facility, and any other constraints or considerations which may impact the efficiency and cost-effectiveness of a unit process.

Other considerations were also evaluated before making generalizations about the costs of any specific agency. For example, influent characteristics or effluent permit limit requirements may make some processes more or less effective at one plant than another. The type and age of the equipment used at each facility can affect costs. Regional differences in the cost of living can also influence cost data.

## DATA PRESENTATION

The O&M Work Group findings are presented in bar graphs, which present cost data in no specific or consistent order and refer to the agencies as Agency A through Agency G to protect the confidentiality of the analyses. Generally speaking, Agency A is the lowest-cost agency and Agency G is the highest-cost agency for most graphs. Because the lowest and highest-cost agencies change from one graph to another no single agency is consistently represented by any single letter throughout the final report. For the same area or process, graphs and tables do use the same letter for a particular agency so that they can be logically viewed together.

The bar graphs allow complementary costs to be summed flexibly across any combination of processes. For example, an agency can determine its total cost for odor control by adding isolated odor control costs from various liquids and solids stream processes. Similarly, an agency can determine its total cost for secondary treatment by adding together all secondary process costs. Care must be taken when combining values to ensure that all values are normalized by the same factor, such as total flow through the facility. Values normalized by different factors are not additive, and will result in inaccurate results.

The bar graphs are discussed in the Benchmarking Results section of this report. Analysis of the differences in cost, and conclusions and recommendations are presented to assist the agencies in choosing appropriate actions to continue the optimization efforts each of the agencies has implemented.

The process benchmarking section includes unique features, impact of regulations, public perception, human resources, areas of challenge, areas of efficiency, impact of capital facilities, and areas of future investigation as discussed at the O&M group meetings. Other information from process benchmarking surveys or other sources is also presented.

## CONSTRAINTS

The Access database allows users to compare data at up to seven levels depending on available data. This flexibility allows the data from any agency to be compared to another agency, regardless of the different treatment processes used at each plant. Cost comparisons alone, however, may lead to misinterpretation of the data, because none of the qualifying information is adequately expressed in the cost data. Also, some agencies may not have accounting systems in place to allow the level of detail in reporting that is necessary for this project. This may affect some of the data reporting.

Conclusions based solely on metric data are bound to contain inaccuracies because they do not account for the factors underlying the numbers. For example, metric data alone would not necessarily show that an agency has an extremely active public involvement program that successfully mitigates neighborhood concerns on planned projects. Raw data might reflect only that the program increases the overall cost of treatment, while failing to indicate the significant time and effort savings that such a program may reap at a later date.

The cost data reflect factors such as differing regulatory constraints, political edicts, or innovative programs that provide value-added products or services to customers, but may not provide the detail or context necessary to fully understand the impact of these factors. For example, each of the agencies participating in the Multi-Agency Benchmarking Project has permit requirements that affect the level and cost of treatment required. These effluent limits are presented in Table 3, FY1997 Effluent Permit Limits.

Some agencies operate under the umbrella of a larger organization over which the agency itself has no control. For example, overhead costs for an agency may be dependent on its role in the larger organization.

Similarly, the approach each agency takes to reclaiming wastewater or recycling biosolids will vary depending on local and state politics and regulations. These programs undoubtedly contribute to the overall cost of treatment, but may at the same time deliver a commensurate benefit to a community, or to an agency, in the form of research and development that may pay dividends in the future.

# General O&M Benchmarking Results

Raw O&M data were collected and allocated using the Master Database and the template definitions. All cost data are presented in U.S. dollars. All labor is presented in full-time equivalents (FTEs), representing a single full-time employee working 1,840 hours per year. Raw data were also collected on electrical consumption in kilowatt-hours (kWh) or pounds (lb) of chemical used, where applicable. Normalization factors (e.g., flow through a process) were also collected to allow a more accurate comparison of data.

Table 4 summarizes the average and range of O&M costs throughout the treatment facility. Costs were normalized by an appropriate normalization factor. For liquid stream processes, this is the flow in million gallons entering the process. For solids stream processes, it is the number of dry or wet tons treated in the process. Because the normalization factors are usually not the same for the various unit processes, costs cannot be summed to calculate the total treatment cost. Values of zero are not used to calculate the averages or presented as the low value. For better accuracy, suspect values were also not included in the calculation of averages.

**Table 4**
**O&M Costs Normalized for Specific Unit Processes and Functions**

| Unit Process | Normalized Cost $/MG or Dry Ton | | | Normalization Factor |
|---|---|---|---|---|
| | Average | Lowest | Highest | |
| Influent pumping | 14.94 | 11.03 | 19.79 | Process flow (MG) |
| Preliminary treatment | 9.72 | 3.30 | 20.59 | Process flow (MG) |
| Grit | 120.78 | 86.91 | 140.58 | Wet ton |
| Screenings | 215.61 | 89.75 | 442.31 | Wet ton |
| Primary treatment | 17.35 | 8.68 | 26.30 | Process flow (MG) |
| Scum | 4.15 | 3.36 | 4.74 | Plant flow (MG) |
| Pumping to secondary | 6.31 | 0.10 | 12.72 | Process flow (MG) |
| Aeration basins | 44.27 | 19.03 | 88.30 | Process flow (MG) |
| Oxygen plant | 18.34 | 7.62 | 27.55 | $O_2$ reactor basin flow (MG) |
| Oxygen reactor basins | 26.80 | 19.04 | 45.21 | Process flow (MG) |
| Other secondary processes | 5.95 | 4.39 | 7.43 | Process flow (MG) |
| Fixed film reactors | 14.17 | 14.17 | 14.17 | Process flow (MG) |
| Secondary clarifiers | 12.93 | 3.45 | 24.53 | Process flow (MG) |
| Liquid stream odor control | 12.15 | 0.54 | 38.04 | Plant flow (MG) |
| Disinfection/dechlorination | 29.08 | 7.67 | 75.56 | Plant flow (MG) |
| Tertiary treatment | 264.31 | 92.46 | 436.15 | Process flow (MG) |
| Effluent pumping/outfall | 7.52 | 2.90 | 11.96 | Plant flow (MG) |
| Water reclamation/conservation | 693.01 | 484.47 | 901.56 | Process flow (MG) |
| Sludge thickening | 21.86 | 15.97 | 30.90 | Dry ton |
| Anaerobic digestion | 24.67 | 11.80 | 51.30 | Dry ton |
| Dewatering | 50.98 | 26.37 | 110.72 | Dry ton |
| Biosolids disposal/reuse | 126.79 | 47.14 | 235.50 | Dry ton |
| Residuals stream odor control | 3.11 | 0.08 | 9.16 | Plant flow (MG) |
| Other residuals handling processes | 2.30 | 0.04 | 4.56 | Plant flow (MG) |
| Plant supervision | 23.10 | 11.36 | 43.58 | Plant flow (MG) |
| Automated control systems | 8.05 | 1.30 | 17.90 | Plant flow (MG) |
| Auxiliaries/utilities | 14.58 | 5.80 | 35.20 | Plant flow (MG) |
| Computerized Maintenance Monitoring System | 3.66 | 2.21 | 4.82 | Plant flow (MG) |

Notes: Costs calculated per quantity treated (in million gallons or tons of solids, as applicable) in the unit process. Zero values are not considered when determining low cost or average cost.

A general overview of total O&M costs is presented at the front of this section to provide context for the subsequent discussions of unit processes. Figure 1 shows the average percent of the total O&M budget that is spent on each unit process and the average total O&M costs to treat wastewater at the agencies. This is intended to give the reader a general impression of "where the money goes." It is not intended to depict the actual proportion for any individual agency, as each agency is different and allocates its budget differently based on the agency's individual circumstances. It does, however, show the average proportions for all of the agencies, and is a good indicator of current trends in budget expenditures.

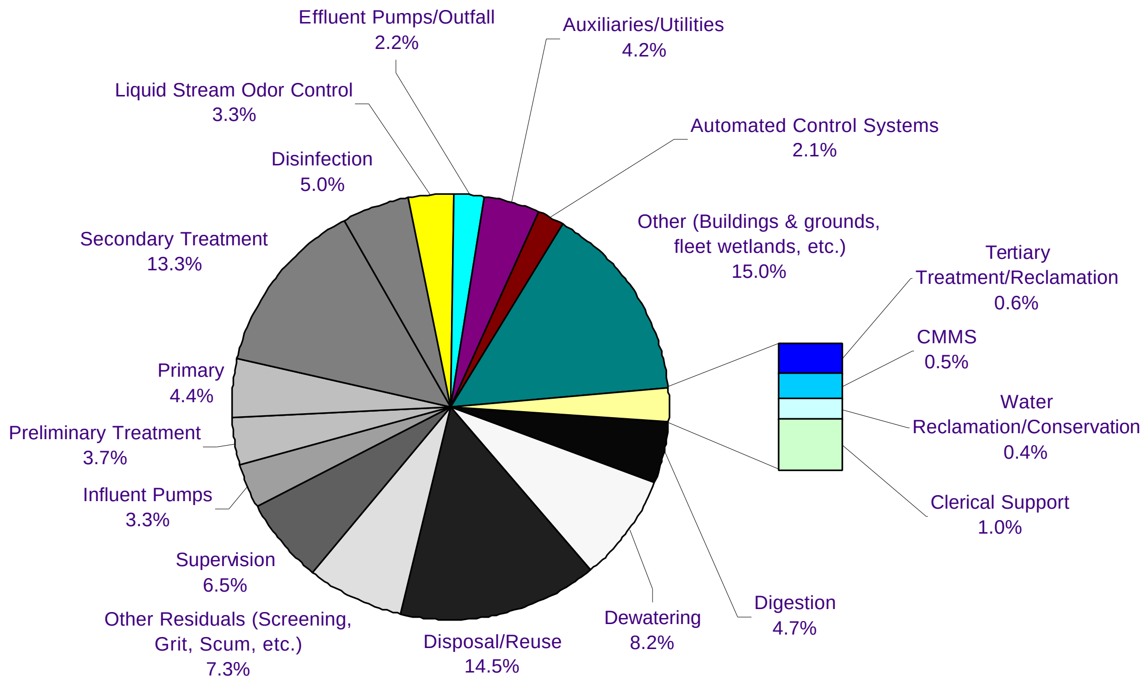



**FIGURE 1: O&M PLANT COST COMPONENTS**

Within each of the subsections, comparative data are provided in tabular form for simplified interpretation. Where requested, comparative graphs are also provided. The comparative tables present the numerical results of the data analyses. These tables present the normalized information for each unit process. The low, average, and high value per normalization factor (such as $/MG) is presented for both "Operations" and "Maintenance." The operations low value shown is the actual lowest value any single agency experienced. The high value similarly shows the actual highest value experienced by any agency.

The comparative tables also show the "total" values for low, average, and high data. The "total" is combined O&M values for each agency, rather than the operations and maintenance components individually. This row shows the lowest, average, and highest total O&M value the agencies experienced, and accounts for the entire process and its operations and maintenance requirements, which impact one another. The "Total" low value will rarely be the sum of the low "Operations" value and the low "Maintenance" value because very rarely does a facility have both the lowest value for operations and the lowest value for maintenance. Similarly, the high "Total" value will typically not be the sum of the high operations value and the high maintenance value.

Zero values are not considered when calculating averages or ranges for the unit process comparative tables. The average values for “Operations” and for “Maintenance” may also not add to the “Total” average if there are agencies with missing, incorrect, or zero values.

Although an extraordinary amount of data was collected by the individual agencies, a limited amount is actually presented and analyzed within the scope of this study. All data, however, are available to each of the agencies for more detailed use and analysis by means of the Master Database, which was delivered electronically to the agencies on February 26, 1999.

The analyses in this study are typically organized by unit process—each process being evaluated for both performance and available process information. Each agency provided descriptions of its treatment plant(s) and processes. These descriptions are included in Appendix D, Overview of Treatment Plants and Processes. Information from process benchmarking survey questionnaires was also reviewed. Information from these sources is coordinated into the discussions about each unit process. Several of the analyses and findings, however, do not fall under individual unit processes, and are presented in following few sections.

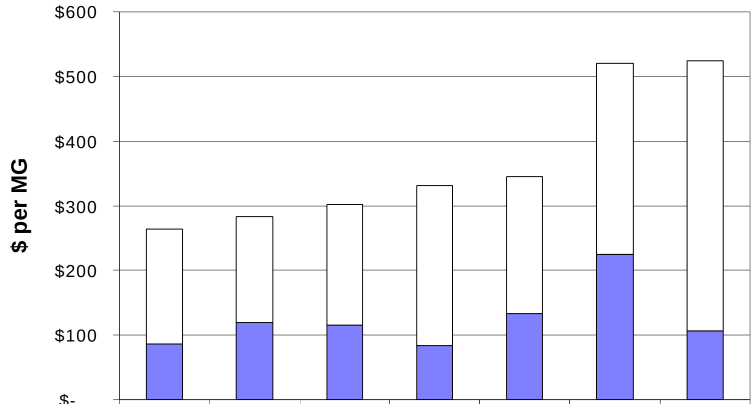
## COSTS AND LABOR

Figures 2 through 7 present total O&M costs and labors FTEs normalized for three separate factors:

- Total plant flow;
- Mass of biochemical oxygen demand (BOD) removed; and
- Mass of total suspended solids (TSS) removed.

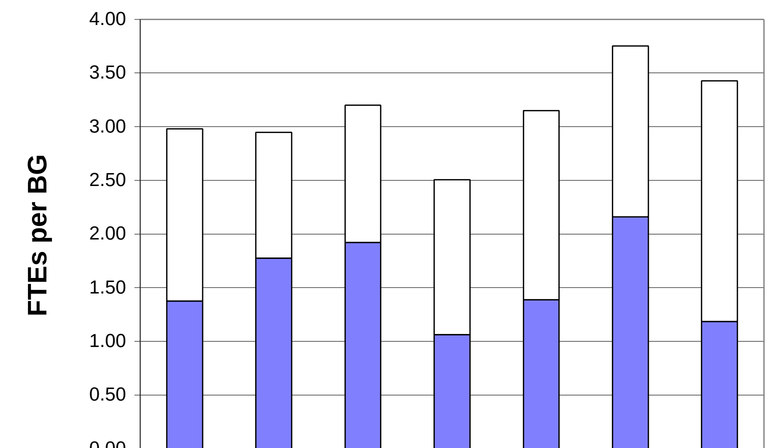
Costs are presented per million gallons treated, while Labor FTEs are presented per billion gallons treated. Values were calculated based on the O&M cost and labor data provided by each of the agencies. They do not include costs for other functional areas, such as administration or technical support.

Total O&M costs per MG ranged from $264/MG to $524/MG (see Figure 2 and Table 5). These total O&M costs were between 40% and 55% of the total agency operating expenditures. There seems to be no correlation between the total costs and the percent spent on O&M functions.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| OpsCost | $178 | $164 | $186 | $247 | $212 | $295 | $417 |
| MaintCost | $86 | $119 | $115 | $83 | $133 | $225 | $107 |

**FIGURE 2: O&M COSTS PER MILLION GALLONS TREATED**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 1.60 | 1.17 | 1.28 | 1.44 | 1.76 | 1.59 | 2.24 |
| Maintenance | 1.38 | 1.78 | 1.92 | 1.06 | 1.39 | 2.16 | 1.19 |

**FIGURE 3: O&M LABOR PER BILLION GALLONS TREATED**

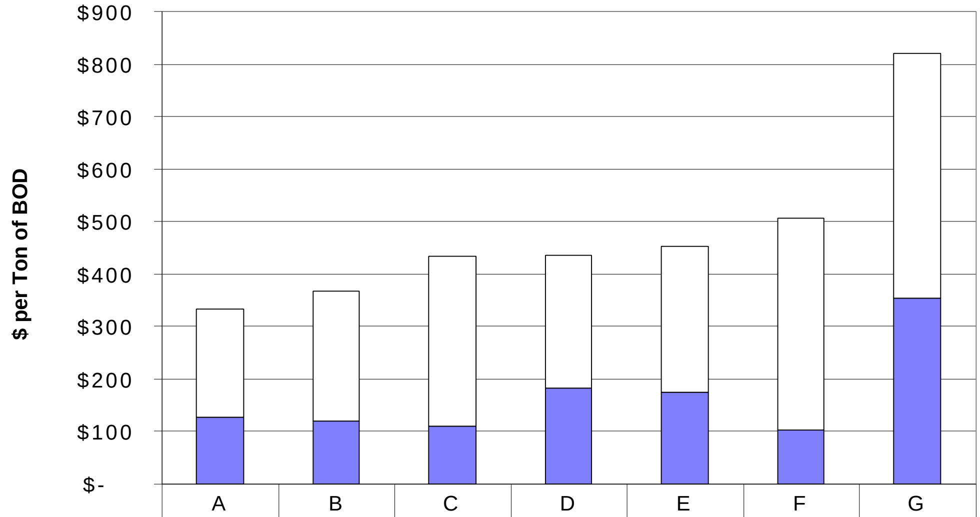
The two agencies with the higher O&M cost and FTEs have distinguishing circumstances that impacted staffing levels and costs. Agency G has relatively high FTEs due, in part, to a labor contract that prohibits reductions in staff until the next contract negotiation. Agency F has several sophisticated processes that demand more staff that are highly skilled and constantly available. The sophistication of the technology also implies higher maintenance costs for repair and/or replacement. In fact, this agency had more maintenance staff than operations staff. Some cost differences between agencies exist because of economies of scale.

| **Table 5<br>O&M Costs and Labor Normalized by Plant Flow** | | | | | | |
|---|---|---|---|---|---|---|
| | **Dollars per Million Gallons Receiving Treatment** | | | **FTEs per Billion Gallons Receiving Treatment** | | |
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $164.12 | $243.83 | $417.20 | 1.170 | 1.590 | 2.241 |
| Maintenance | $83.27 | $124.53 | $225.00 | 1.062 | 1.560 | 2.159 |
| Combined | $263.79 | $366.98 | $524.21 | 2.507 | 3.150 | 3.751 |

## Costs and Labor for Constituent Removal

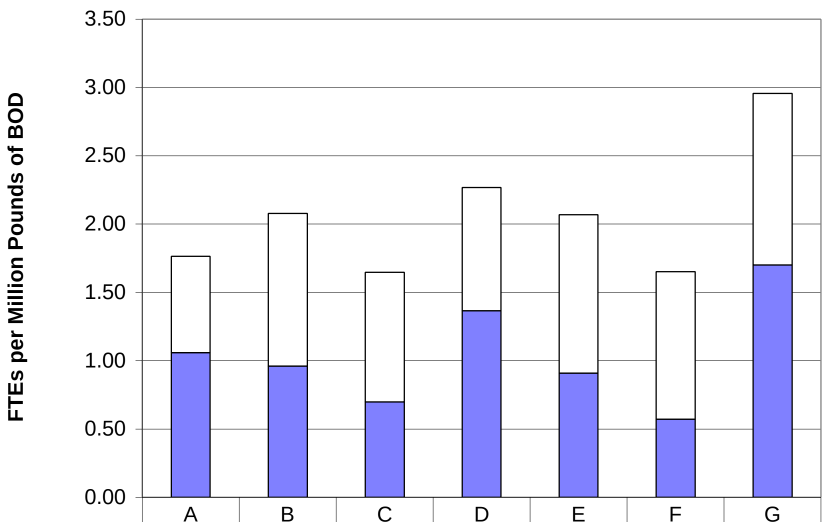
Overall costs and labor expended to remove the constituents of concern were also calculated and evaluated. These constituents are biochemical oxygen demand (BOD) and total suspended solids (TSS) and are both expressed in terms of milligrams per liter (mg/l). The results are presented in Figures 4, 5, 6, and 7. The values were calculated by summing the normalized values provided by each of the agencies for total pounds of the constituent removed in each of the unit processes. Agencies were asked to provide data on BOD removal within the primary and secondary processes. Total pounds of TSS removed were provided for the preliminary treatment, primary treatment, secondary treatment, and tertiary treatment processes by each of the agencies.

The cost for BOD removal ranges from $332 per ton to $820 per ton (see Figures 4 and 5). The FTEs per million pounds of BOD removed ranged from 1.65 to 2.96 FTEs. Economies of scale tend to affect the cost of treatment.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | $205 | $248 | $325 | $253 | $279 | $402 | $465 |
| Maintenance | $127 | $120 | $109 | $184 | $174 | $103 | $355 |

**FIGURE 4: O&M COSTS PER TON OF BOD REMOVED**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 0.70 | 1.12 | 0.95 | 0.90 | 1.16 | 1.08 | 1.26 |
| Maintenance | 1.06 | 0.96 | 0.70 | 1.37 | 0.91 | 0.57 | 1.70 |

**FIGURE 5: O&M LABOR PER MILLION POUNDS OF BOD REMOVED**

Table 6 presents O&M cost per ton and FTE per million pounds for BOD removed during treatment.

| Table 6<br>O&M Costs and Labor Normalized by BOD Removed | | | | | | |
|---|---|---|---|---|---|---|
| | **Dollars per Ton of BOD Removed** | | | **FTEs per Million Pounds of BOD Removed** | | |
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $205 | $311 | $465 | 0.90 | 1.02 | 1.26 |
| Maintenance | $103 | $167 | $355 | 0.57 | 1.04 | 1.70 |
| Combined | $332 | $479 | $820 | 1.65 | 2.11 | 2.96 |

Similar trends are seen in Figures 6 and 7 dealing with TSS removal. The significant difference in these graphs is that Agency F's labor is not tied as strongly to TSS reduction, indicating that chemicals and/or energy are a large component of total cost for TSS removal for Agency F.

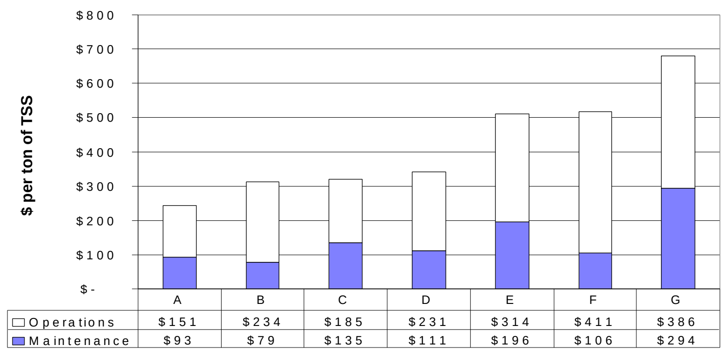



**FIGURE 6: O&M COSTS PER TON OF TSS REMOVED**

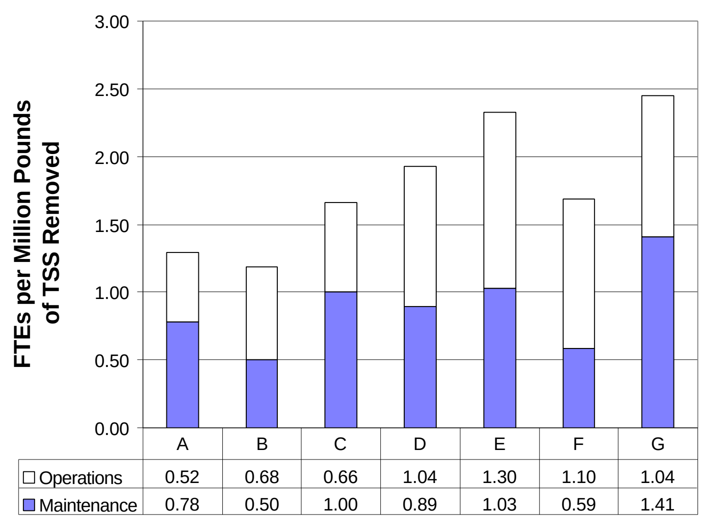



**FIGURE 7: O&M LABOR PER MILLION POUNDS TSS REMOVED**

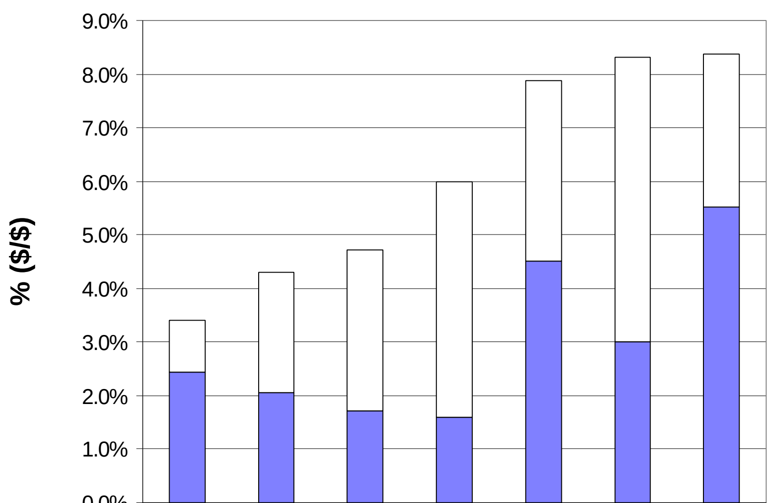
Table 7 presents the normalized cost and labor for TSS removal during treatment.

**Table 7**
**O&M Costs & Labor Normalized by TSS Removal**

| | Dollars per Ton of TSS Removed | | | FTEs per Million pounds of TSS Removed | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | $151 | $273 | $411 | 0.52 | 0.91 | 1.30 |
| Maintenance | $79 | $145 | $294 | 0.50 | 0.88 | 1.41 |
| Combined | $244 | $418 | $679 | 1.18 | 1.79 | 2.45 |

## SUPERVISION

Another factor analyzed is the amount of supervision for the operations and maintenance of a wastewater treatment facility. Supervision costs and labor are presented in Figures 8 and 9. These data were calculated based on the O&M supervisor cost and labor data provided by each of the agencies, and normalized by the total cost of O&M at each agency.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 1.0% | 2.3% | 3.0% | 4.4% | 3.4% | 5.3% | 2.9% |
| Maintenance | 2.4% | 2.1% | 1.7% | 1.6% | 4.5% | 3.0% | 5.5% |

**FIGURE 8: O&M SUPERVISION COSTS PER TOTAL O&M COST**

Figures 8 and 9 show three agencies significantly above the average supervision cost. These higher supervision costs should be analyzed more closely to determine the reasons for the high costs. Agency E has multiple plants, with little or no overlapping supervision, increasing the supervision costs overall. Agency G is a sophisticated, high-tech plant, which may require a more knowledgeable and highly trained senior staff.

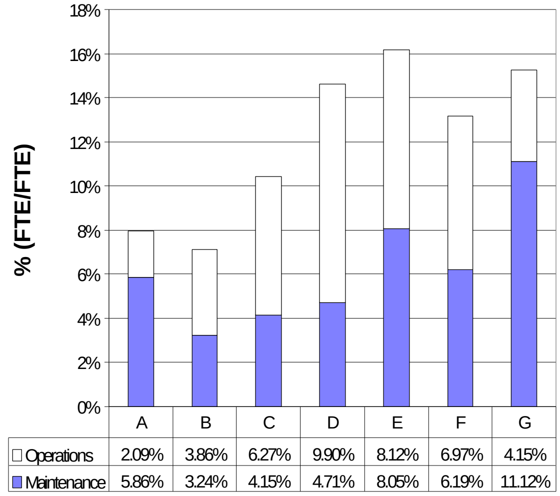



**FIGURE 9: O&M SUPERVISION AS A PERCENT OF O&M LABOR**

Table 8 indicates span of control. It presents the ratio of supervisory cost and labor to total O&M costs and labors. The low, average, and high proportions are presented for both operations and maintenance.

**Table 8**
**O&M Supervision Costs and Labor**

| | Dollars for Supervision per Total O&M Dollar | | | FTEs for Supervision per Total O&M FTEs | | |
|---|---|---|---|---|---|---|
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | 1.0% | 3.2% | 5.3% | 2.09% | 5.9% | 9.9% |
| Maintenance | 1.7% | 3.0% | 5.5% | 3.24% | 6.2% | 11.1% |
| Combined | 3.4% | 6.2% | 8.4% | 7.10% | 12.1% | 16.2% |

# Unit Processes Benchmarking Results

This section is organized to compare and evaluate discrete unit processes or operational functions. Several additional subsections not appropriately assigned to individual unit processes, such as Other Maintenance, Other Issues, and Power Generation/Energy Systems, are included later in the report. A general overview of total O&M costs is presented at the front of this section to provide context for the subsequent discussions of unit processes. The unit processes and operational functions are discussed in the following order:

- Influent Pumping and Preliminary Treatment (combined);
- Primary Treatment;
- Secondary Treatment (includes costs incurred for pumping flow to secondary treatment, aeration basins, oxygen reactor basins, oxygen plant, fixed film reactors, secondary clarifiers, and other secondary processes);
- Tertiary Treatment/Reclamation;
- Water Reclamation/Conservation;
- Residuals Handling (including screenings, grit, primary and secondary sludge thickening, scum, anaerobic digestion, dewatering, biosolids disposal/reuse, and other residuals handling processes);
- Odor Control (for both liquid and residuals streams);
- Disinfection and Dechlorination;
- Effluent Pumping and Outfall;
- Auxiliaries/Utilities; and
- Computer Systems and Automation (includes automated control systems and CMMS systems).

## INFLUENT PUMPING AND PRELIMINARY TREATMENT

Influent pumping is necessary when incoming wastewater (influent) cannot flow by gravity through the wastewater treatment plant. Centrifugal pumps, mixed flow pumps, or screw pumps are typically used to pump the influent into the plant.

Preliminary treatment at the agencies includes screening, grit removal, grinding, and flow metering facilities. Preliminary treatment prepares wastewater influent for further treatment by reducing or removing large solids, rags, and abrasive grit that could otherwise impede operation or unduly increase maintenance of downstream processes and equipment.

## Performance Benchmarking

The costs and the amount of labor required to pump a million gallons of wastewater through influent pumping is presented in Figures 10 and 11.

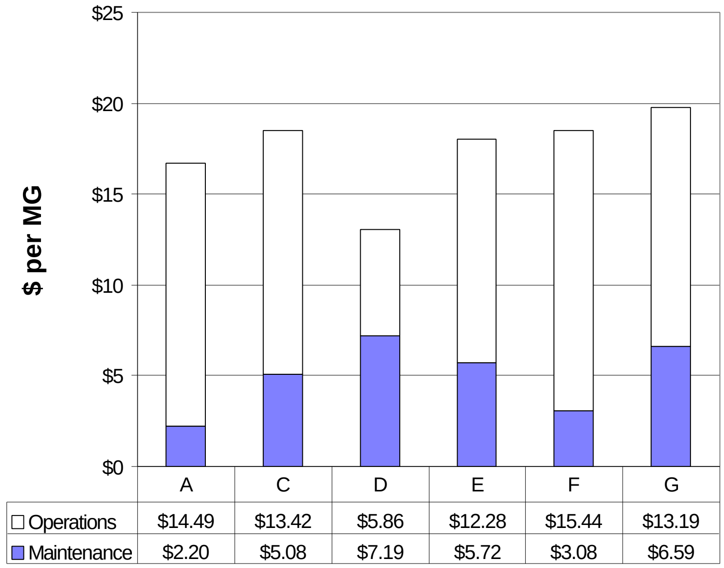



**FIGURE 10: INFLUENT PUMPING COSTS PER MILLION GALLONS PUMPED**

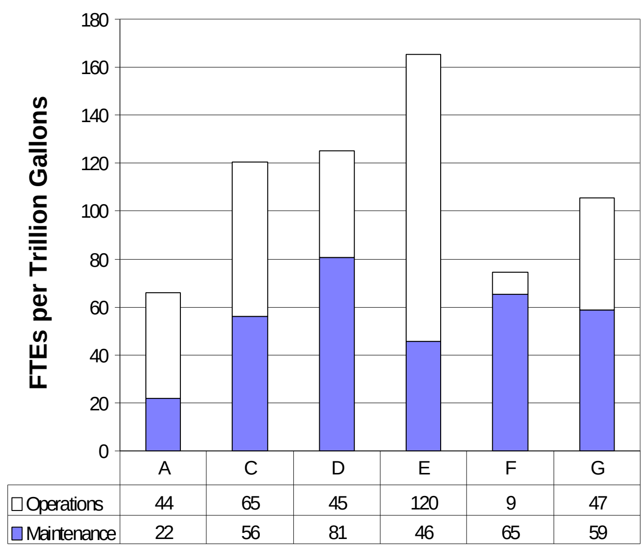



**FIGURE 11: INFLUENT PUMPING LABOR PER TRILLION GALLONS PUMPED**

Table 9 presents the cost per million gallons and FTE per trillion gallons pumped. The low, average, and high normalized costs and FTEs are presented for both operations and maintenance.

**Table 9**
**Influent Pumping Costs and Labor**

| | Dollars per Million Gallons Pumped | | | FTEs per Trillion Gallons Pumped | | |
|---|---|---|---|---|---|---|
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $5.86 | $12.44 | $15.44* | 9.1 | 54.8 | 120* |
| Maintenance | $2.20 | $4.98 | $7.19 | 22 | 54.6 | 81 |
| Combined | $13.05 | $17.42 | $19.76 | 65.9 | 109.4 | 165 |

* IPS facilities at the high cost agency were only used for ¼ of the year.

The cost required to treat each million gallons of wastewater through preliminary treatment systems is presented in Figure 12. Figure 13 shows the O&M labor required for each trillion gallons through preliminary treatment. The preliminary treatment data were normalized by flow through the preliminary treatment system.

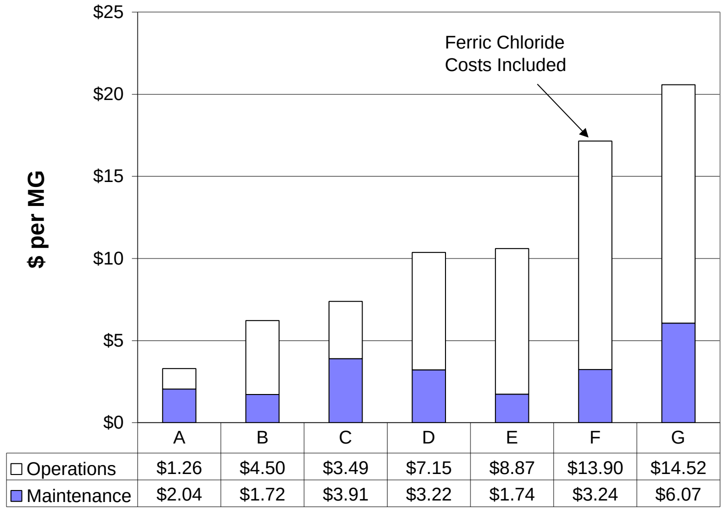



**FIGURE 12: PRELIMINARY TREATMENT COSTS PER MILLION GALLONS TREATED**

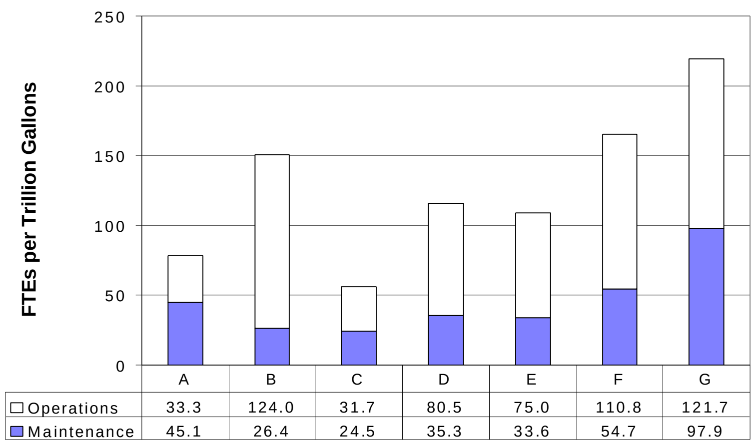



**FIGURE 13: PRELIMINARY TREATMENT LABOR PER TRILLION GALLONS TREATED**

Table 10 presents the cost per million and FTEs per trillion gallons receiving preliminary treatment. The low, average, and high normalized costs and FTEs are presented for both operations and maintenance.

**Table 10**
**Preliminary Treatment Costs and Labor**

| | Dollars per Million Gallons Receiving Preliminary Treatment | | | FTEs per Trillion Gallons Receiving Preliminary Treatment | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | $1.26 | $7.67 | $14.52 | 32 | 82 | 124 |
| Maintenance | $1.72 | $3.13 | $6.07 | 24 | 45 | 98 |
| Combined | $3.30 | $10.80 | $20.59 | 56 | 128 | 220 |

Note: The high agency aerates with concrete channel aeration. Cracks and leaks require maintenance.

## Process Benchmarking

### *Distinguishing Features*

Table 11 summarizes the distinguishing features associated with influent pumping and primary treatment.

**Table 11**
**Influent Pumping and Preliminary Treatment Distinguishing Features**

| Agency | Unique Features |
|---|---|
| A | Partial year use of all grit tanks (some off-line in summer); peroxide used for sulfide control |
| B | Partial year influent pumping (1/4 of year); new facility; bar screens after influent pumping. |
| D | Small bar screen clearances (3/8") at one plant; digester gas-driven centrifugal pumps; partial use of grit system in dry season; secondary grit removal in DAFTs. |
| E | Partial year use of all grit tanks (some off-line in summer) |
| F | Ferric chloride added upstream of large plant headworks for odor control, and improved primary sedimentation; gravity/force main at large plant; bar screens after Influent Pumping at smaller plant. |

### *Areas of Efficiency*

The following efficient practices were identified based upon observations from the performance benchmarking graphs and discussions at the O&M group meetings:

- The agencies typically add chemicals such as chlorine, hydrogen peroxide, ferric chloride, and/or polymers as part of the preliminary treatment process. Most of the agencies have found it to be beneficial for odor control, as well as reaping downstream benefits in primary sedimentation and digestion. (Note: chemical costs were allocated by the agencies to the processes most affected by the chemical addition, regardless of where the chemical was actually applied.)
- An important lesson in grit removal design is to site the grit chambers, classifiers, and hoppers close together to minimize conveyance costs.
- Consider life cycle costs associated with motor driven vs. engine driven pumps which are more costly to maintain.
- Bar screens should be installed before the influent pumps.
- Climbing bar screens will reduce O&M costs.

## Benchmarking Analysis

The following are observations from the performance benchmarking graphs and the O&M group meetings.

- The highest and lowest cost agencies utilize centrifugal pumps for influent pumping. The agency with the highest maintenance costs uses engine driven equipment; the lowest cost agency uses motor driven pumps.
- The highest preliminary treatment costs (as shown in Figure 12 above) are primarily due to the layout of the grit removal system, back rake bar screens, and aeration channel. The majority of its preliminary treatment operating costs (more than 80%) is energy related. Additionally, the high cost agency has very high FTEs per million gallons for mechanical maintenance of its preliminary system.

Table 12 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 12**
**Influent Pumping and Preliminary Treatment Best Practices**

| Parameter | Possible explanations of lower cost | Possible explanations of higher cost |
|---|---|---|
| Equipment | Motor driven centrifugal influent pumps appear to have lower maintenance costs; engine driven pumps have low energy costs. | Agency G has poor grit conveyance layout with back rake bar screens that are O&M intensive;; Agency D has engine driven pumps with low energy costs, but high maintenance costs; Agency D replaced racks during study year which took lots of maintenance time |
| Maintenance | | Agency G has high aerated grit tank blower and replacement screen maintenance costs; Agency D has high screen maintenance costs due to small separation bar screens; Agency D engine driven pumps require significant maintenance |
| Staffing Issues | | Agency D has high FTE costs due to provisions of current union contract |
| Operational Strategies | Agencies A,D and E take some grit tanks off-line in the summer | |

## PRIMARY TREATMENT

Primary treatment follows preliminary treatment. It uses settling and flotation of solids (organic and inorganic) to decrease the load on subsequent biological treatment processes. The wastewater flow is slowed in large tanks called primary clarifiers, which allows suspended solids to settle and be removed, while floatable materials (scum) is skimmed from the surface. Some agencies use enhanced primary treatment that includes the addition of coagulation chemicals to enhance the removal of solids and BOD. The objectives of primary treatment are to produce a liquid effluent suitable for downstream biological treatment and achieve solids separation, which results in a sludge that can be conveniently and economically treated before ultimate disposal.

Primary treatment includes, but is not necessarily limited to, the primary tanks, sludge and scum collection equipment, and associated support systems. This functional area also includes coagulant chemical addition for advanced primary treatment, support systems, and sludge piping up to, but not including, sludge thickening equipment.

Table 13 summarizes the systems used by the agencies.

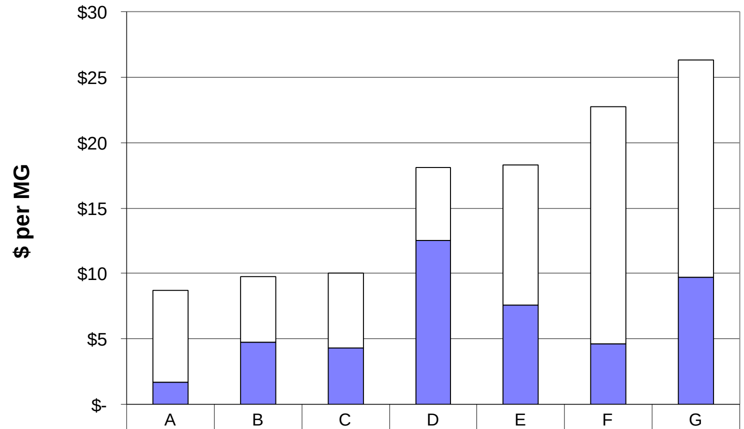
**Table 13**
**Primary Clarifier Design Criteria**

| Agency | Number, Shape | Water Depth (feet) | Design Flow (mgd) | Design Overflow rate[1] (gpd/sq ft) | Design detention time[1] (hours) |
|---|---|---|---|---|---|
| A | 8, rectangular | 12 | 100 | 960<br>@ 100 mgd | 1.94 |
| B, Plant 1 | 12 large rectangular,<br>12 small rectangular | 15 | | 1600 | 1.68 |
| B, Plant 2 | 18, rectangular | 10 | 100 | 1100 | 1.94 |
| B, Plant 3 | 6, rectangular | 11.9 | | 1000 | 2.16 |
| B, Plant 4 | | | | 1280 | 1.5 |
| C, Plant 1 | 12, rectangular | 9.5 | 32.5[2] | 1720 (AWWF)[3]<br>4860 (PWWF)[4] | 0.93 (AWWF)[3]<br>0.33 (PWWF)[4] |
| C, Plant 2 | 12, rectangular | 10 | 110[5] | 1148 (AWWF)[3]<br>3799 (PWWF)[4] | |
| D | 4, rectangular | 9.5 | | 1170 | |
| E | 12, rectangular | 9.5 | 181 | 1560 | 1.09 |
| F, Plant 1 | 3, circular;<br><br>12, rectangular | 9' side wall, 15' center<br><br>10' | 12[2]<br><br>6[2] | 780<br><br>780 | 1.3<br><br>1.3 |
| F, Plant 2 | 14, circular | | 12 | | |
| G | 16 | 10.5 | 80 | | |

1. Values based on average daily flow except where noted.
2. Design flow per tank
3. Average daily wet weather flow
4. Peak wet weather flow
5. Maximum hydraulic capacity per tank

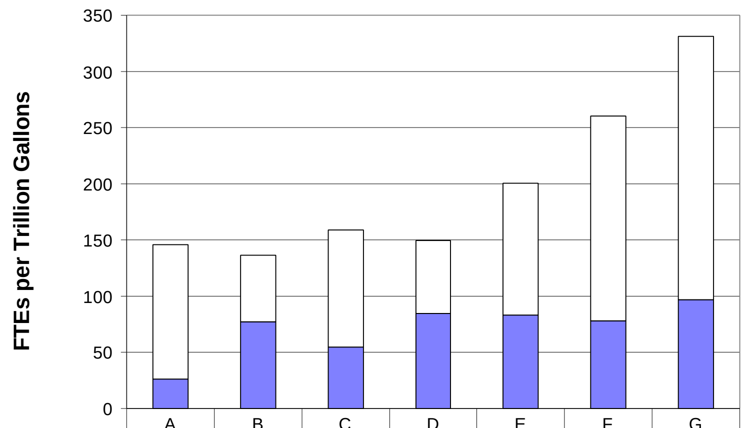
## Performance Benchmarking

Normalized costs and the amount of labor required for primary treatment is presented in Figures 14 and 15. The cost to remove a ton of TSS in the primary treatment system is presented in Figure 16. Table 14 presents the operations and maintenance costs per million gallons and FTEs per trillion gallons receiving primary treatment. Table 15 presents the O&M cost per ton of TSS removed during primary treatment.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | $6.96 | $5.03 | $5.65 | $5.55 | $10.74 | $18.06 | $16.57 |
| Maintenance | $1.72 | $4.73 | $4.35 | $12.53 | $7.55 | $4.64 | $9.73 |

**FIGURE 14: PRIMARY TREATMENT COSTS PER MILLION GALLONS TREATED**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 119 | 59 | 104 | 65 | 118 | 183 | 234 |
| Maintenance | 26 | 77 | 55 | 85 | 83 | 78 | 97 |

**FIGURE 15: PRIMARY TREATMENT LABOR PER TRILLION GALLONS TREATED**

| Table 14<br>Primary Treatment Costs & Labor | | | | | | |
|---|---|---|---|---|---|---|
| | **Dollars per Million Gallons Receiving Primary Treatment** | | | **FTEs per Trillion Gallons Receiving Primary Treatment** | | |
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $5.03 | $9.79 | $18.06 | 59 | 126 | 234 |
| Maintenance | $1.72 | $6.47 | $12.53 | 26 | 72 | 97 |
| Combined | $8.68 | $16.26 | $26.30 | 136 | 217 | 331 |

| Table 15<br>Cost for TSS Removal in Primaries | | | |
|---|---|---|---|
| | **Dollars per ton of TSS Removed during Primary Treatment** | | |
| | **Low** | **Average** | **High** |
| Operations | $4.50 | $17.10 | $31.10 |
| Maintenance | $3.40 | $12.50 | $30.10 |
| Combined | $8.70 | $29.60 | $53.00 |

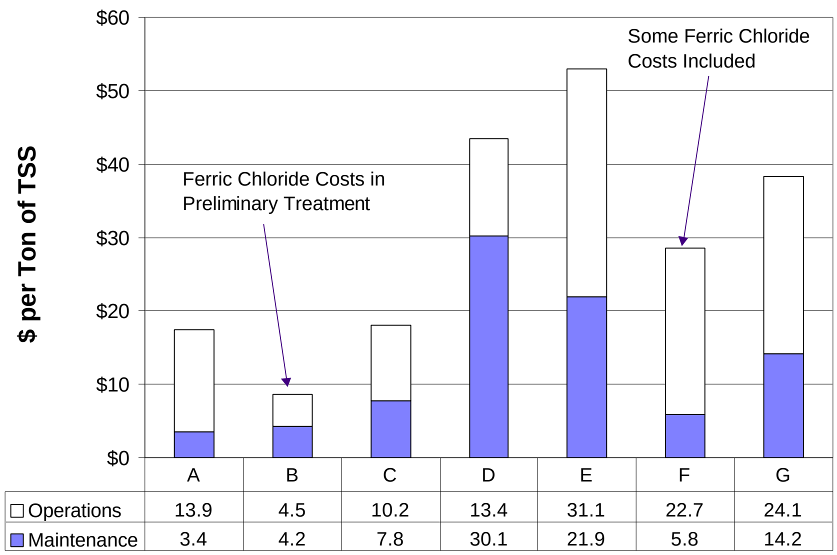



**FIGURE 16: COSTS PER TON OF TSS REMOVED DURING PRIMARY TREATMENT**

## Process Benchmarking

### *Distinguishing Features*

As shown in Table 16, the major difference between primary treatment at the agencies is whether facilities add chemicals at their primaries.

**Table 16**
**Primary Treatment Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | No chemical addition at primaries, Loop chain with fiberglass flights. |
| B | Large plant has ferric chloride and anionic polymer addition; chemical addition for enhanced solids removal; deep primaries (15 ft); converting to loop chain with fiberglass fixtures. |
| C | One plant has high rate primary clarifiers (high overflow rate and continuous sludge withdrawal), no chemical addition at primaries, resin chains and fiberglass flights. Wet weather plant uses stainless steel chain for heavy grit loading applications. |
| D | No chemical addition at primaries, loop chain with fiberglass flights. |
| E | Plastic chains and fiberglass flights in their primary tanks. |
| F | Ferric chloride and anionic polymer added, majority of primaries are circular, non-metallic chain and flights, lots of sampling at the primaries. |
| G | No chemical addition at primaries; non-metallic flights and chain. |

### *Impact of Capital Facilities*

Agency A had low maintenance costs in the fiscal year studied because they were converting to non-metallic chain and flight in their rectangular clarifiers so all maintenance costs were covered under capital improvement.

### *Areas of Efficiency*

The following summarizes observations gleaned from the O&M group meetings.

- The materials used for the flight and chain mechanisms is key. Non-metallic chain is preferred by many agencies because it is not subject to corrosion and is easier to handle and repair. This means that plastic chain and flights afford the operational advantages of being able to take clarifiers out of service without corrosion worries. However, non-metallic chain may wear more quickly, and is more expensive than steel chain.
- Stainless steel chain is better suited for high grit loading applications and combined sewer applications. While more difficult to handle, steel chain is not as frequently repaired as non-metallic.

### *Areas of Future Investigation*

The following areas were identified for possible future investigation:

- Evaluate the correlation between thickening in primary treatment, BOD removal and related efficiencies.

## Benchmarking Analysis

The following are observations from the performance benchmarking graphs and the O&M group meetings.

- There does not appear to be a relationship between the type of flight and chain system used and the overall primary treatment cost per MG.
- As shown in Figures 14 and 15 above, the two agencies that have the highest values (Agencies F and G) both have significantly more operations labor than the remaining agencies
- Chemical addition at the primaries does not appear to be related to the cost per pound of TSS removed. Two of the participating agencies add ferric chloride and anionic polymer at the primaries. Agency F has a below average cost per pound of TSS removed through the primaries even though it spends more than half its primary operating budget on chemicals.
- The flight and chain mechanisms used in rectangular clarifiers require more maintenance than solids removing mechanisms in circular clarifiers.

Table 17 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 17**
**Primary Treatment Best Practices**

| Parameter | Possible Explanations of Lower Cost | Possible Explanations of Higher Cost |
|---|---|---|
| Maintenance | Agency A had new chain and flight installed, maintenance costs are artificially low | |
| Staffing Issues | | Agency G has high FTE costs due to provisions in the current union contract |
| Operational Strategy | Agencies A and C do not add chemicals | Agency F adds ferric and anionic polymer at primaries. Agency B adds ferric chloride before the primaries, but it affects their primary process. |

## SECONDARY TREATMENT

Secondary treatment is a biological process using microorganisms to metabolize organic matter in the wastewater as food. Wastewater is frequently pumped to a bioreactor where the organic matter is aerated. The bioreactors use air (aeration basins) or pure oxygen (oxygen reactor basins) to stimulate cell metabolism and growth. Air-activated sludge and oxygen-activated sludge processes are suspended growth processes in which the growth of the microorganisms occurs in an agitated liquid suspension media (mixed liquor). The aerobic environment in the reactor is achieved by the use of diffused or mechanical aeration, which also serves to maintain the mixed liquor in a completely mixed regime. Pure oxygen plants require pure oxygen that may be produced onsite using an oxygen generation plant. Some plants used fixed film reactors with a fixed media as a substrate for the growth of microorganisms. The media typically is a porous inert material such as rocks or non-metallic. Primary clarifier effluent is distributed evenly over the media, and the microbial mass adhering to the media treats the effluent as it trickles down to the bottom of the reactor. The finishing phase of secondary treatment takes place in the secondary clarifiers. Secondary clarifiers slow the flow to allow suspended solids to settle to the bottom and be drawn out as sludge. Floatable material (scum) is skimmed from the surface. Some plants use other secondary processes that do not fall under the above categories.

Secondary treatment costs include, but are not necessarily limited to the pumping systems to secondary processes, aeration basins, clarifier tanks, cryogenic and/or aeration systems and associated support systems.

Table 18 summarizes information on the secondary processes at the agencies.

## Table 18
## Secondary Treatment Process Operation Criteria

| Agency | CCCSD | CLABS | CPBES | OCSD | | | EBMUD | KCDNR | | SRCSD |
|---|---|---|---|---|---|---|---|---|---|---|
| **Plant** | Main Plant | Hyperion | Columbia Blvd. | Plant 1 | | Plant 2 | Main Plant | East | West | Main Plant |
| **Type of Process** | Air Activated Sludge | Pure Oxygen Activated Sludge | Air Activated Sludge | Air Activated Sludge | Fixed Film Reactor | Pure Oxygen Activated Sludge | Pure Oxygen Activated Sludge | Air Activated Sludge | Pure Oxygen Activated Sludge | Pure Oxygen Activated Sludge |
| **F/M [1]** | 0.61 | 1.7 | 0.3 | 0.77 | 53.3 lb BOD/1000 cf/day[2] | 2.3 | 1.0 | 0.44 | 0.69 | 1.5 |
| **MCRT, days [3]** | | | 4 | | NA[2] | | 2.5 | 5 | 2.9 | 2.3 |
| **SRT, days [4]** | 1.9 | 1.3 | | 2.0 | NA[2] | 0.57 | 1.0 | 4.1 | 2.5 | 1.2 |
| **Detention time, hours[5]** | 1.0 | 1.5 | 4-6 | 6.2[6] | NA[2] | 1.4[7] | 7.5 | 3.4 | 2.0 | 1.6 |
| **Number of stages/ passes** | 4 tanks, 2 passes | 4 modules of 3 trains each; each train has 4 stages | | 4 stages per basin, 10 aeration basins | | 4 stages per reactor, 8 reactor basins | 4 stages per train, 8 trains | 4 passes per aeration tank | 4 stages per aeration basin | 4 stages |
| **Dimensions[5]** | Each pass: 35 ft. wide by 270 ft long. Avg. Water depth: 15 ft. | Each stage 54 ft by 54 ft x 25 ft deep | 400 ft x 40 ft x 17 ft | 275 ft x 45 ft x 15 ft per basin | Each filter: 180 ft diameter, 6 ft deep | | 1.6 MG | 4 tanks 315 ft L x 15 ft deep (@4 passes/ tank @ 4 tanks) | 6 trains; 224 ft x 56 ft x 25 ft deep (each train) | 48 ft x 48 ft x 30 ft (each stage) |
| **BOD[8] in, mg/L** | 108 | 100-110 | 120 | 126 | 130 | 119 | 125 | 92 | 97 | 160 |
| **BOD out, mg/L** | 5 | 15-25 | 15 | 9.8 | 33 | 8.7 | 15 | 13 | 22 | 14 |
| **BOD removal, %** | 95% | 77-85% | 88% | 92% | 75%[18] | 93% | 88% | 86% | 77% | 91% |
| **MLSS[9], mg/L** | 1320 | 900 | 2000 | 728 | NA[2] | 1020 | 1200 | 1300 | 1000 to 2000 | 1300 |
| **RAS[10], mg/L** | 3750 | 5000 | 8000 | 2150 | NA[2] | 4170 | 4000 | 4500 | | 5500 |
| **% return** | 46% | 25-30% | 30% | 40% | 88% | 33% | 27% | 32% | 40% | 31% |
| **Flow type** | Plug | Plug | Plug | Step feed[11] | High rate | Plug | Step feed | Contact reaeration, Jan- April; Plug Flow, May-Dec. | Plug flow; contact reaeration during high flows | Plug |
| **Selectors** | Anaerobic | Anoxic | Anaerobic | None | NA | None | None | No, Jan-May; Yes, June-Dec (anaerobic) | No | None |

**Table 18**

**Secondary Treatment Process Operation Criteria**

| Agency | CCCSD | CLABS | CPBES | OCSD | | | EBMUD | KCDNR | | SRCSD |
|---|---|---|---|---|---|---|---|---|---|---|
| **N or P removal?**[12] | No | No | No | No | No | No | N | No | No | No |
| **Operating temperature range (°F)** | 65-81 | 75 | 50-72 | 68-85 | 68-85 | 68-85 | | 50-72 | 54-72 | 60-85 |
| **SVI**[13] | 80-120 | 100-150 | 90-120 | 548 ml/g | NA[2] | 285 ml/g | 200 | 130 | 181 | 160 |
| **DO, mg/L**[14] | 2.4 | 20 | 1-2 | 0.5 | NA[2] | 12 | 20 | 1-2 | 6.6-14.6 (from LM channel grab readings) | 15 |
| **Diffuser type** | Porous plate/ Fine Bubble | Surface impeller with draft tube mixers | Fine bubble membrane | Wyss tubes – medium bubble | NA[2] | Mechanical mixers (surface aerators) | Surface aeration | Sanitaire 9-inch fine bubble EDPM diffusers | Surface impeller with draft tube mixers | Submerged turbine, pure oxygen |
| **Clarifier depth, ft.** | 4 @ 18; 4 @ 21 | | 12.5 | 9 | 14 | 14 | | 14, 18[15] | 18 | 20 |
| **Clarifier overflow rate, gpd/sf**[16] | 590 | | 800 | 400 | 400 | 400 | | 687, 610[17] | 800-900 | 750 |

Notes:

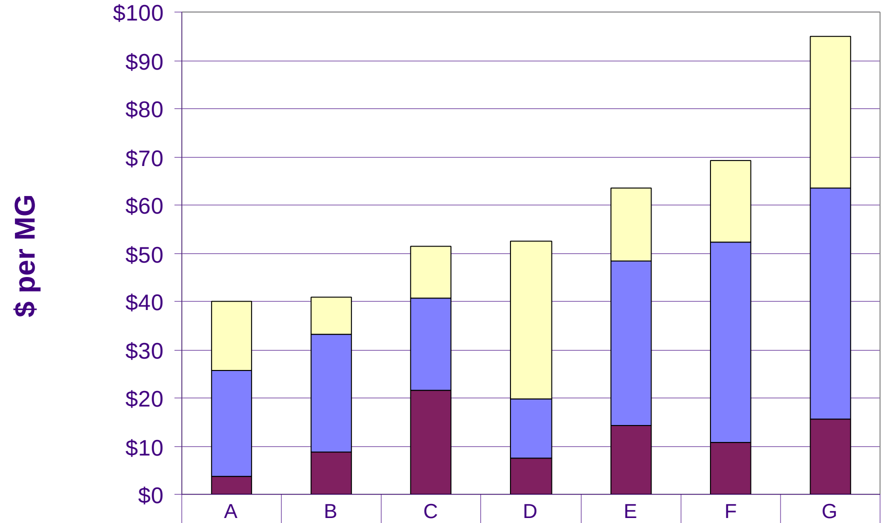
NA = Not applicable

1. Food to Microorganism ratio
2. Rock media trickling filter. Hydraulic loading = 0.2 gpm/sf; Plant comprises 4 filters.
3. Mean cell residence time (includes secondary clarifiers)
4. Solids retention time (excludes secondary clarifiers)
5. Total
6. Only 6 of 10 aeration basins in service during study period
7. 3 of 10 reactors in service for 7 months, 4 reactors in service for 5 months during the study period.
8. Biochemical oxygen demand
9. Mixed liquor suspended solids
10. Return activated sludge
11. Aeration basins may be operated in plug flow or step feed modes.
12. Nitrogen or phosphorus
13. Sludge volume index
14. Dissolved oxygen
15. Four tanks are 14 feet deep, the remaining twelve tanks are 18 feet deep
16. Gallons per day per square foot
17. For average wet weather flow.
18. One of two secondary clarifiers removed to accommodate new biosolids loading facility.

Of the nine major plants included in this survey, five use high purity oxygen activated sludge (HPOAS), three use air activated sludge, and one uses air activated sludge, HPOAS and trickling filter (fixed film reactor) technology (in separate treatment trains). The HPOAS plants either use surface aerators, or have plans to convert to surface aerators. Food to microorganisms (F/M) ratios vary from 0.3 to 2.3, and BOD removal percentages range from 75% to 95%. Oxygen plants typically have higher F/M ratios than air plants. The fixed film reactor facility has lower BOD removal.

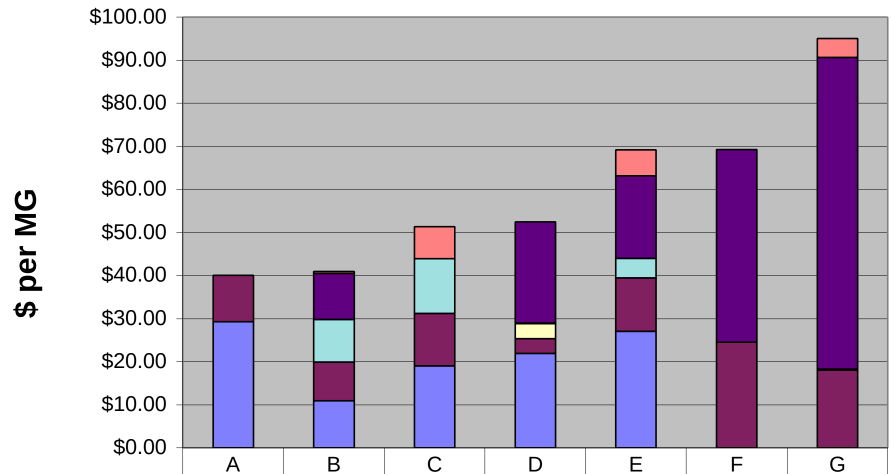
### Overall Secondary Process Data

The costs for each million gallons of wastewater treated through the secondary treatment system is presented in Figures 17 and 18. These data were calculated based on the O&M cost data provided by each of the agencies. Figure 17 shows the breakdown of costs between operations, energy usage and maintenance for secondary treatment. These were calculated using the total secondary treatment costs provided by each agency and normalizing by the total flow receiving secondary treatment. Figure 18 shows the same costs, only by the individual unit processes utilized at each agency rather than operations, energy and maintenance costs. The values are weighted by flow through the unit process, and show the portion of total cost expended at each unit process.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | $14.21 | $7.81 | $10.75 | $32.58 | $15.32 | $16.96 | $31.64 |
| Energy | $22.05 | $24.30 | $18.98 | $12.45 | $33.91 | $41.44 | $47.82 |
| Maintenance | $3.76 | $8.82 | $21.61 | $7.41 | $14.38 | $10.85 | $15.59 |

**FIGURE 17: SECONDARY TREATMENT COSTS PER MILLION GALLONS TREATED**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Other Sec. Processes | | $0.44 | $7.43 | | $6.02 | | $4.39 |
| Pure Oxygen System | | $10.69 | | $23.49 | $19.16 | $44.72 | $72.34 |
| Influent Pumping | | $9.84 | $12.72 | $0.10 | $4.57 | | $0.23 |
| Fixed Film | | | | $3.51 | | | |
| Clarifiers | $10.76 | $9.07 | $12.17 | $3.45 | $12.41 | $24.53 | $18.09 |
| Air Aeration | $29.27 | $10.90 | $19.03 | $21.89 | $27.02 | | |

**FIGURE 18:SECONDARY TREATMENT COSTS WEIGHTED BY FLOW-THROUGH TREATMENT PROCESS**

The operations and maintenance labor for the secondary treatment process is presented in Figure 19.

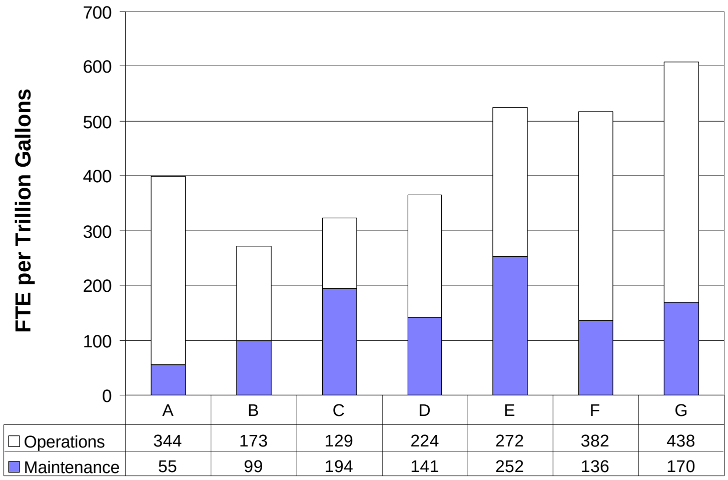



**FIGURE 19: SECONDARY TREATMENT LABOR PER TRILLION GALLONS TREATED**

Data are provided by each of the agencies for the unit processes and areas of the facility listed in Table 19. Not each of these processes is employed at each facility. Please refer to Table 2 (Summary of Operations and Maintenance Cost Centers) for information on which unit processes are at each facility. Table 19 below also identifies the normalization factor for each of the secondary treatment unit processes when calculating the cost to treat wastewater through each unit process.

**Table 19**
**Components of Secondary Treatment**

| Unit Process | | Normalization Factor |
|---|---|---|
| Pumping to Secondaries | | Total flow receiving secondary treatment[1] |
| Biological Processes | | |
| 1 | Aeration Basins | Flow through aeration basins |
| 2A | Oxygen Reactor Basins | Flow through oxygen reactor basins |
| 2B | Oxygen Plant | Flow through oxygen reactor basins |
| 3 | Fixed Film Reactors | Flow through fixed film reactors |
| Secondary Clarifiers | | Total flow receiving secondary treatment |
| Other Secondary Processes | | Total flow receiving secondary treatment |

1 Identified as the sum of the flows through aeration basins, oxygen reactor basins, and fixed film reactors.

Figures 17 and 18 above show a wide range of secondary treatment costs per million gallons treated. The wide range is due primarily to the method of air or oxygen dissolution used. For example, those pure oxygen activated sludge plants using submerged turbines (such as Agencies G and F) have higher overall costs per million gallons treated. The agencies that operate a number of different secondary treatment technologies lower their overall secondary treatment costs. These processes are discussed in further detail in the sections covering Air-activated Sludge Systems, Pure Oxygen-activated Sludge Systems, and Fixed Film Reactors.

Figures 17 and 19 above indicate that Agency G has the highest labor (and associated cost) per MG associated with secondary treatment. The majority of this labor is used at the oxygen system, as evident in Figure 18 above. Other agencies (E and F) have high costs and labor per MG in secondary treatment. Agency E has a low unit energy cost and the oxygen dissolution system is high efficiency, indicating that the majority of their costs are labor related. This is more evident in Figure 19 above, which shows Agency E as second highest in FTEs per MG for secondary treatment. (Note: Agency E was in the start-up phase at their largest treatment plant requiring additional staffing at the time of the study.)

Figure 19 above shows a variation in the amount of labor required to treat a million gallons through the secondary processes. Again, the primary difference between the higher and lower labor utilization agencies appears to be type of method of dissolution used. Two of the higher-cost agencies (G and F) use submerged turbines at their high purity oxygen-activated sludge (HPOAS) plants. Agency E uses higher efficiency surface aerators at their HPOAS plant, but spends a high amount on their air activated sludge system at their other plants, as seen in Figure 18 above. Agency D has high costs associated with their aeration system at one of their plants, constituting almost half of the costs for secondary treatment. Agency D has the highest SVI and the lowest DO concentration of the other facilities, although it is not clear if these factors are affecting the operations costs. These issues are discussed in further detail in Air-activated Sludge Systems, and Pure Oxygen-activated Sludge Systems sections.

Table 20 presents the O&M cost per million gallons and the FTEs per trillion gallons of secondary treatment.

**Table 20**
**Secondary Treatment Costs and Labor**

| | Dollars per Million Gallons Receiving Secondary Treatment | | | FTEs per Trillion Gallons Receiving Secondary Treatment | | |
|---|---|---|---|---|---|---|
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $7.81 | $18.47 | $32.58 | 129 | 284 | 438 |
| Energy | $12.45 | $28.71 | $47.82 | | | |
| Maintenance | $3.76 | $11.77 | $21.61 | 55 | 150 | 252 |
| Combined | $40.02 | $58.95 | $95.05 | 272 | 430 | 608 |

The cost to remove a million pounds of BOD in the secondary treatment systems is presented in Figure 20. The agencies with air activated sludge systems and trickling filters had lower costs than the agencies using oxygen activated sludge systems. Oxygen activated sludge systems, however were often selected due to land use, odor and/or VOC constraints.

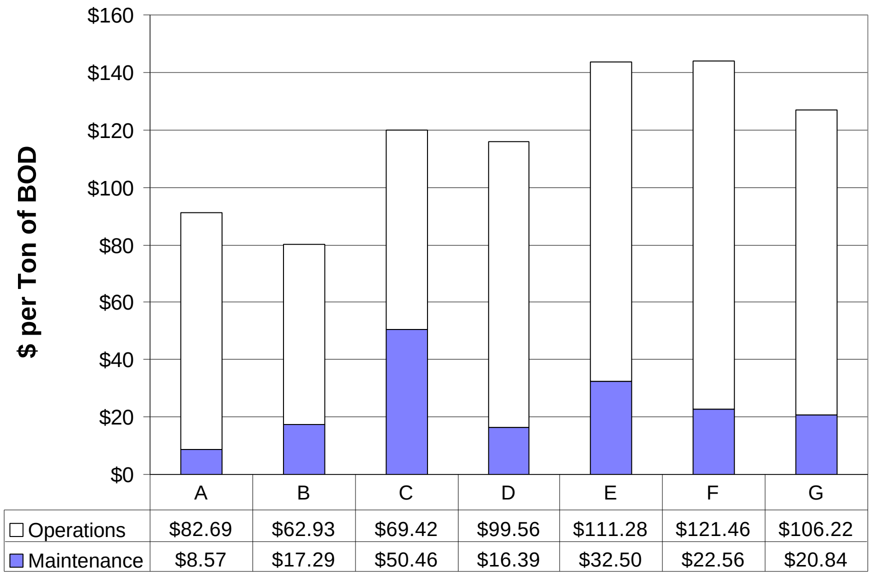



**FIGURE 20: SECONDARY TREATMENT COST PER TON OF BOD REMOVED**

Table 21 presents the operations and maintenance costs per ton of BOD removed during secondary treatment.

**Table 21**
**Cost for BOD Removal in Secondary Treatment**

| | Dollars per Ton of BOD Removed during Secondary Treatment | | |
|---|---|---|---|
| | Low | Average | High |
| Operations | $62.90 | $93.37 | $121.50 |
| Maintenance | $8.60 | $24.09 | $50.50 |
| Combined | $80.20 | $117.46 | $144.00 |

## *Process Benchmarking*

**Distinguishing Features**

Table 22 summarizes the unique features of the secondary treatment processes at the agencies.

| **Table 22<br>Secondary Treatment Distinguishing Features** | |
|---|---|
| **Agency** | **Distinguishing Features** |
| B | Contact reaeration in high flow |
| C | Steam turbines power blowers; achieves 95% BOD removal. |
| D | Partial secondary treatment with constant flow through the secondary processes. Three separate parallel treatment trains: trickling filters, air activated sludge, and HPOAS. Short MCRTs for filament control. HPOAS is operated with second stage aerators turned off intermittently. |
| E | Only partial secondary treatment with constant flow at main plant |
| F | New oxygen reactor basins have surface aerators, older basins use submerged turbines |
| G | Employs tilting weir to control water surface level in oxygen reactors. |

**Areas of Efficiency**

Energy-saving strategies are key in reducing secondary treatment costs, while diffuser technology and secondary clarifier design significantly affect performance. The following summarizes consensus reached at the O&M group meetings.

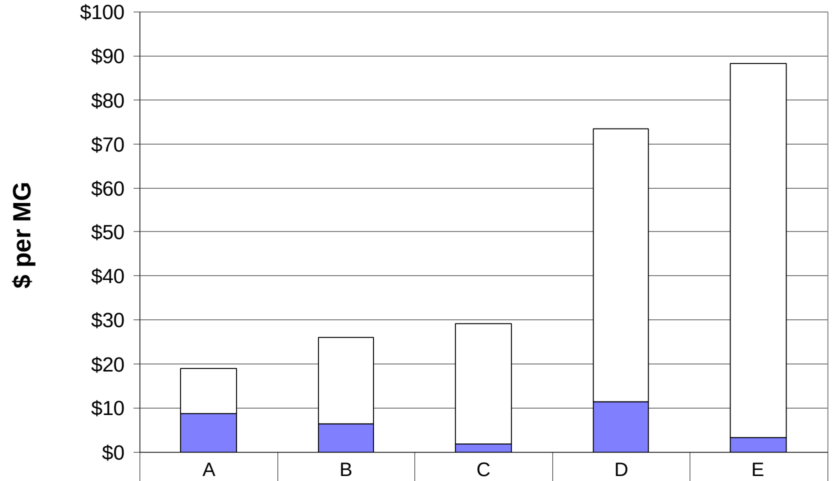
- Fine bubble air activated sludge with membrane diffusers is the preferred alternative from an energy savings standpoint.
- An additional benefit for air activated sludge systems would be to employ aeration blowers with variable automated inlet and outlet guide vanes.
- Increased capacity in the secondary clarifiers leads to increased process flexibility and is beneficial to plant operations. General consensus was that this could be achieved with deep (>20 foot) clarifiers and overflow rates of 400 to 600 gpd/sf.
- The agencies recommend separating mixing zones from aeration zones to promote selector zone technology.
- Low cost agencies for secondary treatment have air-activated sludge or trickling filters.

## Air-activated Sludge Systems

This functional area specifically includes labor, materials and supplies associated with operating air conveyance systems and piping. This includes costs associated with operation of blowers, mixers, or other devices used to mix or introduce air into water. This includes the aeration basins and support systems, such as blowers and diffusers. Clarifiers are not included here, and are presented in the section on Secondary Clarifiers.

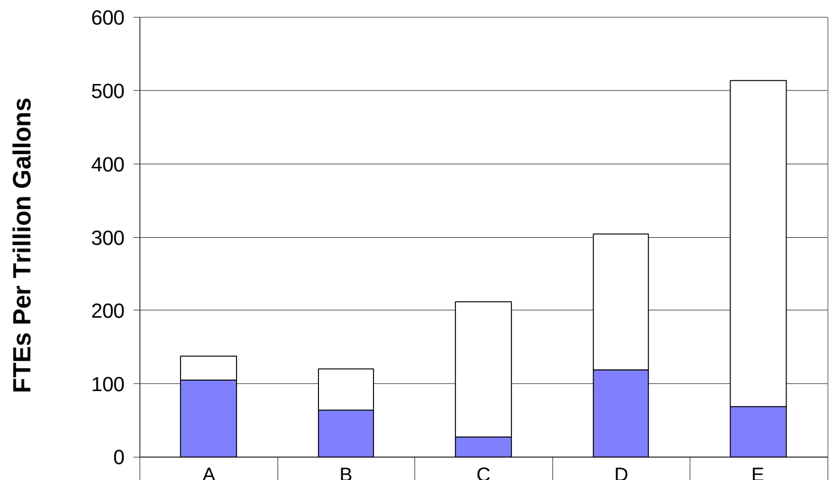
### *Performance Benchmarking*

The costs and the amount of labor required to treat wastewater through the air activated sludge system are presented in Figures 21 and 22. The air-activated sludge data were normalized by flow through the air activated sludge treatment system.




| | A | B | C | D | E |
|---|---|---|---|---|---|
| Operations | $10.29 | $19.59 | $27.46 | $61.94 | $84.97 |
| Maintenance | $8.74 | $6.47 | $1.80 | $11.54 | $3.33 |

**FIGURE 21: AIR-ACTIVATED SLUDGE SYSTEM COSTS PER MILLION GALLONS TREATED**




| | A | B | C | D | E |
|---|---|---|---|---|---|
| Operations | 32 | 56 | 184 | 185 | 445 |
| Maintenance | 105 | 63 | 28 | 119 | 69 |

**FIGURE 22: AIR-ACTIVATED SLUDGE SYSTEM LABOR PER TRILLION GALLONS TREATED**

Table 23 presents the O&M cost per million gallons and the FTEs per trillion gallons of secondary treatment.

**Table 23**
**Air-activated Sludge Systems Costs**

| | Dollars per Million Gallons Receiving Air Activated Sludge Secondary Treatment | | | FTEs per Trillion Gallons Receiving Air Activated Sludge Secondary Treatment | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | $10.29 | $40.86 | $84.97 | 32 | 180 | 445 |
| Maintenance | $1.80 | $6.36 | $11.54 | 28 | 77 | 119 |
| Combined | $19.03 | $47.23 | $88.30 | 120 | 257 | 514 |

### *Process Benchmarking*

**Distinguishing Features**

Table 24 summarizes the distinguishing features of the activated sludge systems at the agencies.

**Table 24**
**Air Activated Sludge Systems Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | Porous plate with air plenum under aeration basin, fine bubble diffusers. Storm peaks diverted into storage ponds prior to secondary treatment. |
| B | Fine bubble membrane diffusers and Turblex blowers |
| C | Fine bubble membrane diffusers, Turblex blowers. |
| D | Fine bubble diffusers |
| E | Medium bubble Wyss tube diffusers, Turblex blowers and fine bubble diffusers added after study period. Maintains constant flows to OS by treating only a portion of flow. |

**Impact of Capital Facilities**

Following the study period, Agency E installed new Turblex blowers and membrane disk fine bubble diffusers. They have realized energy savings of approximately 66%. Other agencies have switched to fine bubble diffusers and have significantly lowered costs through increased oxygen transfer efficiency.

**Areas of Efficiency**

The following efficient practices were identified based upon observations from the performance benchmarking graphs and discussions at the O&M group meetings.

- Converting to fine bubble diffusers and blowers with variable inlet and outlet guide vanes maximizes energy savings in air-activated sludge systems.

Air-activated sludge systems should be more cost-efficient than oxygen-activated systems providing that land constraints, odors, and VOCs are not issues.

Table 25 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 25**
**Air-Activated Sludge Systems Best Practices**

| Parameter | Possible Explanations of Lower Cost | Possible Explanations of Higher Cost |
|---|---|---|
| Equipment | Use of fine bubble diffusers and Turblex blowers to increase energy efficiency. | Agency E utilizes medium bubble diffusers. |
| Maintenance | | Agency A includes boiler maintenance costs in secondary treatment cost accounting because the aeration blowers are indirectly powered by boilers through direct-coupled steam turbines. |
| Staffing Issues | | Agency E uses nearly 5 FTEs to operate AAS Process. |
| Operational Strategy | Agency B operates in a seasonal flow mode: contact reaeration during high flows (January – April), Plug flow during lower flows (May-December) | Agency D purchases power for their outlying treatment plants at an industrial rate.<br>Agencies D and E operate at higher detention times than the lower operating cost plants. |

## Pure Oxygen-activated Sludge Systems

These systems costs generally include operations and maintenance data for the oxygen reactor basins and support systems, such as blowers and/or re-circulation air compressors (also known as oxygen deck compressors). These also include costs associated with the oxygen production facilities, such as a cryogenic plant or pressure or vacuum swing absorption unit, and support systems, including the main air compressors. Clarifiers are not included here, and are presented in the Secondary Clarifiers section.

### *Performance Benchmarking*

The costs and the amount of labor required to treat each million gallons of wastewater treated through the pure oxygen activated sludge systems are presented in Figures 23 and 24.

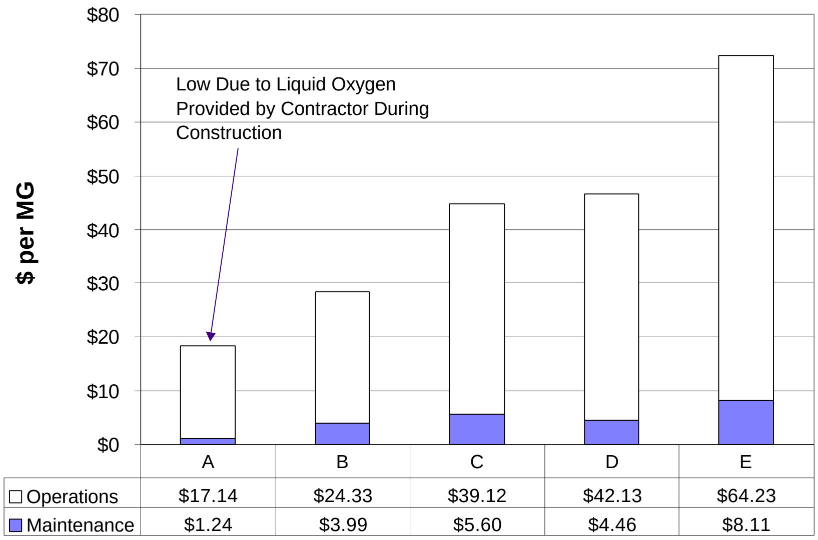



**FIGURE 23: PURE OXYGEN SYSTEMS COSTS PER MILLION GALLONS TREATED**

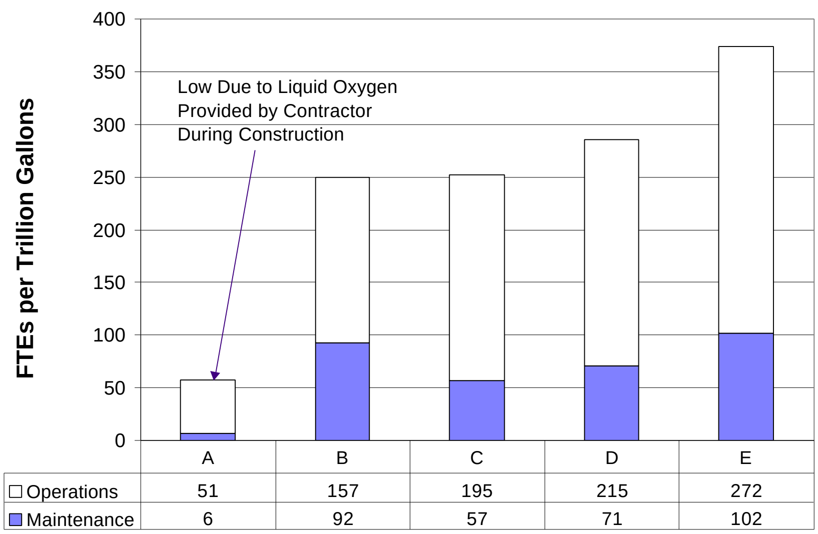



**FIGURE 24: PURE OXYGEN SYSTEMS LABOR PER TRILLION GALLONS TREATED**

Table 26 presents the costs per million gallons and labor per trillion gallons receiving treatment.

| Table 26 Pure Oxygen Systems Costs and Labor | | | | | | |
|---|---|---|---|---|---|---|
| | Dollars Per Million Gallons Receiving Pure Oxygen-activated Sludge Secondary Treatment | | | FTEs Per Trillion Gallons Receiving Pure Oxygen-activated Sludge Secondary Treatment | | |
| | Low | Average | High | Low | Average | High |
| Operations | $17.14 | $37.58 | $64.23 | 51 | 178 | 272 |
| Maintenance | $1.24 | $4.68 | $8.11 | 6 | 66 | 102 |
| Combined | $18.37 | $42.07 | $72.34 | 58 | 244 | 374 |

The cost and labor data to produce a ton of oxygen onsite are presented in Figures 25 and 26. The data are normalized by the amount of pure oxygen generated onsite. Please note in Figure 26 that Agency D contracts out operation and maintenance of the oxygen generation facility, so the labor provided includes only Agency D staff for oversight and oxygen dissolution. Note that costs and labor for Agency A are low because some costs were capitalized as part of system startup.

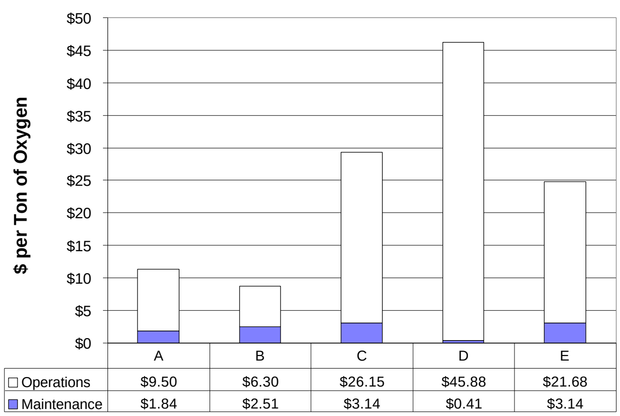



**FIGURE 25: PURE OXYGEN SYSTEMS COSTS PER TON OF OXYGEN PRODUCED**

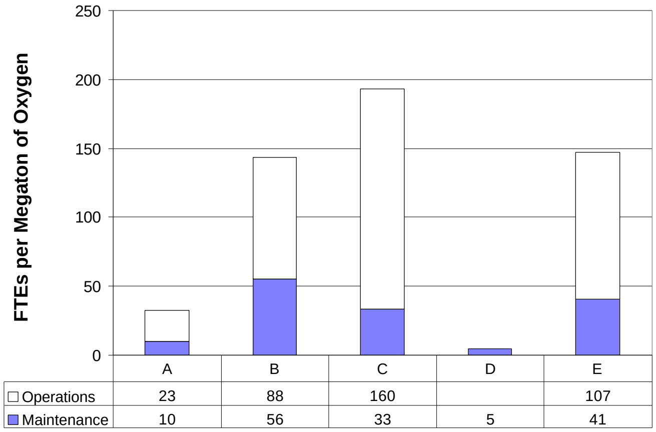



**FIGURE 26: PURE OXYGEN SYSTEMS LABOR PER MEGATON OF OXYGEN PRODUCED**

Table 27 presents the normalized O&M costs and labor FTEs for pure oxygen generation onsite.

| **Table 27 Oxygen Production Costs and Labor** | | | | | | |
|---|---|---|---|---|---|---|
| | **Dollars Per ton of Pure Oxygen Produced** | | | **FTEs Per Megaton of Pure Oxygen Produced** | | |
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $6.30 | $21.90 | $45.88 | 23 | 75 | 160 |
| Maintenance | $0.41 | $2.21 | $3.14 | 4.5 | 29 | 56 |
| Combined | $8.82 | $24.10 | $46.30 | 32 | 104 | 193 |

Please refer to Table 18 (Secondary Treatment Process Operation Criteria), for more detailed data on the operational criteria each facility employs.

## *Process Benchmarking*

### Distinguishing Features

Table 28 summarizes the distinguishing features specifically applicable to those agencies with pure oxygen-activated sludge systems.

**Table 28**
**Pure Oxygen-activated Sludge System Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | Vacuum swing adsorption system for oxygen production; part of LOX provided by contractor under capital budget. |
| B* | Surface impeller with draft tube mixers; 3 oxygen generation cold boxes; low energy prices. |
| C | Submerged turbines (8 older tanks); Surface aerators (4 new tanks, not in operation during study period); 2 cryogenic plants (generally one on-line) |
| D* | Surface aerators; O2 (oxygen) plant operated based on vent purity; O2 plant operated under private contract |
| E | Submerged turbines (converted to surface aerators after study period); tilting weir to control water surface level in oxygenation reactors; cryogenic oxygen plant |

* Operated its oxygen plant at 60% turndown.

### Human Resources

Agency D is the only HPOAS plant to contract out the oxygen generation. As can be seen in Figure 25 above, this results in no operations labor associated with this process. However, the operational expense is shown in Figure 26 above. The cost for this contract operation is 50% higher than the next highest cost agency that generates oxygen in-house.

### Impact of Capital Facilities

Agency A trucked in oxygen under a capital project budget for a portion of the year, understating the true costs associated with producing oxygen during the study year. This impacts both the costs shown in Figure 25 above, as well as the labor FTEs shown in Figure 26 above. The oxygen production values may be skewed low because of this data.

Since the study period, both Agencies C and E have installed surface aerators for pure oxygenation within the reactor basins. Agency E’s reactor basins utilize surface aeration with a draft tube. Agency C has installed four new oxygenation tanks that use surface aerators. The original eight reactor basins still use submerged turbines, but are scheduled for conversion to surface aerators in the future. Both agencies anticipate significantly improved energy efficiency with the conversion.

Agency B is building 250 mgd of additional secondary treatment capacity.

**Areas of Efficiency**

The following efficient practices were identified based upon observations from the performance benchmarking graphs and discussions at the O&M group meetings.

- The use of surface aerators results in lower operating costs, primarily resulting from energy savings.
- There is evidence that cycling the surface aerators to match changes in diurnal flows and loads can save energy without compromising treatment performance.

To conserve energy, Agency D has reduced the number of in-service reactor trains from eight to four. Additionally, the 75 horsepower (HP) surface mixers located on the second stage of each reactor train have been shut down except for 30 minutes per day. Agency D has been able to treat up to 75 MGD using half of its reactor trains. Based upon data comparisons from the Tri-Agency Study, Agency D negotiated a 55% decrease in its contract cost for O&M of the cryogenic facility.

Agency B is the low cost agency for pure oxygen production costs, primarily because the rate for power is significantly lower than other agencies. Figure 26 above shows that Agency B is around the average for labor, confirming that the savings they are experiencing are energy related.

## *Benchmarking Analysis*

The following are observations from the performance benchmarking graphs and the O&M group meetings.

- When contracting oxygen production, agencies should be aware of oxygen production costs in order to keep costs in line with other users.
- The maintenance needs of Variable Swing Adsorption (VSA) oxygen production appear to be substantial due to the numerous valves and their frequent operation.
- Surface impellers are more efficient than submerged turbines. Submerged turbines use more energy than surface impellers.

Table 29 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 29**
**Pure Oxygen Activated Sludge System Best Practices**

| Parameter | Possible Explanations of Lower Cost | Possible Explanations of Higher Cost |
|---|---|---|
| Equipment | HPOAS surface aeration technology is more energy efficient. | HPOAS submerged turbine technology has higher energy costs associated with it. |
| Staffing Issues | Keeping oxygen production “in-house”. | |
| Operational Strategy | Agency D turns off surface aerators in second stage. Agency A trucked in oxygen as part of a capital project, understating true costs. | The higher cost agencies are usually leveraged by the high cost of energy or limited turndown. |

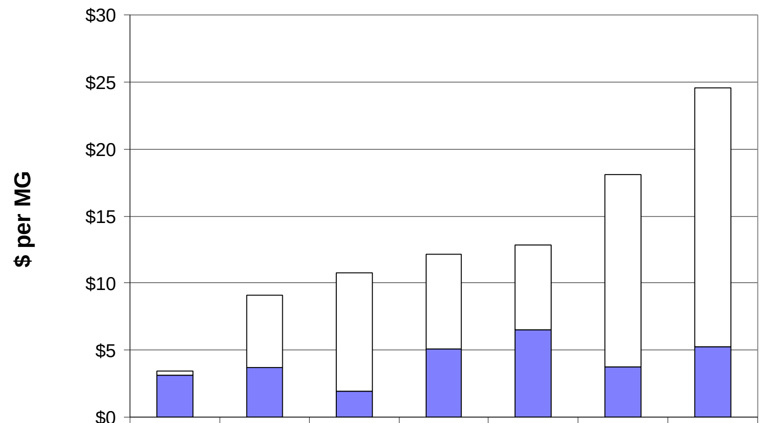
## Secondary Clarifiers

Secondary clarifiers or sedimentation tanks are circular or rectangular basins in which mixed liquor from the activated sludge tanks is allowed to settle. Settling produces a two-phase liquid stream consisting of an upper clarified phase (secondary effluent) and a lower, concentrated phase consisting of settled biological organisms (solids). The clarified secondary effluent overflows weirs located about the periphery of the clarifiers, while the settled solids are returned to the activated sludge basin (return activated sludge) or wasted to solids processing facilities (waste activated sludge).

This functional area generally includes the clarifier basins, mechanical collection equipment, and support systems, such as the mixed liquor distribution channels, return activated sludge pumping, waste activated sludge pumping, channel aeration equipment, activated sludge collectors, and scum collectors. This does not include costs associated with waste activated sludge thickening or scum thickening.

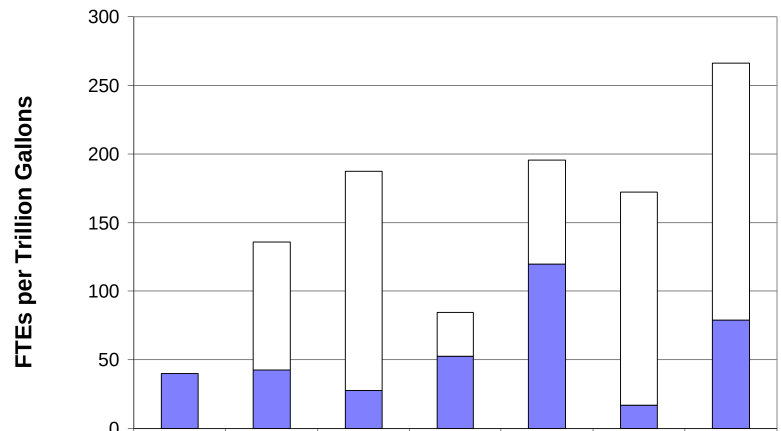
### *Performance Benchmarking*

The costs and the amount of labor required to treat each million gallons of wastewater treated through the secondary clarifiers are presented in Figures 27 and 28.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | $0.29 | $5.39 | $8.80 | $7.12 | $6.28 | $14.32 | $19.29 |
| Maintenance | $3.16 | $3.68 | $1.96 | $5.05 | $6.54 | $3.77 | $5.24 |

**FIGURE 27: SECONDARY CLARIFICATION TREATMENT COSTS PER MILLION GALLONS TREATED**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 0 | 93 | 160 | 32 | 75 | 155 | 187 |
| Maintenance | 40 | 43 | 28 | 53 | 120 | 17 | 79 |

**FIGURE 28: SECONDARY CLARIFICATION TREATMENT LABOR PER MILLION GALLONS TREATED**

## *Process Benchmarking*

### Distinguishing Features

Table 30 summarizes the distinguishing features of the secondary clarifiers at the agencies.

**Table 30**
**Secondary Clarifiers Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | Circular clarifier follows trickling filter, rectangular clarifiers follow HPOAS and AAS; shallow clarifiers (some 9 ft.) operates at low overflow rate (400 gpd/sf) |
| B | Deep clarifiers (18 ft.) with peak overflow rates (1400-1600 gpd/sf); vacuum sweep sludge collectors |
| C | Shallow clarifiers (12.5 ft.), square clarifiers with perimeter-hugging circular sweeps. |
| D | 2 clarifier sets – 4 @ 18’, 4 @ 21’; high overflow rate |
| E | Shallow circular clarifiers (20’ center, 12’ SWD); rectangular at 1 plant; effluent end collection at another plant. |
| G | Deep clarifiers (20 ft.) and high overflow rates (750 gpd/sf) |

### Areas of Efficiency

The following efficient practices were identified based upon discussions at the O&M group meetings:

- It is desirable to design a conservative surface overflow rate (SOR) at 400-600 gpd/square foot.
- Some agencies recommend that secondary clarifiers be designed with sufficient depth (18 feet minimum, 20 feet preferred) to improve performance.

### Areas of Future Investigation

- In-reactor micro and ultra-filtration to replace secondary clarifiers.
- Improvements to CLABS clarifier energy dissipation

## *Benchmarking Analysis*

The following are observations from the performance benchmarking graphs and the O&M group meetings.

- Agency A has secondary clarifier costs that are lower than other agencies because the most time is spent checking D.O., SVIs, and performing microbial analyses. In addition, Agencies A and E do not need to accommodate storm flow and operate at constant flow.

- Agency G has high secondary clarification costs, again because of its centralized concrete channel aeration system. This results in high agitation air costs in the mixed liquor channels to the clarifiers.

## Fixed Film Reactors

Fixed film reactors employ biological mass attached to some media, either fixed or rotating. This functional area specifically includes labor, materials, and supplies associated with operating fixed media process systems.

Table 31 summarizes design criteria for the trickling filters at Agency D.

**Table 31**
**Fixed Film Reactor Design Criteria (Agency D)**

| Item | Design Criteria | Operating Condition |
|---|---|---|
| Diameter | 180 ft | |
| Media Depth | 6 ft of rock media | |
| Flow rate | 5 mgd | 7.5 mgd |

### *Performance Benchmarking*

Data for fixed film reactors are included in Figures 17, 18 and 19 above. The cost to operate the fixed film reactors at Agency D is $14.17 per million gallons through the reactors.

### *Process Benchmarking*

#### <u>Unique Features</u>

Agency D is the only one of the agencies with trickling filters. The trickling filter plant is comprised of four high-rate type filters and one secondary clarifier. Each trickling filter is rated at 5 mgd capacity, but currently operates at 7.5 mgd. The rock filter media is 6 feet deep with clay underdrains. The effluent TSS and BOD from this highly loaded trickling filter system ranges from 40-50 mg/L. The secondary clarifier is fed three times the hydraulic flow that it was designed for.

#### <u>Areas of Efficiency</u>

At the O&M group meetings, it was observed that this “low tech” treatment method was significantly less expensive than both activated sludge and HPOAS, due to large energy savings relative to the other processes. Trickling filters do not require the air or oxygen generating and/or dispersion equipment (with the associated energy usage) required by other secondary treatment technologies. On the other hand, the anticipated level of treatment of fixed film reactors is generally significantly lower than air activated or oxygen activated sludge processes.

## RESIDUALS PROCESSING AND HANDLING

Residuals processing and handling refer to all processes dealing with the biological and inorganic solid matter (biosolids) removed from the wastewater during the treatment process. Screenings and grit are removed during preliminary treatment. Scum is removed during primary and secondary treatment. Sludge thickening is necessary to decrease the amount of water in the solids removed from the primary and secondary clarifiers. These thickened solids are then sent to digesters or to other solids handling facilities. Digestion involves the decomposition of organic and inorganic matter in the absence of molecular oxygen. Anaerobic digesters stabilize the solids that have settled out in the clarifiers during primary and secondary treatment. Anaerobic digesters produce gas that can be used beneficially in the plant or sold to a local utility. Biosolids dewatering decreases the amount of liquid in the biosolids and reduces subsequent treatment and handling costs. Belt filter presses, centrifuges, and other devices are typically used for dewatering. Biosolids disposal/reuse refers to the many possibilities for ultimate reuse and/or disposal of the biosolids, such as composting and landfilling. Some plants may use other residuals handling processes not specified above. Many of the biosolids handling processes may require residuals stream odor control processes.

Residuals processing and handling consists of screenings and grit, hauling and disposal, primary sludge thickening, scum thickening, waste activated sludge thickening, digestion, dewatering, biosolids treatment/disposal/reuse, and associated support systems. Residuals processing and handling costs include operations and maintenance costs associated with the various residual solids treatment systems.

Table 32 presents data provided by each of the agencies for the unit processes and areas of the facility, and identifies the normalization factor for each of the unit processes.

**Table 32**
**Components of Residuals Processing and Handling**

| Unit Process (Per Dry ton of Solids Treated) | Normalization Factor |
|---|---|
| Total Residuals Processing/Handling (includes digestion, dewatering, and disposal/reuse only) | Dry tons of solids into solids handling * |
| Primary Sludge Thickening | Dry tons of solids produced in primaries |
| Waste Activated Sludge (WAS)Thickening | Dry tons of solids produced in secondaries |
| Digestion | Dry tons of solids fed into digestion |
| Dewatering | Dry tons of solids fed into dewatering |
| Biosolids Disposal/Reuse | Dry tons of biosolids hauled/disposed/reused |

* Note that for all facilities except Agency E, this value is the dry tons of solids entering digestion. For Agency E, this value is the dry tons of solids entering dewatering. Agency E does not have anaerobic digestion facilities and incinerates its dewatered biosolids.

The costs required to process and handle residuals are presented in Figure 29 (Residual Treatment Costs per Dry Ton of Solids), which includes data for the major solids handling processes (digestion, dewatering, and biosolids disposal/reuse). The residuals treatment data were normalized by flow through each residuals treatment system. The individual unit process costs, in $/dry ton, were then summed to provide the data presented in Figure 29.

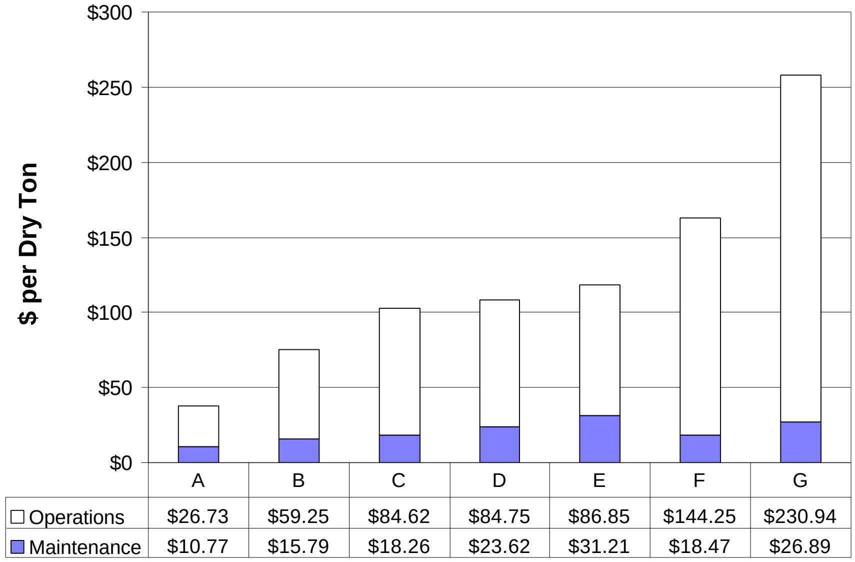



**FIGURE 29: RESIDUALS TREATMENT COSTS PER DRY TON OF SOLIDS.**

More detailed information about each of these processes is provided below.

The high cost agency, Agency G, has high chemical costs and high labor costs culminating in overall residuals treatment costs significantly above the average values. More detail on the costs and the breakdowns is given in the sections discussing each of the unit processes.

Table 33 presents the low, average, and high normalized cost per dry ton and FTEs per thousand dry tons of solids receiving residuals treatment.

**Table 33**
**Residuals Treatment Costs & Labor**

| | Dollars per Dry Ton of Solids Receiving Residuals Treatment* | | |
|---|---|---|---|
| | **Low** | **Average** | **High** |
| Operations | $26.73 | $102.68 | $230.94 |
| Maintenance | $10.77 | $20.05 | $31.21 |
| Combined | $37.50 | $122.73 | $257.84 |

* For the purposes of this table, residuals treatment includes only digestion, dewatering, and disposal/reuse

## Grit, Screenings, and Scum

This includes the rag storage and handling area, and equipment or processes after the scraper/rake on the screening process. This section also covers any floatables (scum) separated at any of the liquid processes.

### *Process Benchmarking*

#### Distinguishing Features

Table 34 summarizes the distinguishing features associated with grit, screenings, and scum systems.

**Table 34**
**Grit, Screenings, and Scum Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| CCCSD | Screenings ground and returned to influent flow |
| KCDNR | Co-thicken primary scum in dissolved air flotation thickeners (East Plant) |
| OCSD | Primary scum manually dewatered (plant 1 rectangulars only) then pumped to digestion |
| SRCSD | Dewatered screenings ground and sent to landfill, scum combined with primary sludge and WAS then sent to digesters |

## Sludge Thickening

Sludge thickening is a process to increase the solids content of sludge by removing some of the entrained water. This process reduces the volumetric loading to, or increases the efficiency of, subsequent solids processing systems. There are several methods of sludge thickening including gravity thickening, dissolved air flotation, centrifugal thickening, rotary drum thickening, and gravity belt thickening.

Table 35 summarizes information on the sludge thickening processes.

**Table 35**
**Sludge Thickening Design Criteria**

| Agency | Type of Process Primary/ Secondary | Number of Units Primary/ Secondary | Loading Primary/ Secondary | Detention time (hours) Primary/ Secondary | Polymer dosage Primary/ Secondary |
|---|---|---|---|---|---|
| A | DAFT* | 4 | 17 lbs/sf/day | 4 | None |
| B | DAFT* | 3 | | | Intermittent |
| C, One Plant | DAFT* | 1 | 1.27(lb/hr/sq ft)<br>100-300 gpm | 1 | 5 lb/ton |
| D, Plant 1 | DAFT* | 3 | 15 lbs/cf/day | | 7.5 dry lbs/dry ton |
| D, Plant 2 | DAFT* | 4 | 15 lbs/cf/day | | None |
| E, Plant 1 | DAFT* | 4 | | | 2.5 lb/dry ton |
| F | Gravity (primary)<br>GBT** (secondary) | 3<br>3 | 900 gpm | | N/A |
| G | Centrifuges<br>GBT(2) | 2<br>1 | | | |

* Dissolved air flotation thickeners
** Gravity belt thickeners

### *Performance Benchmarking*

The costs and labor required for primary sludge thickening are presented on Figures 30 and 31. The primary sludge thickening data were normalized by mass of solids sent to primary thickening.

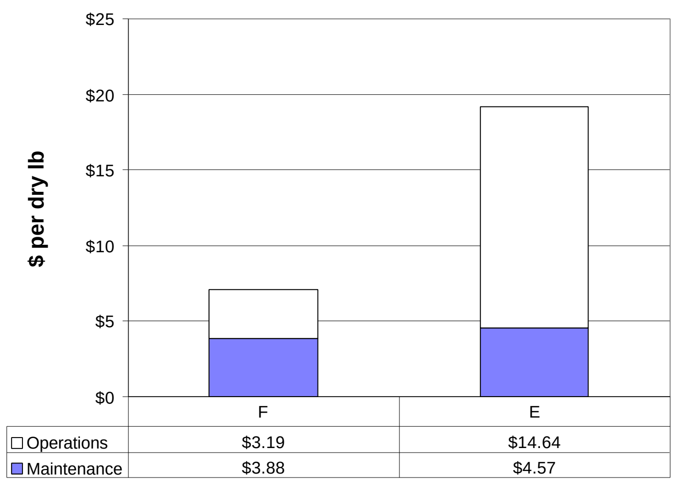



**FIGURE 30: PRIMARY SLUDGE THICKENING COSTS PER DRY TON TREATED**

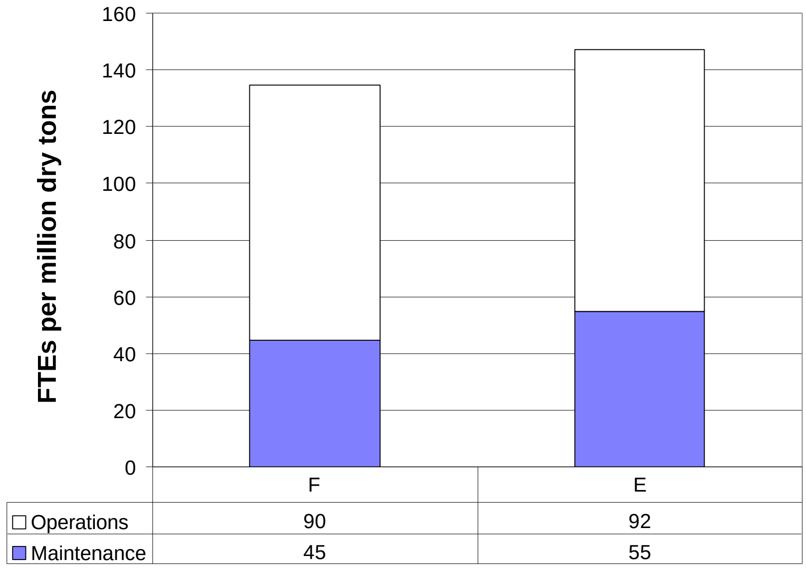


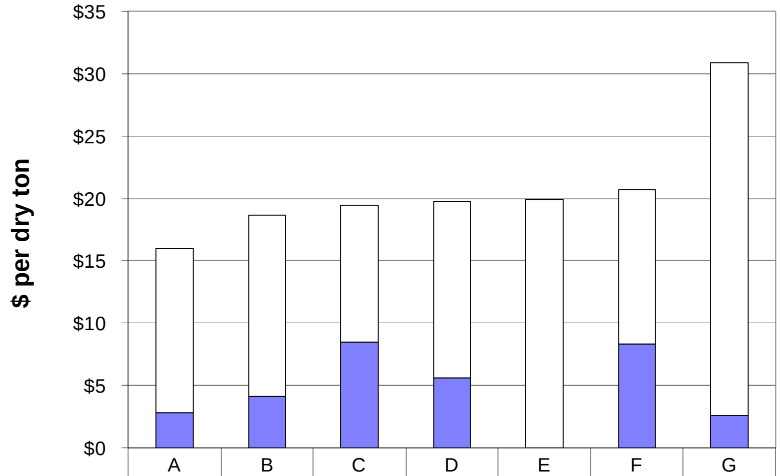

**FIGURE 31: PRIMARY SLUDGE THICKENING LABOR PER MILLION DRY TON TREATED**

Table 36 presents the costs per dry ton and FTEs per million dry tons treated through primary sludge thickening.

**Table 36**
**Primary Sludge Thickening Costs and Labor**

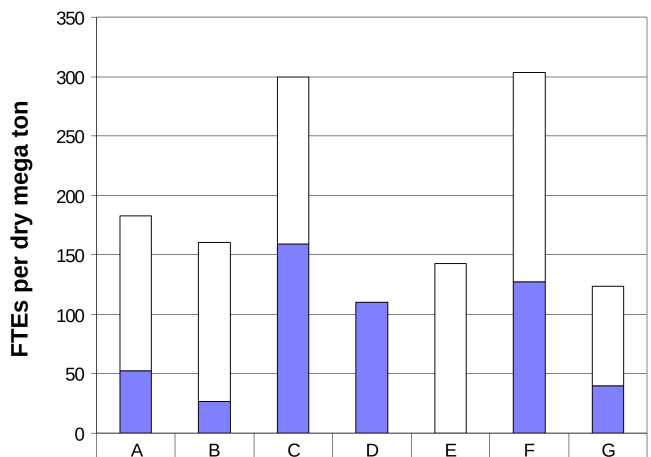
| | Dollars per Dry Ton Treated through Primary Sludge Thickening | | | FTEs per Million Dry Tons Treated through Primary Sludge Thickening | | |
|---|---|---|---|---|---|---|
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $3.19 | $8.91 | $14.64 | 90 | 91 | 92 |
| Maintenance | $3.88 | $4.22 | $4.57 | 45 | 50 | 55 |
| Combined | $7.06 | $13.14 | $19.21 | 135 | 141 | 147 |

The costs and of labor required to treat solids during secondary sludge thickening are presented in Figures 32 and 33. The secondary sludge thickening data were normalized by mass of solids sent to waste activated sludge thickening.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | $13.20 | $14.47 | $10.98 | $14.15 | $19.88 | $12.36 | $28.30 |
| Maintenance | $2.77 | $4.15 | $8.46 | $5.57 | | $8.33 | $2.60 |

**FIGURE 32: SECONDARY SLUDGE THICKENING COSTS PER DRY TONS TREATED**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 131 | 134 | 141 | 0 | 142 | 176 | 84 |
| Maintenance | 52 | 27 | 159 | 110 | 0 | 127 | 40 |

**FIGURE 33: SECONDARY SLUDGE THICKENING LABOR PER MILLION DRY TONS TREATED**

Table 37 presents the low, average, and high normalized cost per dry ton and FTEs per million dry tons treated through secondary sludge thickening.

**Table 37**
**Secondary Sludge Thickening Costs and Labor**

| | Dollars per Dry Ton Treated through Secondary Sludge Thickening | | | FTEs per Million Dry Ton Treated through Secondary Sludge Thickening | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | $10.98 | $16.16 | $28.30 | 84 | 115 | 176 |
| Maintenance | $2.60 | $4.55 | $8.46 | 27 | 74 | 159 |
| Combined | $15.97 | $20.71 | $30.90 | 123 | 189 | 304 |

### *Process Benchmarking*

**Distinguishing Features**

Table 38 summarizes the distinguishing features associated with the sludge thickening systems.

**Table 38**
**Sludge Thickening Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | DAF thickening of WAS; GBT available (not normally used) |
| B | Dissolved air flotation thickeners; intermittent chemical use (cationic polymer) |
| C, Plant 2 | DAF thickening of WAS |
| D | DAF thickening of WAS |
| E, Plant 1 | Co-thickening of primary sludge, scum, and WAS in dissolved air flotation tanks |
| E, Plant 2 | Primary sludge, WAS and secondary scum are co-thickened on GBTs |
| F | Gravity thickeners for primary sludge, GBTs for WAS |
| G | Centrifuges and gravity belt thickener |

## Digestion

Anaerobic digestion involves the decomposition of organic matter in biosolids in the absence of molecular oxygen. Anaerobic digesters stabilize the solids that have settled out in the clarifiers during primary and secondary treatment.

Table 39 summarizes information on the anaerobic digestion processes.

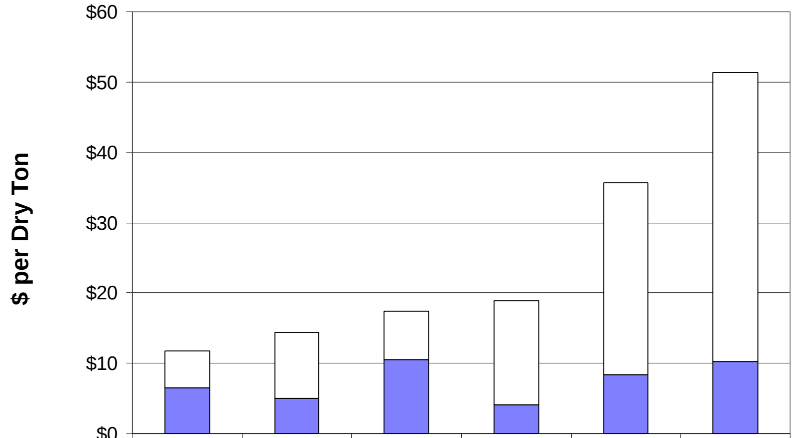
**Table 39**
**Digestion Design Criteria**

| Agency | Type of Design | Number of Units | Loading (lb VSS/cf)[1] | Detention time (days) | Temperature (degrees F) |
|---|---|---|---|---|---|
| A, Plant 1 | American Conventional | 18 | | Over 15 | 95 |
| A, Plant 2 | Egg-shaped | 4 | 0.10 | Over 16 | Over 95 |
| B, Plant 1 | | 4[2] | 0.12 | 28.2 | 97 |
| B, Plant 2 | Floating cover | 5 | 0.10 | 27.2 | 96 |
| C | Floating cover | 8 | 0.21 | 30 | 92 |
| D | Fixed cover | 9[5] | 0.12 | Over 15 | 97 |
| E, Plant 1 | Fixed cover | 10[3] | 0.09-0.15 | 20-30 | 98 |
| E, Plant 2 | Fixed cover | 13[4] | 0.09-0.15 | 20-30 | 98 |
| F | 10 w/ floating cover, 1 with fixed cover | 11 | | | 95 |
| G | No digestion at this facility. | | | | |

Notes:
1 Pounds of volatile suspended solids per cubic foot
2 Only 3 digesters were in use at any one time during the study year
3 10 working digesters, and two holding digesters
4 13 working digesters, five holding digesters, and two emergency units
5 9 conventional digesters, and two blending digesters

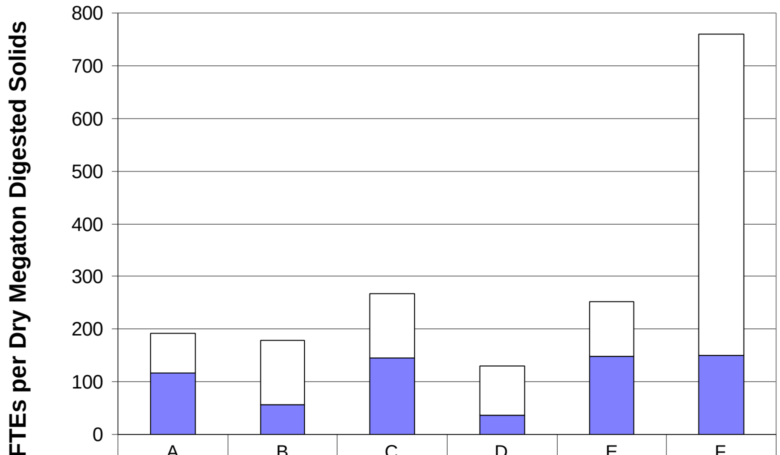
### *Performance Benchmarking*

The costs and labor required to treat solids during digestion are presented in Figures 34 and 35. These digestion graphs include cost and labor data provided by the agencies. The digestion data were normalized by mass of solids fed into digestion. Analysis of these graphs takes place in Benchmarking Analysis. No data were provided for Agency G, since Agency G does not have digesters. Note that for Agency F, normalized flow into digestion is less than flow into dewatering. It is suspected that normalization factor for digestion is low, and is skewing the results shown on these two graphs.




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Operations | $5.32 | $9.44 | $6.88 | $14.84 | $27.30 | $41.03 |
| Maintenance | $6.50 | $4.99 | $10.48 | $4.09 | $8.34 | $10.27 |

**FIGURE 34: DIGESTION COSTS PER DRY TON TREATED**




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Operations | 75 | 123 | 121 | 93 | 103 | 610 |
| Maintenance | 117 | 56 | 145 | 37 | 148 | 151 |

**FIGURE 35: DIGESTION LABOR PER MILLION DRY TON OF DIGESTED SOLIDS**

Table 40 presents costs per dry ton and FTEs per million dry tons treated through digestion.

**Table 40**
**Digestion Costs and Labor**

| | Dollars per Dry Ton Treated through Digestion | | | FTEs per Million Dry Ton Treated through Digestion | | |
|---|---|---|---|---|---|---|
| | **Low** | **Average** | **High** | **Low** | **Average** | **High** |
| Operations | $5.30 | $17.47 | $41.03 | 75 | 188 | 610 |
| Maintenance | $4.09 | $7.44 | $10.48 | 37 | 109 | 151 |
| Combined | $11.82 | $24.91 | $51.30 | 112 | 297 | 761 |

## *Process Benchmarking*

**Distinguishing Features**

Table 41 summarizes the distinguishing features associated with digestion.

**Table 41**
**Digestion Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A, Plant 1 | Two-stage digestion; steam injection |
| A, Plant 2 | Conventional heat exchangers |
| B, Plant 1 | Digester gas recirculation, digested sludge recirculation (side to side and bottom to top) with in-line grinders |
| B, Plant 2 | Continuous digester gas and digested sludge recirculation. Cyclical operation with feed, recirculation, and draw-down stages. |
| C | Spiral heat exchangers |
| D | External draft tube mixers, internal draft tube mixers, heat exchangers, sludge circulation pumps |
| E | Spiral heat exchangers, Ferric chloride addition. |
| F | Two-stage digestion, hot water heat exchanger, provisions for gas mixing |

**Impact of Regulations**

In order to burn the methane produced by the digesters, the South Coast Air Quality Management District (SCAQMD) requires that sulfide levels in the gas be less than 40 parts per million. Agency E spends more than half their digester operating budget on iron salts to control the sulfides content of the digester gas.

Agency A, also in the SCAQMD, burned digester gas in 1996-1997 with lower chemical costs. They spent 16K on an iron scrubber that takes hydrogen sulfide down from up to 400 down to 20 ppm. The SCAQMD limit of 40 ppm was therefore not a problem. Agency A also adds a smaller amount of Ferric chloride to the digesters for struvite control, and to the primaries for coagulation.

**Areas of Challenge**

Digester cleaning was seen as an area of challenge. Several of the agencies remarked on the amount of grit and sand found in their digesters, reducing the working volume of the digester. Digester cleaning is a labor- and time-intensive task for any facility.

**Impact of Capital Facilities**

Agency C has several characteristics of their digestion system which consume extensive maintenance time—four boilers used to heat the digesters, as well as a system layout which necessitates pumping the digested sludge a long distance.

Agency D reported elimination of plugging problems in the after installing a Muffin Monster grinder upstream of the digesters.

**Areas of Efficiency**

The following efficient practices were identified based upon observations from the performance benchmarking graphs and discussions at the O&M group meetings.

- The amount of grit collecting in the digesters can be reduced by proper design and operations of grit removal earlier in the treatment train.
- Several suggestions to reduce foaming in the digesters were presented: 1) Fixed covers; 2) longer detention times with reduced temperatures (92ºF); and 3) making adjustments to the secondaries to inhibit filament growth.
- Mechanical seals are preferred over packed seals. Use of mechanical seals reduces water added to the digesters. As high solids pumps can be very hard on mechanical seals, the agencies recommend bellows seals.

### *Benchmarking Analysis*

The following are observations from the performance benchmarking graphs and the O&M group meetings.

- Typically, agencies with grinders (Muffin Monsters, etc.) prior to digestion appear to have lower operating costs.
- Typically, agencies that combine primary and secondary sludges prior to or at the digesters appear to have lower maintenance costs.
- Lower operating costs are generally seen at those agencies that have one mode of operation (either combining sludges or keeping sludges separate); rather than switching back and forth between modes of operation. Agency F, the high cost and high labor agency as shown in Figures 34 and 35 alternates modes of operation.
- Grinding sludge prior to digestion appears to impact maintenance costs favorably. The majority of low cost agencies have grinding prior to digestion. While both the low maintenance cost and high maintenance cost facilities have grinders prior to their digesters, the high maintenance cost facility has other digestion-related facilities that have very high maintenance demands. Note that the highest operations cost facility does not grind prior to the digesters.

Table 42 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 42**
**Digestion Best Practices**

| Parameter | Possible Explanations of Lower Cost | Possible Explanations of Higher Cost |
|---|---|---|
| Equipment | Grinders (Muffin Monsters, etc), prior to digestion, reduce costs. Egg-shaped digesters are self-cleaning. | Poor grit chamber efficiency results in excess sand/grit in digesters. |
| Maintenance | Grinding prior to digestion appears to result in lower maintenance costs. | Digested sludge pumped a long way. Heating boilers require intensive maintenance. |
| Staffing Issues | | Agency F spends 90% of the operating budget on labor costs. |

| | Table 42 continued | |
|---|---|---|
| Operational Strategy | | High chemical addition costs to keep H2S levels in digester gas low. Switching back and forth between combined sludge digestion and separate sludge digestion may increase operational costs. |

## Dewatering

Biosolids dewatering decreases the amount of liquid in the biosolids and reduces subsequent treatment and handling costs. Belt filter presses, centrifuges, and other devices typically accomplish dewatering.

Table 43 summarizes information on the dewatering processes.

**Table 43**
**Dewatering Operating Criteria**

| Agency | Technology | # of Units | Loading | Chemical Addition | % solids in | % cake |
|---|---|---|---|---|---|---|
| A, Plant 1 | Ashbrook belt filter press (2.2 meter) | 8 | 100-120 gpm | Mannich type cationic polymer | 2.35 | 21.75 |
| A, Plant 2 | Ashbrook belt filter press (2.2 meter) | 15 | 100-120 gpm | Mannich type cationic polymer | 2.66 | 22.78 |
| B, Plant 1 | Centrifuges | 3 | | Polymer | | 28.3 |
| B, Plant 2 | Centrifuges | 2 | 150 gpm[1] | Polymer | | 15.0 |
| C | Ashbrook belt filter press (2.2 meter) | 4 | 750-1000 lb/hr/meter | Polymer | 2.5 | 22.0 |
| D | Horizontal solid bowl centrifuges | 4 | 100 gpm | Polymer and carbide lime for incineration | 4 | 23.0 |
| E, Plant 1 | Andritz SMX belt filter presses (2.2 meter) | 8[2] | 45-55 gpm/press | Polymer | 2.9 | 21.24 |
| E, Plant 2 | Centrifuges | | | Polymer | 2.8 | |
| F | Medium speed Humboldt centrifuges | 4 | 150 gpm | Polymer | | |
| G | No dewatering facilities[3] | | | | | |

1. Gallons per minute.
2. 8 available, 4 usually in use.
3. Digested sludge is sent directly to on-site facultative lagoons.

### *Performance Benchmarking*

The costs and the amount of labor required to dewater each dry ton of solids is presented on Figures 36 and 37. The dewatering data were normalized by mass of solids fed into dewatering. Analysis of these graphs takes place in Benchmarking Analysis.

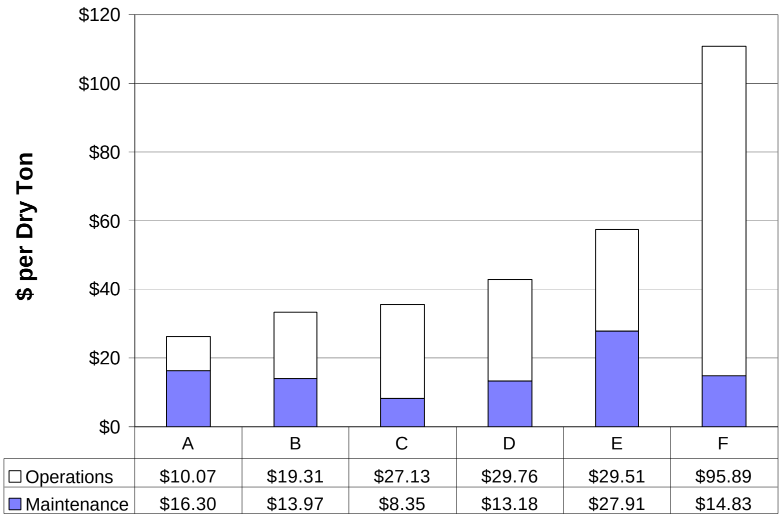



**FIGURE 36: BIOSOLIDS DEWATERING COSTS PER DRY TON TREATED**

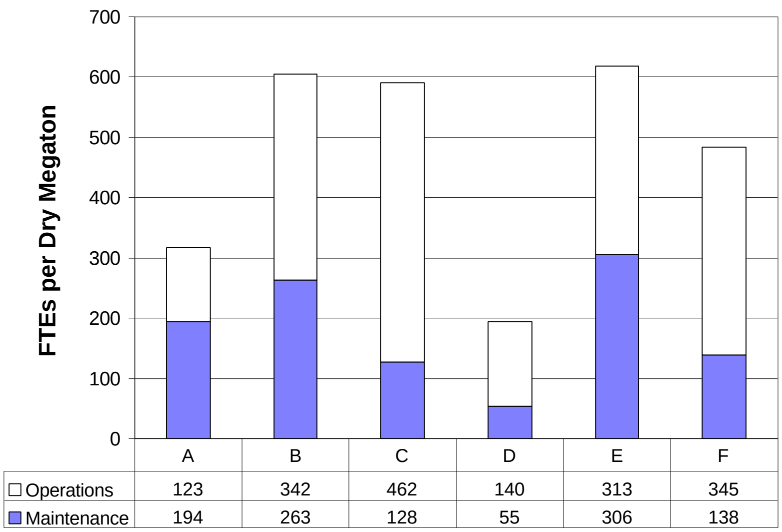



**FIGURE 37: BIOSOLIDS DEWATERING LABOR PER DRY TON TREATED**

Table 44 presents the costs per dry ton and FTEs per million dry tons treated through dewatering.

**Table 44**
**Dewatering Costs and Labor**

| | Dollars per Dry Ton Treated through Dewatering | | | FTEs per Million Dry Ton Treated through Dewatering | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | $10.07 | $35.35 | $95.89 | 123 | 293 | 462 |
| Maintenance | $8.35 | $15.63 | $27.91 | 55 | 172 | 306 |
| Combined | $26.40 | $50.98 | $110.70 | 194 | 465 | 619 |

## *Process Benchmarking*

### Distinguishing Features

Table 45 lists the distinguishing features associated with dewatering.

**Table 45**
**Dewatering Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| C | Digester and lagoon sludges dewatered separately. * |
| D | Centrifuges plus liquid cationic polymer dewater undigested sludge. |
| G | No dewatering facilities. |

* Lagoon sludges used for compost & digested sludges land applied.

### Human Resources

There was a brief discussion at the O&M group meetings about the feasibility of operating dewatering equipment unattended, as is done in Europe. There was some concern expressed about the small operator savings that would result from this when compared to the risk of damaging expensive equipment. It may be feasible to put the dewatering equipment on operator rounds rather than having continuous attention.

### Areas of Challenge

Agency F has a very high polymer demand for dewatering. After extensive testing, they have identified one polymer that gives them the desired results. Unfortunately, the polymer is very expensive. The high unit cost combined with the high demand results in a very high overall operating cost for their dewatering facilities.

### Areas of Efficiency

The following efficient practices were identified based upon observations from the performance benchmarking graphs and discussions at the O&M group meetings:

- Some agencies use advances in technology (for example, high-solids centrifuges) for dewatering to produce a drier cake. This reduces disposal costs, especially for those agencies requiring significant truck hauling.
- If using high cake centrifuges, a conveyance method should be selected carefully. The chute slope into the hoppers should be steep enough to minimize bridging.
- Agencies recommend pumping dewatered cake as opposed to using mechanical conveyors. Agencies recommend minimizing conveyance length. The advantages of pumping dewatered sludge are as follows: a) odors are completely enclosed; and b) difficult maintenance on enclosed conveyor belts is eliminated.

**Areas of Future Investigation**

The agencies will continue to research unattended or minimally attended operation of dewatering equipment, as allowable by their individual systems and requirements.

### *Benchmarking Analysis*

The following are observations from the performance benchmarking graphs and the O&M group meetings.

- There does not seem to be a relationship between operating cost or labor and the type of dewatering equipment used (centrifuges vs. belt filter presses).
- The high cost agency, Agency F, is operating with the constraint of a single type of polymer that produces the required results. This polymer is very expensive, and drives the overall costs for dewatering high. As is seen in Figure 37 above, Agency F's labor for dewatering is very reasonable.
- Agency F's maintenance costs for dewatering are understated because the costs associated with overhauling all the belt filter presses (during the study period) were applied to the capital budget, and do not appear in the O&M monies.

Table 46 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 46**
**Dewatering Best Practices**

| Parameter | Possible explanations of lower cost | Possible explanations of higher cost |
|---|---|---|
| Equipment | | Ashbrook Winklepress belt filter presses require lots of operator maintenance/cleaning. Selection of polymer may adversely impact costs. |
| Maintenance | Maintenance strategies. | |
| Staffing Issues | Operational attendance strategies. | |
| Operational Strategy | | Type of polymer used and means of dispersion/ mixing. Limited options on effective polymer types may increase costs. |

## Biosolids Disposal/Reuse

Biosolids disposal/reuse refers to the many possibilities for ultimate reuse and/or disposal of the biosolids, such as composting, land application, landfilling, and incineration (including landfill of ash).

This functional area includes costs associated with the biosolids reuse disposal program. It also includes any process to further reduce pathogens, such as composting. Contracts for disposal/reuse are also included in this area along with the contractors, siting, administration, and monitoring of these sites. Agency site inspection and administration are included in this item.

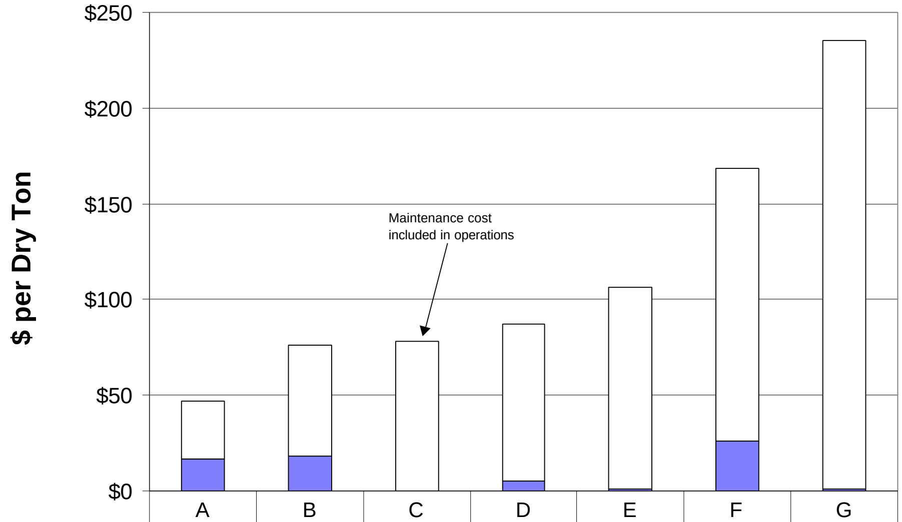
Table 47 summarizes information on biosolids disposal/reuse.

**Table 47**
**Biosolids Disposal/Reuse Overview**

| Agency | Total O&M Cost ($) | $/Dry Ton | Dry Ton | FTEs | Notes/Comments |
|---|---|---|---|---|---|
| A | 894,048 | $47.14 | 19,000 | 18.1 | On-site lagoons; dedicated land disposal |
| B | 1,252,021 | $76.22 | 16,400 | 6.10 | Raw sludge to incineration. Ash hauled to landfill |
| C | 1,365,154 | $78.08 | 17,500 | 1.69 | 22% solids (no maintenance data provided) |
| D | 6,496,235 | $87.03 | 74,643 | 4.20 | 71,643 dry tons land application<br>3,000 dry tons compost<br>No on-site facilities except truck loading, wet cake storage (3,600 wet tons); daily production dewatering/trucking loading on section. |
| E | 4,288,739 | $106.43 | 40,300 | 1.97 | @ 21.9% solids<br>0.44 dry ton/MG |
| F | 2,030,092 | $168.64 | 12,000 | 12.50 | 18,070 dry tons – land application<br>3,264 dry tons – compost<br>Older lagoon material that is land applied as part of a capital lagoon renovation project is not part of the O&M budget. (Hence, these figures do not sum to the Normalization factor of 12,038). |
| G | 6,440,010 | $235.50 | 27,300 | 15.40 | Privatized drying facility $1.2 million—contract terminated<br>0.37 dry tons/MG<br>Nutrient and timber revenue $219,000<br>No capital included |

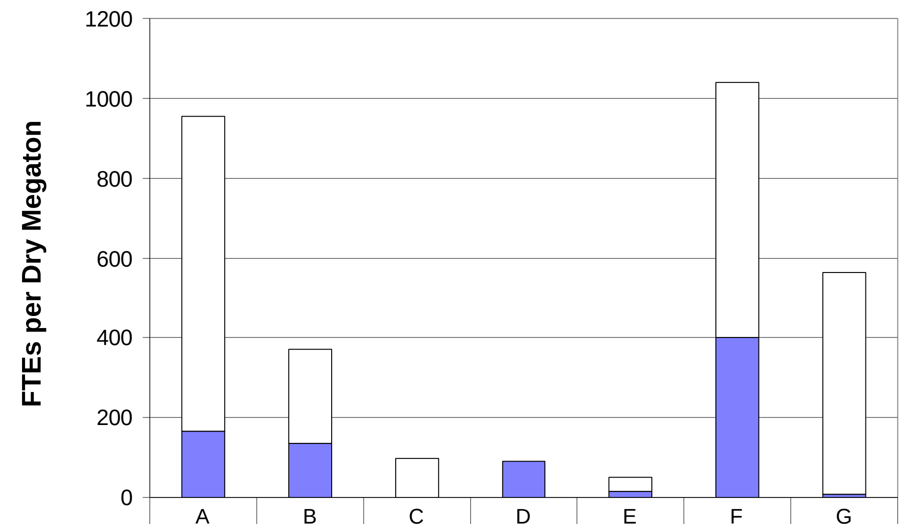
## *Performance Benchmarking*

The costs and labor required to handle, reuse, and/or dispose of the solids after treatment is presented in Figures 38 and 39.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | $30.18 | $57.93 | $78.08 | $81.89 | $105.25 | $142.32 | $234.65 |
| Maintenance | $16.96 | $18.29 | | $5.14 | $1.18 | $26.32 | $0.85 |

**FIGURE 38: DISPOSAL/REUSE COST PER DRY TON**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Operations | 789 | 236 | 97 | | 34 | 639 | 555 |
| Maintenance | 166 | 136 | | 90 | 15 | 402 | 8 |

**FIGURE 39: DISPOSAL/REUSE LABOR PER DRY MEGATON**

Table 48 presents costs per dry ton and FTEs per million dry tons processed through biosolids disposal/reuse.

**Table 48**
**Biosolids Disposal/Reuse Costs and Labor**

| | Dollars per Dry Ton Processed through Biosolids Disposal/Reuse | | | FTEs per Million Dry Ton Processed through Biosolids Disposal/Reuse | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | $30.18 | $104.33 | $234.65 | 34 | 336 | 789 |
| Maintenance | $0.85 | $9.82 | $26.32 | 8 | 117 | 402 |
| Combined | $47.14 | $114.15 | $235.50 | 49 | 452 | 1041 |

### *Process Benchmarking*

**Distinguishing Features**

Six of the agencies produce at least Class B biosolids. One agency incinerates sludge and scum producing ash that meets appropriate 503 standards. Some compost a portion of their biosolids to meet Class A requirements. The majority of agencies contract to land apply their biosolids to agricultural/range land/forest. Some agencies also use biosolids for the land reclamation of marginal soils. Table 49 summarizes the distinguishing features associated with biosolids/reuse.

**Table 49**
**Biosolids Disposal/Reuse Distinguishing Features**

| Agency | Unique Features |
|---|---|
| A | On-site Dedicated Land Disposal (DLDs), sludge lagoons. |
| B | On-site multiple hearth furnace; ash is landfilled. |
| C | Truck drivers load their own trucks. |
| D | On-site drying and incineration facility shut down. |
| E | Multiple haulers. |
| F | On-site solids storage lagoons; land application plus seasonal retail compost operation; in-vessel composting. |
| G | Silviculture land application; on-site privatized steam drying facility shut down. |

Biosolids disposal and reuse are very heavily impacted by regulations. The majority of agencies require off-site options for disposal/reuse, increasing the number of stakeholders interested and concerned about the actions taken. Discussion of some of the regulations affecting the agencies is included in Appendix E, Impact of Biosolids Regulations.

#### Human Resources

Agency C's labor is comparatively low because they take the form of contract administrators rather than operators handling the disposal directly. The Agency E biosolids program has minimal staffing because the hauling and land application programs are contracted out, and there are no programs established internally for biosolids disposal.

The Agency A biosolids program has low costs because of the on-site disposal, but high FTEs for this process. The 15 FTEs for field operations include 12 maintenance helpers, who are involved in driving the tractors, and other activities in support of the on-site disposal program. There are also three FTEs primarily for maintenance of heavy equipment. Other program costs include fuel for the tractors, materials and services for equipment maintenance, and electricity for running pumps and other equipment.

#### Areas of Challenge

The following areas of challenge were identified through discussions at the O&M group meetings:

- Future approaches for biosolids will need to consider processing and distribution costs, markets, regulations/permitting, technology, marketing, risk, and life cycle costs
- Extreme concerns with public perception
- Challenges are more dynamic than other O&M areas.
- One of the four major cost centers of O&M, with transportation representing a substantial portion of the cost.
- Privatization is an issue of which all agencies should be aware and evaluating.

Planning, testing, promoting long-term partnerships, and producing biosolids with a high solids content are important in keeping biosolids disposal/reuse program costs down in an environment heavily influenced by changing regulations.

#### Areas of Efficiency

The following efficient practices were identified based upon observations from the performance benchmarking graphs and discussions at the O&M group meetings.

- The lowest cost agencies use biosolids disposal technologies that other agencies may not be able to use because of land restrictions, permitting considerations, or neighborhood concerns.
- Some agencies are planning diverse biosolids disposal/reuse programs. The plan might include, for example, jurisdictional diversity for land application sites, or multiple disposal/reuse options.
- Some agencies reduce costs by seeking multiple bidders for hauling and application of biosolids.
- Some agencies use sludge lagoons to reduce mass, increase quality, and to allow seasonal land application. It appears that the low-cost agencies incinerate or use biosolids onsite. Both strategies reduce truck-hauling costs.

- Several agencies recommend complete and detailed pilot testing and market development of new options and technologies prior to committing to full scale and long term commitment.
- Generation of Class "A" biosolids may open up more ultimate reuse or disposal options and may decrease reuse/disposal costs.
- Off-site inspections by in-house personnel can find potential problems and compliance issues, prevent violations, and reduce risk.
- Get involved during development of regulations.
- Promote long-term relationships with contractors, regulators, farmers, and the public.
- Encourage competition: Having multiple contracts can reduce costs, by forcing competitive pricing between contract haulers, or other service providers.

#### Areas of Future Investigation

The following items were identified as possible areas of future investigation at the O&M group meetings.

- Conduct joint research. Establish a long-term joint research group/effort. Coordinate programs to reduce duplication of effort.
- Work together to influence Environmental Protection Agency/Water Environmental Research Foundation (EPA/WERF) to do pertinent research.
- Conduct joint biosolids/reuse contract negotiations.
- Perform an analysis to balance Class 'A' cost with market and risk.
- Work to improve public relations and education about biosolids use.
- Continue participation in development of biosolids disposal/reuse regulations.

### Benchmarking Analysis

Table 50 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 50**
**Biosolids Disposal/Reuse Practices**

| Parameter | Possible Explanations of Lower Cost | Possible Explanations of Higher Cost |
|---|---|---|
| Equipment | Most of land application equipment is owned/maintained by contractors. | Very diverse, multi-component biosolids disposal/reuse programs may require more and various types of equipment and significant administrative oversight to administer. |
| Maintenance | Most of land application equipment is owned/maintained by contractors. (So cost is reflected in operations budget as a contract item, rather than maintenance budget) | In-vessel composting, incineration, and in-house land application have higher than average mechanical maintenance costs. |
| Staffing Issues | | Certain processes (incineration, dedicated land disposal) are very labor intensive and require additional staff to operate.<br>Very diverse programs require in-house staff to monitor/administrate/etc. |
| Operational Strategy | | Choosing to maintain very diverse biosolids programs can require more staff involvement and thus have higher costs. |

Although diverse programs may not indicate a high efficiency (if defined as low cost and labor); the efficiency issue must be balanced with the benefits (not necessarily monetary) of having multiple disposal/reuse options available as backup plans.

## ODOR CONTROL

Odor control (liquid stream and residuals stream) occurs throughout the plant, frequently even upstream of the actual plant in the collection system. Although domestic wastewater odors are caused by a variety of organic and inorganic compounds, hydrogen sulfide is typically the predominant odor-causing compound. Odors generated from the wastewater or its treatment are minimized through any number of processes, such as adding chemicals, installing odor-containing covers, and scrubbing the foul off-gas with wet- or dry-type air scrubbers.

This functional area generally consists of influent chlorination system equipment and chemical addition systems and scrubber facilities for both liquid stream odor control and biosolids odor control.

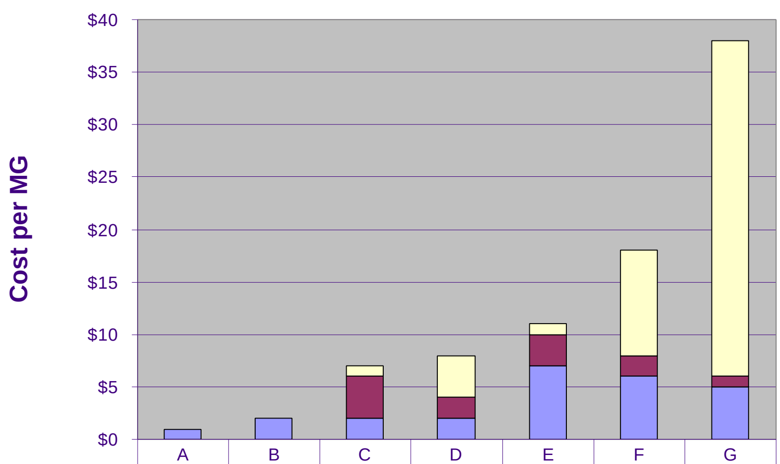
A brief summary of available odor control processes is as follows:

- Covers: This is a physical method in which containment (often using non-metallic, aluminum or concrete covers) prevents the odorous air from escaping the treatment process. Often the foul air is subsequently treated (via a scrubbing method) or routed into another process (such as into the activated sludge process via aeration blowers).

- Masking agents/odor neutralizers: This is a vapor phase treatment method in which a scented solution (chocolate, peppermint, etc) is added to the odorous air to hide its undesirable qualities.
- Chemical addition: This is a liquid-phase treatment method in which various chemicals can be added to the liquid stream. This method is primarily used in collection systems, but can also effectively used at treatment facilities. For example, chemicals can be added to oxidize dissolved sulfides, form metal sulfide precipitates, or adjust the pH of the wastewater to keep sulfides in solution.
- Scrubbing: Gas-phase odor control technologies transfer gaseous contaminants into the liquid phase via absorption or adsorption mechanisms. Gas-phase odor control technologies include scrubbing (packed tower, atomized mist, and multiple stage scrubbers), adsorption (activated carbon, or other media such as impregnated wood used in the Marcab scrubber at SRCSD), and biofilters (compost and mineral).

### *Performance Benchmarking*

The costs for odor control are presented in Figure 40.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Chemicals | | | $1 | $4 | $1 | $10 | $32 |
| Maintenance | | | $4 | $2 | $3 | $2 | $1 |
| Operations | $1 | $2 | $2 | $2 | $7 | $6 | $5 |

**FIGURE 40: ODOR CONTROL COSTS PER MILLION GALLONS OF PLANT FLOW**

### *Process Benchmarking*

Table 51 summarizes odor control methods. Several of the agencies utilize chemical addition at their primaries for both immediate and downstream benefits. They have found that ferric chloride addition at the primaries reduces odors at the primaries, as well as reducing the sulfide concentrations in the digester gas.

**Table 51**
**Odor Control Methods**

| Agency | Collection System/ Upstream of Headworks | Headworks/ Preliminary | Primary | Secondary | Solids Thickening | Solids Handling |
|---|---|---|---|---|---|---|
| A | | | | | | Dual, packed tower wet chemical scrubbers |
| B, Plant 1 | Chemical addition (caustic soda); prechlorination; activated carbon adsorption at septage facility | | | | Activated carbon adsorption | Activated carbon adsorption |
| B, Plant 2 | Chemical addition (caustic soda); prechlorination | Ferric Chloride addition possible | Packed tower scrubbers using NaOH and/or $H_2O_2$ | | | |
| C | Chemical addition (hydrogen peroxide, sodium hydroxide) | Con-current spray scrubbers (mist towers); chemical addition (hydrogen peroxide) | Vapor phase reactants | Vapor phase reactants | Biofiltration | Counter-current packed bed scrubbers; chemical addition (hydrogen peroxide) |
| D, Plant 1 | | Ferric Chloride addition | Packed tower wet chemical scrubbers and/or carbon adsorption towers. Ferrous chloride addition to digester feed sludge. | | | |
| D, Plant 2 | | Foul air routed to process air compressors; Odor neutralizer | Foul air routed to process air compressors | | | |
| D, Plant 3 | | Foul air routed to aeration blowers | Foul air routed to aeration blowers | | Activated carbon adsorption system | Foul air routed to aeration blowers |
| E | Chemical addition (sodium hypochlorite, chlorine gas) | Mist towers; fixed carbon units for backup | Mist towers; fixed carbon units for backup | | | Marcab scrubber |
| F | Chemical addition (hydrogen peroxide) | Packed tower chemical scrubber systems (caustic soda) | Packed tower chemical scrubber systems (caustic soda) | | | |
| G | Chemical addition (sodium hypochlorite upstream of influent pumping) | Chemical addition (sodium hypochlorite); dual, packed tower wet chemical scrubbers | | | | Dual, packed tower wet chemical scrubbers |

### *Distinguishing Features*

The agencies utilizes many different odor control methods, including covering and containing processes and treating or recycling the off-gases. Table 52 presents some unique odor control features among the Agencies.

**Table 52**
**Odor Control Distinguishing Features**

| Agency | Unique Features |
|---|---|
| C | Biofilter on DAF. |
| D | Foul air recirculated to process blowers/aeration processes. |
| E | Marcab scrubber (iron impregnated wood media) for digester gas. |

### *Impact of Regulations*

Air emissions from wastewater treatment facilities are increasingly being regulated by Federal, state, and local air quality agencies. Regulatory control generally takes two forms:

- 1. Permitting requirements and limitations for new facilities (or additions and modifications to existing facilities); and
- 2. Prohibitory regulations (primarily targeting off-site nuisance odors).

Many of the agencies are regulated by a local air quality management district (AQMD) or air pollution control district (APCD). These AQMDs have been given regulatory enforcement authority by federal and state agencies to implement and enforce air quality regulations. The permitting process implemented by these AQMDs is designed to minimize negative impacts on local air quality and health. Generally, any process modifications or additions to the wastewater treatment plant must be approved by the local AQMD.

The agencies have developed in-house odor policies to take a proactive approach to odor complaints coming from surrounding neighbors. Generally, this involves maintaining odor complaint records and working with plant staff and neighbors to identify and address sources of odor complaints at the plant. Note that odor complaints directed at wastewater treatment plants do not always originate there. Sometimes, due to wind direction or physical location of many wastewater treatment facilities, odors that are blamed on the wastewater treatment plant may come from another facility or natural phenomenon.

### *Areas of Future Investigation*

Discussions on odor control led to a commitment to spend time on this subject in future phases of the project.

## DISINFECTION AND DECHLORINATION

Disinfection is the selective destruction of pathogenic (disease causing) organisms in the treated effluent prior to discharge or reuse. Typical pathogen indicator organisms are coliform (fecal and total) and *E. coli*. Disinfection is most commonly accomplished by the use of chemical agents or physical agency. The agencies use chemical agents (chlorine or sodium hypochlorite) and physical agents (ultraviolet light).

A brief summary of available disinfection chemicals and processes is as follows:

- Chlorine. Chlorine is a powerful chemical oxidant and is one of the most common disinfectants used at wastewater treatment plants. Chlorine is normally fed from on-site storage cylinders and/or bulk storage containers in gaseous or liquid form. Liquid feeding of chlorine is more rapid than gaseous feeding, but requires a chlorine evaporator to vaporize the liquid into a gas before sending it to the chlorination control system. While effective and economical, chlorine has significant safety and regulatory issues associated with its transportation, storage, and handling.
- Sodium Hypochlorite. Sodium hypochlorite is an aqueous solution, generally available from 1.5 to 15 percent. The solution decomposes more readily and is further degraded by light and heat. These issues can result in higher operation costs for this disinfection method. However, sodium hypochlorite has fewer handling safety concerns than chlorine.
- Ultraviolet (UV) Light. Ultraviolet disinfection is a physical process in which ultraviolet energy is absorbed in the deoxyribonucleic acid (DNA) of microorganisms, causing structural changes in the DNA that prevent microorganisms from propagating. One of its principal advantages is that it leaves no adverse chlorine residual in the treated wastewater to affect aquatic life in the receiving waters. UV disinfection also avoids the safety concerns associated with chlorine.

Effluent dechlorination often is required to mitigate the adverse effects of chlorinated effluent on aquatic life in the water body to which the treated effluent is discharged. Where chlorination residual limitations are severe, effluent dechlorination must be practiced. Dechlorination typically is achieved by adding a chemical such as sulfur dioxide or sodium bisulfite to the chlorinated effluent stream. Because the reactions of sulfur dioxide and sodium bisulfite with residual chlorine and chloramines are nearly instantaneous, contact time is not usually a factor and contact chambers are not used. However, rapid and positive mixing at the point of application is required.

A brief summary of available dechlorination chemicals is as follows:

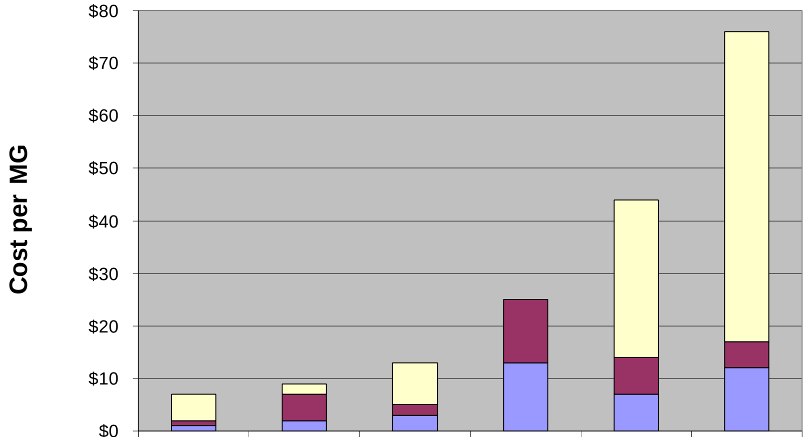
- Sodium Bisulfite. Sodium bisulfite is provided in an aqueous form, which results in easier handling and increased safety. Facilities for feeding, storing, and handling sodium bisulfite are very similar to those used for sodium hypochlorite. There are no major safety concerns.
- Sulfur Dioxide. The facilities for sulfur dioxide are very similar to the equipment used in the storage, feeding, and handling of chlorine. Sulfur dioxide gas is chemically combined with water, and the aqueous solution is fed to processes using a sulfonator control system. Sulfur dioxide has many of the same safety issues as chlorine.

Disinfection costs include operation and maintenance costs associated with disinfection and dechlorination systems. This includes chemical addition systems, tanks, contact basins/channels, process devices, or other related facilities. The costs for safety and regulatory development programs are not included in this O&M section.

The agencies utilize a variety of methods for disinfection at their facilities. Some facilities are required to chlorinate, but not to dechlorinate. Some of the facilities have very strict residual chlorine discharge limits. Table 53 summarizes the disinfection/dechlorination practices utilized by the agencies.

### *Performance Benchmarking*

The costs for disinfection are presented in Figure 41.




| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| Chemicals | $5 | $2 | $8 | | $30 | $59 |
| Maintenance | $1 | $5 | $2 | $12 | $7 | $5 |
| Operations | $1 | $2 | $3 | $13 | $7 | $12 |

**FIGURE 41: DISINFECTION COSTS PER MILLION GALLONS**

## Table 53
## Disinfection/Dechlorination Practices Summary

| | Disinfection | | | | | | | Dechlorination | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Agency** | **Type of Disinfection** | **Ave. Avail. Chlor. Dosage (mg/l)** | **Ave. UV Dosage (μW – s/cm2)** | **UV System** | **Effluent Limitations (MPN/100 ml) (1)** | **Disinfect Cost ($/MG) 14** | **Type of Control System** | **Type of Chemical** | **Ave. Chemical Dose (mg/l)** | **Effluent Limitations Chlorine residual (mg/l)** | **Dechlor Cost ($/MG)** | **Type of Control System** |
| A, Plant 1 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 0.84 (2) | N/A | N/A |
| A, Plant 2 | Chlorine | | N/A | N/A | 2.2 (3) | | | Sulfur dioxide | | 0.1 (4) | | |
| A, Plant 3 | N/A | | N/A | N/A | N/A | | | | | 0.1 (4) | | |
| A, Plant 4 | Chlorine/ bleach[15] | | N/A | N/A | 2.2 (3,5) | | | | | 0.1 (4) | | |
| B | Chlorine | | N/A | N/A | 200 (6) | | | N/A | N/A | 1.0 (2) | N/A | N/A |
| C, Plant 1 | Chlorine | 3.5 | N/A | N/A | 200 (6) | | Feedback | Sulfur dioxide | Zero | 0.66 (7) | Zero | "Renton" system (8) |
| C, Plant 2 | Chlorine | 3.26 | N/A | N/A | 200 (6) | 6.19 | Feedback | Sodium Bisulfite | 2.44 | 0.216 (7) | 5.16 | "Renton" system (8) |
| D | UV | N/A | 71.85 | Low press ure | 200 (1) | 8.43 (14) | Manual/ operator | N/A | N/A | 0.0 (2) | N/A | N/A |
| E | Chlorine | 13.3 | N/A | N/A | 23 (9) | 13.87 | Compound Loop | Sulfur Dioxide (11) | 12.96 (12) | 0.018 (12) | 13.81 (11) | "Renton" system (8) |
| F | Sodium Hypochlorite | | N/A | N/A | 240 (3) | | | Sodium Bisulfite | | 0.0 (2) | | |
| G, Plant 1 | N/A | N/A | N/A | N/A | N/A | | | N/A | N/A | 0.001 | N/A | N/A |
| G, Plant 2 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 0.001 | | |

N/A = not applicable
1. Most probable number (MPN) per 100 milliliters
2. Thirty-day log mean for fecal coliform.
3. Instantaneous maximum.
4. Total coliform.
5. Daily maximum.
6. Seven-day moving median.
7. Fecal coliform.
8. Monthly average.
9. "Renton" system - Compound loop, with feed forward based on dechlorinated final effluent (DFE) residual setpoint, and feedback based on DFE measured negative chlorine residual.
10. Monthly median.
11. Sodium bisulfite for trimming or emergency backup.
12. Sulfur dioxide only.
13. Daily average.
14. Average disinfection cost – components included: Chemical and energy applied.
15. Energy only
16. Glendale converted to bleach in mid-year.

## Process Benchmarking

### *Distinguishing Features*

Table 54 presents the distinguishing features for each agency.

**Table 54**
**Disinfection/Dechlorination Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | No disinfection performed in outfall at Plant 1. Gravity feed system for hypochlorite used for disinfection at Plant 1. |
| B | No dechlorination currently required. |
| C | Hach colorimetric chlorine analyzers used for chlorination process control. "Renton" system used for control of dechlorination process. |
| D | Ultraviolet (UV) disinfection with sodium hypochlorite/sodium bisulfite backup. |
| E | Joint contract with other POTW for purchase of liquid chlorine. Sulfur dioxide used for dechlorination. "Renton" system used for control of dechlorination process. Sodium bisulfite as backup system. |
| F | Zero effluent chlorine residual allowed (0.0 mg/l). Has switched to hypochlorite and sodium bisulfite. |
| G | No effluent disinfection allowed. |

### *Impact of Regulations*

Table 55 presents the limits regulating the disinfection and dechlorination of effluents.

**Table 55**
**Effluent Permit Limits Relating to Disinfection**

| Agency | Plant | Cl2 Residual (mg/l) | Coliform (MPN/100 ml)[1] | |
|---|---|---|---|---|
| | | | Total | Fecal |
| D | | 0.0[2] | N/A[3] | 200 |
| A | 1 | 0.84[2] | 1,000 | 200 |
| | 2 | 0.1[4] | 2.2[5] | N/A |
| | 3 | 0.1[4] | 1,000 | 200 |
| | 4 | 0.1[4] | 2.2[5] | N/A |
| B | | 1.0[2] | N/A | 200 |
| F | | 0.0[2] | 240[6] | N/A |
| C | 1 | 0.66[7] | N/A | 200 |
| | 2 | 0.216[7] | N/A | 200 |
| G | 1 | 0.001 | N/A | N/A |
| | 2 | 0.001 | N/A | N/A |
| E | | 0.018[8] | 23[9] | N/A |

1. Coliform count, most probable number (MPN) per 100 milliliters – monthly average
2. Instantaneous maximum
3. Not applicable
4. Daily maximum
5. 7-day moving median
6. Most recent permit limitation is 500 fecal coliform
7. Monthly average
8. Daily average (monthly average is 0.011 mg/l)
9. Monthly median

Table 56 presents critical information on the limits regulating the disinfection and dechlorination of effluents. Regulations drive disinfection and dechlorination, and therefore have a major influence on the processes.

**Table 56**
**Key Regulatory Limitations**

| Agency | Key Regulatory Limitations |
|---|---|
| A | California Title 22 regulations require effluent total coliform limitations of 2.2 MPN per 100 ml be applied to the two plants since a small downstream portion of the discharge river is unlined. Stringent residual chlorine limitations of 0.1 mg/l have also been imposed for these plants. |
| B | No total coliform limit. |
| C | No total coliform limit. |
| D | Stringent chlorine residual limitations (none allowed). |
| E | Stringent chlorine residual requirements (0.018 mg/l). |
| F | Stringent chlorine residual requirements (none allowed). |
| G | Stringent chlorine residual limitations (0.001 mg/l). |

### *Public Perception*

Public perception has impacted the agencies. Agency A discontinued the use of chlorine because of fire department restrictions and public safety concerns. The City has substituted chlorine with sodium hypochlorite instead. Other agencies, such as Agency F, switched to hypochlorite for public safety reasons. Other agencies may be similarly impacted in the future for these reasons and also for the risk management issues associated with handling and storing chlorine. These decisions have led to higher chemical costs for the agencies.

### *Areas of Challenge*

Several of the agencies reported maintenance or operational related mechanical difficulties with equipment (Table 57).

**Table 57**
**Areas of Disinfection/Dechlorination Challenge**

| Agency | Areas of Challenge |
|---|---|
| B | Sporadic maintenance problems if chlorine is dirty. Overhaul chlorine evaporators every five years. |
| C | Must overhaul chlorine evaporators every year. |
| E | Difficulties with sulfur dioxide purity resulting in clogged lines and corrosive precipitate in evaporators. |

These areas of challenge were not universally experienced. For example, Agency B overhauls its Wallace Tiernan chlorine evaporators only once every five years, as compared to Agency C, which must overhaul their Fischer Porter and Wallace Tiernan evaporators each year.

The agencies that use chlorine pay widely variable costs for their chlorine. Agency E bid a joint contract with another agency (not participating in this study), and paid approximately $177 per ton for chlorine delivered in 90-ton rail cars. Agency B, on the other hand, paid $300 per ton for chlorine also delivered in 90-ton rail cars.

### *Impact of Capital Facilities*

Several of the agencies have capital facilities that impacted their costs as summarized in Table 58.

**Table 58**
**Impact of Capital Facilities**

| Agency | Impact of Capital Facilities |
|---|---|
| B | Very large diffuser |
| C | 12-mile outfall at Plant 1; overhaul chlorine evaporators every year. |

### *Areas of Efficiency*

Agency E has extraordinarily stringent discharge requirements for coliform bacteria.

Some of the agencies have found that better instrumentation can be used to improve chemical dosing and reduce chemical expenditures. The subject of alternate control technologies was discussed at the O&M group meetings, specifically utilizing oxidation-reduction potential (ORP) probes. Agency C has tried ORP probes, but found they did not respond well to on combined chlorine residuals. Agency C has also tried many different chlorine residual analyzers and has concluded that Hach colorimetric works the best for them.

Agency F, which used sodium hypochlorite during the study period, had recently switched because it is much less labor intensive, has fewer safety issues, and avoids the risk management issues associated with chlorine, and has greatly impacted Agency F’s chemical costs.

## EFFLUENT PUMPING/OUTFALL

Effluent pumping is required when treated effluent cannot leave the plant by gravity. Large centrifugal, mixed flow, screw, or vertical turbine pumps are often used for this purpose. A conveyance structure or pipeline called an outfall carries the treated effluent to the receiving waters.

Effluent pumping costs only include those costs associated with pumping equipment including the auxiliary devices, equipment, control systems, or other support. This functional area also includes effluent metering, outfall, and associated systems.

Table 59 summarizes the systems used by the agencies

**Table 59**
**Effluent Pumping/Outfall Design Criteria**

| Agency | Plant | Effluent Pumps | Length of Outfall | Outfall Diameter (inches) | Number of Diffusers | Depth of Outfall (feet) |
|---|---|---|---|---|---|---|
| Central Contra Costa Sanitary District | | 2 @ 75 mgd each[10] | 18,600 ft (land) + 1,900 ft (submarine) | 72 | 11 @ 24 inch diameter | 26[1] |
| City of Los Angeles Bureau of Sanitation | Hyperion | 5 @ 200 mgd[2] | 5 miles | 144 | 2 – 4000' (Y-type) | 190 |
| | Tillman | Effluent not pumped to outfall. Water reclamation facility. | | | | |
| | Terminal Island | 3 @ 75 mgd[3] | 6,000 ft | 48 to 60 to 72[4] | | |
| | LA-Glendale | Effluent not pumped to outfall. Water reclamation facility. | | | | |
| City of Portland Bureau of Environmental Services | | 3 @ 78 mgd[5]<br>2 @ 72 mgd[6,10] | 2 miles | 102 | 350 ft long flow diffuser structure | |
| East Bay Municipal Utility District | | 2 @107 mgd each[7] | | | | |
| King County Department of Natural Resources | East Plant | 4 duty, 4 peaking, 280 MGD capacity | 12 miles of force main + 10,000 ft (submarine) | 96" force main; 2-64" outfall pipes | 48" diameter, 500 ft long diffuser | 580[1] |
| | West Plant | 4 pumps, 150 MGD each | | | | |
| Orange County Sanitation District[8] | | 5 @ 120 mgd each[11] | 5 miles | 120 | 1 mile long | 200 |
| Sacramento Regional County Sanitation District | | 4 @ 125 mgd each[9,10] | 1.5 miles | 120 | 49 open<br>50 future | 20-40, depending on river elevation[12] |

1. At mean sea level
2. Pumps used during daily diurnal peaks above 325 mgd; gravity flow the rest of the day
3. At 29 ft of head
4. Outfall changes size
5. Low head pumps with rated head of 17 ft
6. High head pumps with rated head of 32 feet
7. At 44 feet total design head
8. Primary outfall described; emergency outfall available; third extreme emergency outfall available
9. At a maximum head of 41 feet
10. Gravity flow when river or tide elevation and plant flow allow it
11. One unit designated as standby.
12. Elevations: Top of Diffuser = -16 ft., Low River Elevation = +3 ft., High River Elevation = +25 ft.

## Process Benchmarking

### *Distinguishing Features*

The primary difference between effluent pumping/outfall systems at the agencies is whether facilities pump exclusively or use gravity discharge under most conditions. Table 60 summarizes distinguishing features at some of the plants in the study.

**Table 60**
**Effluent Pumping/Outfall Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| CLABS | Pumps used for daily diurnal peaks, gravity flow the remainder of the time (Hyperion). |
| CPBES | Pumps used under high river levels or increased plant flow, gravity discharge is used under most operating conditions. |
| KCDNR | Force main from East Plant to Puget Sound. |
| OCSD | 3 outfalls available: one primary, one emergency, one extreme emergency; Plant 1 and Plant 2 flows combined. |

# COMPUTER SYSTEMS AND AUTOMATION

Automated control systems refer to the various computer and automation systems used for monitoring and control at the plant.

## Process Benchmarking

### *Distinguishing Features*

Table 61 summarizes some of the distinguishing features of the agencies’ computer and automation systems.

## Table 61
## Computer System and Automation Distinguishing Features

| Agency | Plant | Control System | Number of I/O Points (digital, analog) | | Number of Control Loops | Use of home PCs tied to operating system? | Future Plans |
|---|---|---|---|---|---|---|---|
| | | | Input | Output | | | |
| Central Contra Costa Sanitary District | | Dual, redundant, central computer and PLC network | 3640, 1408 (1) | 1280, 560 (1) | 175 (1) | Yes | Move to an open architecture (in place of mainframes) |
| City of Los Angeles Bureau of Sanitation | Hyperion | DCS, PLCs, SCADA, RTU, Loop controller (2) | 10300, 6500 | 6500, 6300 | 11100 | Not answered in survey | Increase levels of standardization |
| | Tillman | Distributed Control System (DCS) | Information not available in either plant description or survey | | | | |
| | Terminal Island | Information not available in either plant description or survey | | | | | |
| | LA-Glendale | Information not available in either plant description or survey | | | | Yes | Information not available in either plant description or survey (unless Hyperion answer is CLABS- wide) |
| City of Portland Bureau of Environmental Services | | Three-layer system: local control, backup panel control, and computerized control. PC-based system with Intellution/ DMACS software. | 4000, 600 | 2000, 200 | No answer in survey | No (planning to test soon) | Procure system components which employ open architecture whenever available and compatible with standard PLCs; anticipate changing existing system architecture to make it more redundant and reliable; integrating PLCs and their data more in future |
| East Bay Municipal Utility District | | Distributed Control System (DCS) | 4000, 1100 | 2000, 500 | 600 | Yes | Identify opportunities to utilize automation to improve reliability and provide opportunities for greater efficiency |
| King County Department of Natural Resources | East plant | Three-layer system: local control, backup panel control, and computerized control | 4480, 1392 | 1870, 496 | 480 | No | Procure system components which employ open architecture |
| | West plant | | 4650, 3103 | 2340, 1585 | 1665 | | |
| Orange County Sanitation District | Plant 1 | Two layer system: local control, SCADA control | 2356, 489 | 2915, 834 | 37 | Yes (testing only) | Replace existing SCADA system within the next 5-8 years |
| | Plant 2 | | 2915, 834 | 1120, 91 | 52 | | |
| Sacramento Regional County Sanitation District | | Three layer system: local control, discrete/analog panel control with alarm panels, and computerized control | 5271, 1586 | 2455, 279 | 2361 | No | Installation of DSC is underway to replace backup analog area control systems and provide for remote computerized control from designated stations |

1 Notes: Main I/O system. Plant-wide number another order of magnitude (approximately).

2 DCS = Distributed Control System PLC = Programmable Logic Controller SCADA = Supervisory Control and Data Acquisition RTU = Remote Terminal Unit

### *Areas of Challenge*

The following areas of challenge were identified through discussions at the O&M group meetings.

- Y2K compliance is an issue for the agencies. Some systems (such as Modicon) are already Y2K compliant. Other systems require additional work or replacement to become compliant.
- Standardization is an issue at some facilities. Depending on the age of different parts of the plant there may be different manufacturers or control systems, which complicates operations and maintenance.
- Public purchasing laws/policies restrict ability to standardize on a manufacturer.
- Obsolescence of the control system or portion of the control system (for non-standardized systems) makes obtaining parts and technical support and interfacing between other control systems difficult.
- Staff perception of the reliability and complexity of automated systems.

The agencies recognize a tradeoff between increased plant reliability from reduction of operator error and reduction in reliability from the shear number of failure points in a complicated automated system. The optimal level of automation may be seen on a graph of simplicity to operate, simplicity of design (ease of troubleshooting), and flexibility of the system through increased automation, OCSD has observed increased reliability and recognized quantifiable savings.

### *Areas of Efficiency*

The following areas were identified as efficient practices.

- Standardization on one type and manufacturer of control system in order to simplify operations, maintenance of the control systems, as well as warehousing of spare parts, and training of personnel.
- Critical systems should have hot back-up.

### *Areas of Future Investigation*

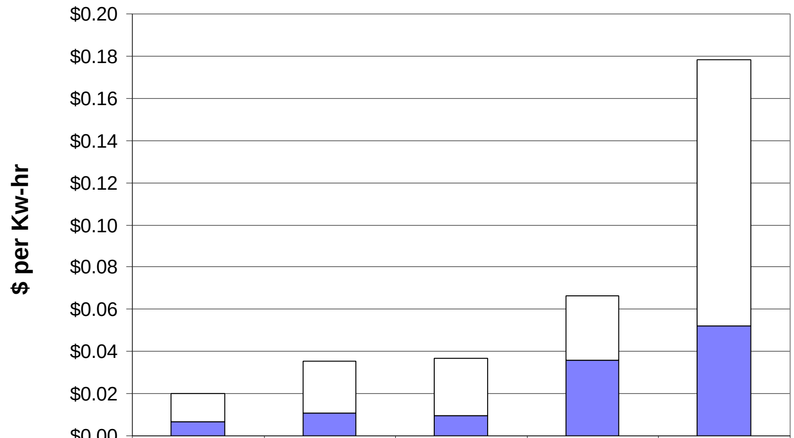
The O&M Group identified standardization and increased automation as areas of future investigation.

# POWER GENERATION/ENERGY SYSTEMS

Power (electrical energy) generation uses digester gas, a byproduct of the anaerobic digestion process, as a source of energy. Inherently high in methane content, digester gas lends itself well to energy/resource recovery efforts because it has a typical energy value of approximately 600 British thermal units (Btu) per standard cubic foot of gas. Power generation data were considered separately from the other O&M data, thus power generation costs and revenues are not included in the overall average cost for treatment calculations.

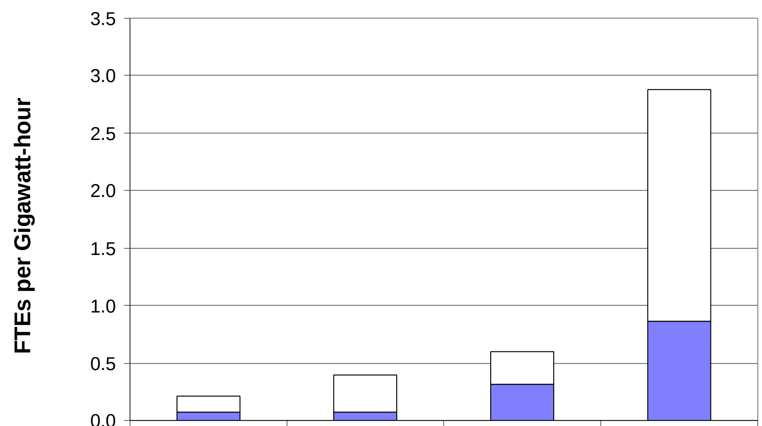
## Performance Benchmarking

The costs and labor required to produce each kilowatt-hour using cogeneration are presented in Figures 42 and 43. The cogeneration data were normalized by kWh generated by the cogeneration plant. Analysis of these graphs takes place in Benchmarking Analysis.




| | A | B | C | D | E |
|---|---|---|---|---|---|
| Operations | $0.013 | $0.024 | $0.027 | $0.031 | $0.126 |
| Maintenance | $0.006 | $0.011 | $0.009 | $0.036 | $0.052 |

**FIGURE 42: COGENERATION COSTS PER KILOWATT-HOUR PRODUCED**




| | A | B | D | E |
|---|---|---|---|---|
| Operations | 0.140 | 0.324 | 0.286 | 2.016 |
| Maintenance | 0.070 | 0.074 | 0.314 | 0.864 |

**FIGURE 43: COGENERATION LABOR PER GIGAWATT HOUR PRODUCED**

Table 62 presents the cost per kilowatt hour and FTEs per gigawatt hour produced through cogeneration.

**Table 62**
**Cogeneration Costs and Labor**

| | Dollars per Kilowatt Hour Produced through Cogeneration | | | FTEs per Gigawatt Hour Produced through Cogeneration | | |
|---|---|---|---|---|---|---|
| | Low | Average | High | Low | Average | High |
| Operations | 0.013 | 0.023 | 0.126 | 0.14 | 0.691 | 2.016 |
| Maintenance | 0.006 | 0.044 | 0.052 | 0.07 | 0.331 | 0.864 |
| Combined | 0.020 | 0.067 | 0.178 | 0.21 | 1.020 | 2.880 |

Note: The high agency was fully staffed on a standby mode for much of the year though they only operated part of the time. During FY97, this agency negotiated an agreement with an energy provider to swapped gas for electricity at 1.3 cents/Kwh. Incremental at 5.6 cents Kwh.

## Process Benchmarking

### *Distinguishing Features*

As shown in Table 63, the agencies utilize a variety of techniques to cogenerate power at their facilities.

**Table 63**
**Cogeneration Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| A | Three 2.5 MW engine gen sets and 5 3.2 MW engine gen sets. All process power requirements met through cogeneration. |
| B | Dual gas fired engines. |
| C | Turbine system utilizing purchased natural gas. |
| D | Permit requires “full back-up.” |
| E | Stationary gas turbine. |
| F | Sell digester gas to utility and buy back power. |

### *Impact of Regulations*

Several of the participating agencies have power generation capabilities due to regulatory requirements. For example, Agency A's NPDES permit requires fail-safe power generating capability. In fact, the two cogeneration plants are not permitted to operate at full capacity (by the South Coast AQMD) unless an emergency has been declared. Other agencies, which may not have "full back-up" or power generating capability, are required by permit to have redundant power feeds or alternate power sources.

### *Areas of Efficiency*

Discussion on power and energy indicate that there is a cost benefit to having the ability to generate power onsite. Turbine engine plants are more efficient, and are less expensive to maintain than combustion engine plants.

### *Areas of Future Investigation*

Agency G is experimenting with a pilot scale fuel cell system to generate power from digester gas.

## Benchmarking Analysis

The following are observations from the performance benchmarking graphs and the O&M group meetings.

Agency D has high cogeneration costs, as shown in Figure 42, primarily due to the combination of old equipment (which results in high maintenance costs), and the placement of that equipment in space not originally designed for it.

Table 64 summarizes observations from the performance benchmarking graphs and the O&M group meetings.

**Table 64**
**Power Generation and Energy Systems Best Practices**

| Parameter | Possible Explanations of Lower Cost | Possible Explanations of Higher Cost |
|---|---|---|
| Equipment | | Old equipment resulting in higher maintenance costs |
| Maintenance | Operators perform "light maintenance"; engine maintenance handled by mechanical technicians. | Cogeneration equipment located in space not designed for it resulting in higher maintenance costs. |
| Staffing Issues | Some process areas periodically unattended and/or coverage during rounds only. | |
| Operational Strategy | | Continued operation of facilities with unfavorable life cycle costs. |

# OTHER MAINTENANCE

## Fleet Services

Table 65 presents other maintenance distinguishing features for four of the agencies.

| **Table 65<br>Other Maintenance Distinguishing Features** | |
|---|---|
| **Agency** | **Distinguishing Features** |
| CPBES | Inter-agency agreements with other bureaus handle fleet, grounds, and HVAC. |
| OCSD | Most plant facilities services contracted; most minor fleet maintenance and services (LOF & Smog check) conducted in-house. |
| EBMUD | District handles fleet. |
| SRCSD | County handles fleet maintenance. Staff of 12 maintain wetlands habitat in the buffer lands. |

### *Process Benchmarking—Fleet Services Survey Summary*

Central Contra Costa Sanitary District has a replacement fund for vehicles; the agency services vehicles in-house with a staff of three.

The City of Los Angeles Bureau of Sanitation has a replacement fund for vehicles. A screening list of probable replacement vehicles is developed based on criteria such as age, mileage, etc., and sent to each department. Department managers review and recommend the actual replacement/changes needed. Purchases are then made depending on fund limitations. The vehicles are mostly serviced in-house and through the city Fleet Services Division. Only 3% of the work is outsourced.

The City of Portland has conducted fleet efficiency studies over the last three years. The vehicles are currently serviced through an interagency agreement (IAA) and Bureau of General Services (BGS)/Fleet. Annual costs are based upon vehicle class, three year maintenance history, and overhead costs. The rates are: sedan - $870; minivan - $670; 1 ton utility pick-up - $1,870; class 8 truck/tractor - $9,750; and dump truck (5-6 yards) - $5,000. The treatment plant portion of O&M costs is $60,000 through IAA.

East Bay Municipal Utility District leases vehicles on an hourly basis from the Water System car pool. No plant staff supports the fleet since this division performs all work.

King County has a replacement policy under the capital budget. In 1996, the fleet was reduced by 30% and the vehicles were replaced by electric carts with no adverse effects. All work on the fleet is contracted out.

The Orange County Sanitation District (OCSD) does not have a replacement fund. Four certified mechanics and four equipment operators maintain all equipment and vehicles at the district. Staff does all general repairs and maintenance: lube, oil, and filter; smog check; and safety inspections and reports on large vehicles (>26,000 pounds, three or more axles weighing over 10,000 pounds, buses, etc) according to the California Highway Patrol Biennial Terminal Inspection

Program. Forty vehicles were identified for disposal in an attempt to reduce fleet size; however, many have been replaced with new vehicles. OCSD has initiated a policy concerning alternative fuel vehicles. If a vehicle is used for local driving, its replacement will be the lease of an electric vehicle. (Electric vehicles cannot be purchased, only leased) or the purchase of a $CH_6$ vehicle.

The Sacramento Regional Water Treatment Plant leases all vehicles from the County General Services or Transportation Divisions. These divisions perform all maintenance on the leased vehicles. Each month the plant pays a minimum fee plus mileage fee per vehicle; these fees go into a replacement fund.

Table 66 presents vehicles, carts, and bicycles serviced by agency staff.

**Table 66**
**Vehicles, Carts, and Bicycles Serviced by Agency Staff**

| | CCCSD | CLABS* | CPBES | EBMUD** | KCDNR | OCSD | SRWTP |
|---|---|---|---|---|---|---|---|
| Sedans | 17 | 7 | 5 | 0 | 9 | 34 | 24 |
| Pick-up Trucks | 34 | 82 | 4 | 0 | 20 | 69 | 43 |
| Commuter Vans | 0 | 4 | 0 | 0 | 0 | 6 | 0 |
| General Use Vans | 3 | 8 | 4 | 0 | 39 | 8 | 15 |
| Solids Hauling Trucks | 0 | 0 | 1 | 0 | 4 | 1 | 0 |
| Maintenance Vehicles | 10 | 128 | 5 | 0 | 23 | 41 | 0 |
| Other | 40 | 140 | 9 | 0 | 12 | 0 | 15 |
| Electric Carts | 0 | 0 | 17 | 10 | 44 | 186 | 70 |
| Bicycles | 0 | 0 | 59 | 6 | 20 | 101 | 35 |
| Total | 104 | 369 | 104 | 16 | 171 | 446 | 202 |

* CLABS information is covered in attachments.
** EBMUD leases all vehicles from the Water System.

Table 67 presents replacement policy information for each of the agencies.

**Table 67**
**Replacement Policies**

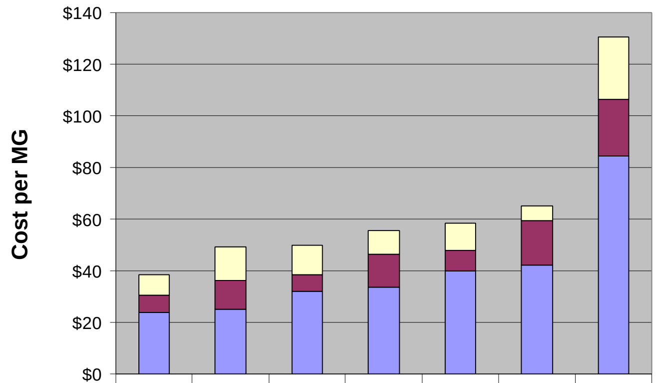
| | CCCSD | CLABS | CPBES | EBMUD* | KCDNR | OCSD | SRWTP**** |
|---|---|---|---|---|---|---|---|
| Sedans | | | | | | | |
| Age | 10 | 7 | 7 | | 8 | 6 | |
| Mileage | | 80,000 | | | 80,000 | 100,000 | |
| Other | | | | | | | |
| | | | | | | | |
| Pick-ups | | | | | | | |
| Age | 12 | 8 | 7 | | | 6 | |
| Mileage | | 95,000 | | | | 100,000 | |
| Other | | | | | | | |
| | | | | | | | |
| Other | | | | | | | |
| Age | | 11** | 10** | | 9** | | |
| Mileage | | 100,000 | | | 90,000 | | |
| Other | | | | | | | |
| | | | | | | | |
| Other | | | | | | | |
| Age | Varies | 11** | 15*** | | 10*** | Varies | |
| Mileage | | 100,000 | | | 100,000 | | |
| Other | | | | | | | |

* Leases all vehicles.
** Medium duty.
*** Heavy duty.
**** 85,000 - 115,000 depending on type and usage.

## Maintenance Planning

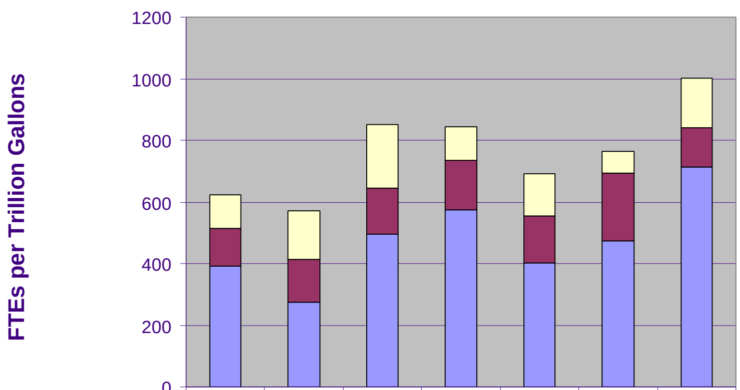
### *Performance Benchmarking*

Figure 44 shows the maintenance costs per million gallons divided into instrumentation, electrical and mechanical costs. Figure 45 shows maintenance labor divided the same way.




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Instrumentation | $7.68 | $13.13 | $11.51 | $9.33 | $10.55 | $5.72 | $24.04 |
| Electrical | $6.97 | $11.12 | $6.29 | $12.63 | $7.93 | $16.87 | $21.98 |
| Mechanical | $23.66 | $25.09 | $31.99 | $33.66 | $40.08 | $42.38 | $84.38 |

**FIGURE 44: TOTAL ELECTRICAL, MECHANICAL, AND INSTRUMENTATION MAINTENANCE COSTS PER MILLION GALLONS TREATED.**




| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| Instrumentation | 109 | 160 | 208 | 109 | 137 | 70 | 161 |
| Electrical | 123 | 137 | 148 | 160 | 152 | 220 | 129 |
| Mechanical | 391 | 276 | 497 | 574 | 404 | 474 | 712 |

**FIGURE 45: TOTAL ELECTRICAL, MECHANICAL, AND INSTRUMENTATION LABOR PER TRILLION GALLONS TREATED**

### *Process Benchmarking*

Lower cost agencies make use of a dedicated maintenance planning staff to provide job planning. Maintenance planning staff are also involved with preventative maintenance scheduling; seasonal or exceptional work coordination with all maintenance disciplines, as well as operations, to provide the maximum effective use of equipment down time and process system outages.

A dedicated maintenance planning effort is an essential function to reduce reactive and emergency maintenance work and increase the amount of planned maintenance that is performed.

Planned maintenance is more cost effective than reactive maintenance given the fact that reactive maintenance often includes additional costs for over time and priority shipping of parts, materials, and services; and may increase the risk of discharge permit violations.

Most agencies use a dedicated maintenance planning staff to schedule upcoming repair or equipment outages with both maintenance and operations staff. In most cases, a craft level lead person is responsible for day-to-day activities of individual maintenance personnel and managing the work order backlog.

Effective maintenance planners must have a high degree of technical knowledge or trade experience to adequately serve the needs of the maintenance disciplines.

## Predictive Maintenance

Predictive maintenance is used to identify equipment deficiencies, which if detected in a timely manner, can be corrected with a minimum level of effort, avoid major repairs and extended downtime, and increase the efficiency of equipment.

Most agencies are currently involved in the periodic measurement of certain machinery condition elements. Vibration analysis, Oil Analysis, and Infrared (thermal imaging) are the most popular disciplines. In many cases these technologies are taken advantage of through the use of outside contracts, although many agencies have found it to be beneficial to dedicate regular maintenance personnel to these tasks.

Other observations include:

- Predictive Maintenance technologies are typically costly to set up initially due to the high cost of hardware, software and training of personnel. Utilization of these assets is often an issue as well.
- The true benefit of a comprehensive predictive maintenance program that takes advantage of vibration analysis, oil analysis, and infrared technologies is difficult to measure. The optimum cost/benefit of such technologies may make it very difficult to determine what is the right level of effort to invest in terms of labor, training and equipment and software purchases.
- The use of predictive maintenance technologies can increase the amount of "planned maintenance" that is performed and decrease the amount of "reactive maintenance".
- Planned maintenance is more cost effective than reactive maintenance in that reactive maintenance often includes additional costs for overtime and priority shipping of parts, materials, and services. Reactive maintenance may increase the risk of discharge permit violations.
- A predictive maintenance program may increase the level of effort that is required by maintenance personnel initially rather than decreasing it. (Predictive maintenance technologies help maintenance personnel discover inefficiencies and problems that may have been undetectable with conventional trouble shooting means.) This trend is believed to be temporary as the corrective work that is generated by a predictive

maintenance program will eventually decrease as problems are detected and corrected plant wide.

- Equipment with a high replacement cost or high process criticality is the best place to implement a periodic predictive maintenance condition-monitoring program.
- Predictive maintenance programs can substantially reduce the unexpected failure of equipment, increase system reliability and increase the efficiency of rotating machinery. (e.g. It has demonstrated that any given piece of rotating machinery will require less power when running under low levels of vibration than if it were operation under a high vibration condition.)
- Most agencies do not perform routine predictive maintenance on rotating machinery under five horsepower, or machinery that has redundant back up systems. However, the ability to determine equipment deterioration that will lead to more serious, and perhaps more difficult to correct problems, as well as any efficiency gains that are realized, may suggest that there is value in assessing these types of machinery on a less periodic basis. Given the large number of machinery that falls into either the non critical, or under five horsepower grouping, the efficiency gain alone may support value in "spot checks" or annual assessment.
- Predictive maintenance technologies help maintenance personnel determine the true root cause of equipment failure and/or degeneration in equipment and machinery. Rather than spending time, energy and resources to correct the symptom of a problem, maintenance crews can make use of predictive maintenance technologies to more accurately determine the root cause and correct it.

All agencies in the Multi-Agency Benchmarking Study utilize some level of predictive maintenance programs and automated tracking systems. The ability to closely track differently coded types of work orders enabled the agencies to break down work into different categories. Each agency reported the following observations due to predictive maintenance programs:

- Breakdowns and unplanned work orders decreased.
- Costly repairs were avoided.
- Reduced frequency of major repairs.
- Overall staffing will not decrease, but rather remain the same or increase because of more planned maintenance.
- All agencies assume lowered energy costs; however, only one had measured any savings.

### *Process Benchmarking*

Tables 68 through 71 outline the agencies' programs. The agencies are indicated by numbers one through seven, except for Table 70 (Total Staff Hours) where the numbers indicate the agency with the lowest staffing hours ranging to the agency with the highest staffing hours.

**Table 68**
**In-House Analyses**

| Analysis | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Vibration | | X | X | X | X | | X |
| Infrared | | X | X | X | | | |
| Lubrication | | | | | | | |
| Ultrasonic | X | X | X | | | X | X |
| Other | | X* | | | | | X |

* Borescope.
Note: Two agencies have staff dedicated to vibration analyses; all other analyses are performed as routine maintenance activities.

**Table 69**
**Contracted Services: "As-Needed" Basis (AN) or Periodic (P)**

| Analysis | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Vibration | P | | | AN | | AN | |
| Infrared | P | | | AN | AN | P | AN |
| Lubrication | AN | P, AN | AN | AN | AN | P | P |
| Ultrasonic | AN | | | AN | | P | |

**Table 70**
**Total Staff Hours (from lowest to highest agency)**

| Maintenance Type | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Mechanical | 49,680 | 25,760 | 35,360 | 40,760 | 74,800 | 120,811 | 128,960 |
| Instrumentation | | 9,200 | 10,400 | 14,929 | 31,200 | 54,130 | 69,316 |
| Electrical | | 7,360 | 18,720 | 16,606 | 24,960 | 62,752 | 57,564 |
| Other | | 18,400 | 4,160 | 17,864 | | 20,263 | 4,160 |
| Total | 49,680 | 60,720 | 68,640 | 90,159 | 130,960 | 257,956 | 260,000 |

**Table 71**
**Maintenance Activity Table**

| Activity | CCCSD | CLABS | CPBES | OCSD | EBMUD | KCDNR | SRCSD |
|---|---|---|---|---|---|---|---|
| Predictive Maintenance (Vibe, infrared, etc.) | 2% | 0.5% | 10% | 2% | 0.8% | 4% | 5% |
| Preventative Maintenance (Lubrication & PMs, etc) | 16% | 26% | 30% | 41% | 9.1% | 55% | 27% |
| Reactive Maintenance (repair work as the result of failure) | 37% | 18% | 15% | 8% | 14.6% | 5% | 27% |
| Planned or Routine Maintenance (General Repair work and corrections) | 32% | 40% | 20% | 32% | 41.7% | 28% | 33% |
| Project support by maintenance staff (CIP support, start-ups, etc) | 13% | 4% | 20% | 9% | 11.0% | 8% | 5% |
| Other types of maintenance work | 0% | 11.5% | 5% | 8% | 22.8% | 0% | 3% |

#### Areas of Efficiency

Four potential strategies for operating a P/PM program were identified:

- Assign predictive maintenance to critical, high cost equipment.
- Run to failure non-critical, low-cost equipment.
- Dedicated staff to plan preventive maintenance and repair of non-critical equipment.
- Ratio of preventive to predictive maintenance greater than 30%.

## Off-Shift Staffing

### *Process Benchmarking*

#### Distinguishing Features

Table 72 presents off-shift staffing distinguishing features.

| **Table 72**<br>**Off-Shift Staffing Distinguishing Features** | |
|---|---|
| **Agency** | **Distinguishing Features** |
| CLABS | 5.5% night premium; "bid system" staff can stay in one section for years – promotes specialty of 1 area in depth; Hyperion has 1 electrician 24/7 on 12-hour shifts. |
| CPBES | Managers share a pro-bono, on-call rotation for response to alarms occurring during off-shift hours. |
| OCSD | 12-hour shifts; use bulletin board to transfer information for downshift; operations emergency response team for rain and electrical outages; relief operators "float" with extra pay. |
| KCDNR | Rotating shifts; "reverse seniority" (the most senior crew member is most likely to get "bumped" to another crew); 7 person crews are "self-relieving" for vacation, sick time, etc; shift operators rotate through plant; rotating shifts are not reduced for off-shift hours. |

**Impact of Regulations**

Table 73 presents off-shift staffing impact of regulations.

| **Table 73**<br>**Off-Shift Staffing Impact of Regulations** | |
|---|---|
| **Agency** | **Regulatory Requirements** |
| CCCSD | Furnace control room must be staffed to respond to boiler alarm. |
| CPBES | Instrumentation and electrical staff must hold license. |
| KCDNR | Control room must be staffed (Fire Dept.) for chemical and fire alarms. |

**Impact of Capital Facilities**

Assign an operator to keep up with construction as needed.

**Areas of Challenge**

The following are the areas of challenge identified at the O&M group meetings.

- Communication between shifts
- Scheduling training of off shift staff.
- Emergency response – staffing for emergencies/spills
- Changing workload; rain events are a typical impetus.

**Areas of Efficiency**

The following are the areas of efficiency identified at the O&M group meetings:

- OCSD/CLABS has found that having a relief operator reduces overtime and expense. Calling in on forecast of rain events.

- Rotating shifts at CCCSD accommodate training for operators on off-shifts.
- OCSD has developed a special team that is called in ahead of major storms rather than permanently staffed-shifts.
- The best training time is on weekends or evenings: fewer distractions.
- Assign an operator to keep up with new construction.

#### Areas of Future Investigation

The following are the areas of future investigation identified at the O&M group meetings:

- OCSD looking at fixed weekend crews.
- CCCSD planning to duplicate control room in furnace control room, so shift supervisor can be stationed there and consolidating staff during back shifts.
- KDNR is considering using standby personnel to reduce crew size.
- CLABS is considering operating centrifuges during days only.

## Combined Operations and Maintenance

### *Process Benchmarking*

#### Distinguishing Features

Table 74 presents combined O&M distinguishing features for four of the agencies.

**Table 74**
**Combined O&M Distinguishing Features**

| Agency | Distinguishing Features |
|---|---|
| CLABS | Separate. |
| OCSD | Separate, but work together as business unit. |
| KCDNR | Separate, but work together as business unit. |
| SRCSD | Separate in FY97; have since been combined into process area teams. |

#### Impact of Regulations

The California agencies have licensing restrictions that prevent maintenance personnel from performing operations work. There is no such operator licensing requirement in Washington. Oregon, however, has maintenance licensing requirements for electricians and instrument technicians.

#### Human Resources

- Pay issues: reconciling level of training with pay; electrical vs. instrumentation, for example (agencies)
- Cross training: operators with certification; Maintenance without certification
- Cooperation btw O&M vs. cross training.

**Areas of Challenge**

- MOUs
- Class specifications
- Getting the unions to "buy-in" (LA has 66 maintenance classifications, 75 including operators—not clerical); union/employee opposition to combined O&M.
- Pay scales

**Areas of Efficiency**

- Broad training
- Mechanics that are trained to "handle anything"
- Hire by practical knowledge (by test rather than by interview alone)
- Certify mechanical staff for limited operations to streamline work.

**Areas of Future Investigation**

- More combining of operations and maintenance.
- What type of MOUs work best.
- Privatizers – employees are broadly trained.
- Should goal be to develop depth of knowledge or breadth of knowledge?

## Workforce Flexibility/Skill-based Pay

### *Process Benchmarking*

**Distinguishing Features**

Table 75 presents distinguishing features for workforce flexibility/skill-based pay for two of the agencies.

**Table 75**
**Distinguishing Features for Workforce Flexibility/Skill-based Pay**

| Agency | Distinguishing Features |
|---|---|
| CLABS | 75 classifications in O&M. |
| KCDNR | Job progression program. |

**Human Resources**

- MOU restraints
- Class specifications
- At KCDNR, unions and management developed the skill-based program together. All employees are in one union; all participate in job progression. This was an enormous amount of work to establish and negotiate. A consultant was brought in to set up the job

progression program. But in the long term, it takes pressure off HR because employees are evaluated by people in their own craft.

**Areas of Challenge**

- Perception of fairness issues—goes against Civil Service mode of operation
- Resistance
- Some existing employees felt threatened by new system.

**Areas of Efficiency**

Skill based pay—merit in giving raises based on knowledge, skill, and ability.

## Labor Management Relations

### *Process Benchmarking*

**Distinguishing Features**

Table 76 presents distinguishing features for labor management relations for four of the agencies.

**Table 76**
**Distinguishing Features for Labor Management Relations**

| Agency | Distinguishing Features |
|---|---|
| CLABS | Joint labor group. |
| OCSD | Will be developing a joint labor-management group. |
| KCDNR | Joint labor management committee. |
| SRCSD | All non-management staff, including supervisors, is unionized. |

**Areas of Future Investigation**

- What are quantifiable benefits?
- How do you measure them?

# MANAGED MAINTENANCE PROGRAMS

## Asset Management

Asset Management as a best management practice is the combination of management, both financial and economic, engineering and other practices applied to physical assets with the objective of providing the required level of service in the most cost effective manner. To effectively implement this best management practice one should implement the following six components.

- Financial planning
- Value added design criteria
- User-focused construction and startup
- Proactive operations
- Managed maintenance
- Retirement and disposal of assets

## Managed Maintenance

Managed maintenance is the process of gathering, analyzing and utilizing technical and financial data. To implement this component of asset management, the organization should integrate the following concepts.

- Asset identification
- Asset information
- Life-cycle replacement data
- Equipment hierarchy
- Equipment tracking
- Asset documentation
- Asset history
- Asset criticality

## Prioritization of Work

The replacement cost and process criticality of equipment should be considered when determining what level of maintenance is required (e.g. Is it more cost effective to maintain the equipment with a preventive maintenance program than to run the equipment to failure and simply replace it?). O&M should jointly develop the criteria that will establish a consistent method of prioritizing maintenance work. These criteria must be supported by a priority system that clearly identifies which work task should be performed first. The priority system becomes the means of determining which tasks are the most important regardless if they are corrective or preventive maintenance tasks.

Best maintenance practices will place the highest priority on preventive maintenance tasks. However, based on established criteria such as process criticality or safety related concerns, certain corrective maintenance will take priority over the preventive maintenance activities.

Best maintenance practices also place a high priority on predictive maintenance. The predictive maintenance programs that are available focus on the use of the most recent technology to determine the condition of machinery and equipment while in operation to more effectively forecast eminent failure and other potential problems. Predictive maintenance technologies are also valuable in determining root causes of equipment failure. A more detailed analysis of the effective use of predictive maintenance programs is included on page 95 of this report.

## Maintenance Planning

The Managed Maintenance component, supported by well-defined criteria, becomes the foundation for the implementation of a successful planning and scheduling effort. Planning and scheduling allows for improved coordination between various disciplines with regard to performing regularly scheduled maintenance activities. The planning and scheduling effort is intended to plan both preventive maintenance and corrective maintenance tasks with the goal of reducing overall maintenance costs.

## Purchasing and Stores

A successful managed maintenance program is dependent on a seamless working relationship with the warehouse and purchasing functions. The productivity of maintenance personnel will be enhanced with the ability to reserve and stage materials and parts for all scheduled maintenance activities. Warehouse parts inventory must be aligned with the process criticality of equipment. The ability to standardize on equipment types has the potential to significantly reduce inventories, parts costs, training costs and to simplify the procurement processes.

## Sole Source Equipment Purchases

State purchasing laws that require competitive bidding and open competition are a topic of considerable discussion in most public organizations. There is a fine line supported by regulations that must be followed to ensure that the lowest possible price is obtained for specified equipment and that multiple manufactures and suppliers are given the opportunity to compete to provide products and services. These purchasing requirements often fail to allow for a common sense approach to equipment and service purchases. Some agencies are clearly more restricted than others with regard to sole purchases due to internal and external factors such as specific requirements imposed by city governments or other local jurisdictions and economic development programs. Even where proven experience would suggest that a particular product is inferior, or when compatibility with existing equipment and spare parts inventory would suggest that it makes the most sense to purchase a particular brand or manufacturer, public agencies are often unable to make purchases that make sense from a business perspective. Furthermore, the competitive bidding process is often costly and may produce poor results for the end user.

For new equipment purchases, the use of a pre-qualification process one possible method to ensure that a product will meet the operational and maintenance needs of the organization. This process allows for an evaluation period to determine performance characteristics against the project specifications, as well as field testing of the reliability and maintenance requirements during the shake down process. While this process does not allow for the sole source purchase of equipment, it ensures that the equipment under consideration meets the specifications and will perform well when the project has been completed. This process is often time- and labor-intensive, but may produce better long-term results than competitive bidding.

The integration of equipment into an existing process or system is also a challenge with regard to the sole source purchase of equipment or technology. In many cases the successful integration of new equipment or facilities expansion depends on purchasing specific equipment or technology to ensure compatibility or trouble free operation within the existing process. The replacement or expansion requirements can be used to justify a sole source purchase with the approval of appropriate management and purchasing personnel or governing board.

There are also some State purchasing programs which award contracts through the competitive bidding process for pre-qualified equipment. These programs pre-qualify different types of commonly purchased equipment and makes the information available to other government agencies for their use. While this program does not qualify as a sole source program it does reduce the list of potential suppliers based on their ability to meet certain performance and pricing criteria.

## Contracted Services

The managed maintenance program is focused on the cost-effective maintenance of facilities and equipment. In most cases, the program will meet organizational needs for core services to be provided. However, some tasks and “non-core” services that may be more cost effectively outsourced. The goal of the maintenance program should be to continually evaluate the services required against the most cost-effective or best value service provider. In some cases the best value service provider may not necessarily be from within the organization. Some types of work may require specialized tools, equipment, or specific knowledge that can more effectively be offered by a contracted service provider.

## Training

Training of personnel is an extremely important component of the managed maintenance program. Some of the areas where training is essential are:

- Safety
- Technical
- Cross Training
- Business Culture

Training should be focused on improving knowledge, skill, abilities and overall job performance. The success of the training program is to a large part dependent on the support of management. The productivity of the maintenance program is directly related to the organization’s willingness to invest in its’ human resources.

## Benchmarking Analysis

A proactive maintenance program includes asset management, managed maintenance and planning and scheduling. These components are fundamental to the success of any maintenance program but must be supplemented with other business previously discussed. The focus on continuous improvement is a key component in developing or improving maintenance practices within an increasingly competitive industry.

# Summary, Conclusions and Recommendations

The key conclusions drawn from the benchmarking analysis are presented in this section. Costs and data were evaluated on two levels. One level looked at the factors that drive unit process costs (i.e., higher chemical use in dewatering). The other level looked at the factors that influence the general cost centers of labor, energy and chemical costs. General conclusions and summary items are presented first, followed by unit process conclusions. The findings and conclusions reflect the "Best Practices" found in the study.

## GENERAL CONCLUSIONS

On average the seven agencies spent $729 per million gallons (passing through their treatment facilities) in FY97 on overall agency costs. Figure 44 shows how the overall agency spending was distributed between the major cost centers. About 50% of the total ($367 per million gallons) was spent for Operations and Maintenance of the treatment facilities.

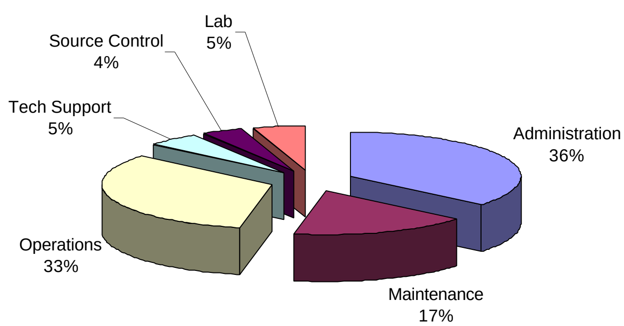



**FIGURE 46: COST CENTER ALLOCATION BREAKDOWN**

The average total O&M cost for the seven agencies is $367/MG. Costs range from $264/MG to $524/MG with two agencies at the high end of this range.

The average total O&M cost to remove a ton of BOD is $478. Costs range from $368 to $820 per ton with one agency showing considerably higher costs per ton removed.

Following are some general findings:

- On average, the agencies spend approximately 50% of their overall expenditures on the operation and maintenance of their wastewater facilities.
- Of the costs for operation and maintenance of the facilities, the seven agencies average 34.7% of their expenditures on residuals processing and handling, and 13.3% on secondary treatment. Almost half of the O&M expenditures are spent on these two functions.
- O&M costs are strongly influenced by labor or staffing costs. Using labor in the most efficient manner for each unit processes will reduce the overall cost for that process.

- Union contract provisions strongly influence labor cost efficiencies.
- Agencies operating at significantly below or above design capacity are likely to experience operational inefficiencies. An agency operating significantly below design capacity will incur extra O&M cost for the reserve capacity. An agency operating at above capacity is stressing the system, and may experience greater O&M costs to keep the facility operating at above its intended design capacity.
- Economies of scale influence O&M costs.
- Agencies are affected by factors out of their immediate control. The low cost agency for a unit process frequently enjoys a unique operational environment not available to others.
- Low cost does not always correlate to high efficiency. Costs can be driven by other applicable factors, such as site constraints, policy decisions, and regulatory requirements.
- The cost of power is affected by energy rates, consumption, (economies of scale), and levels of pumping (local topography is a strong influence).
- Taking equipment, systems, or unit processes out of service to meet seasonal loading variations will decrease the overall costs.
- Plant automation and standardization of equipment lower operation and maintenance costs.
- Access to comparative cost data better enables an agency to negotiate contract costs for services commensurate with those paid for such services by other agencies.

## UNIT PROCESS CONCLUSIONS

### Influent Pumping and Preliminary Treatment

- Electric motor-driven equipment has lower maintenance costs than combustion engine driven equipment.
- Good grit capture is a key factor to controlling preliminary treatment costs. Grit removal also affects downstream processes such as digestion and equipment wear.
- Lower cost agencies use front rake climber screens.
- Chemical addition in the front end of the plant (e.g. ferric chloride addition in the preliminary treatment process) results in decreased odor emissions, better primary settling, reduced secondary treatment costs, improved digestion, and reduced solids handling costs.
- No particular influent pump technology (screw pumps, centrifugal pumps, etc.) appears to be inherently more cost efficient.

### Primary Treatment

- The flight and chain mechanisms used in rectangular clarifiers require more maintenance than solids removing mechanisms in circular clarifiers.
- The materials used for the flight and chain mechanisms is key. Non-metallic chain is preferred by many agencies because it is not subject to corrosion and is easier to handle and repair. This means that non-metallic chain and flights afford the operational advantages of being able to take clarifiers out of service without corrosion worries. However, non-metallic chain may wear more quickly, and is more expensive than steel

chain. Stainless steel chain is better suited for high grit loading applications and combined sewer applications. While more difficult to handle, steel chain is not as frequently repaired as non-metallic.

- There does not appear to be a correlation between the type of primary clarifier used (i.e. rectangular or circular) and the overall cost of treatment.

### Secondary Treatment

- Energy is the primary component of activated sludge treatment costs.
- The agencies pay an average of 5.7¢ per pound of BOD removed during secondary treatment. The costs range from 4.0¢ to 7.2¢ per pound removed.
- Oxygen activated sludge treatment is more expensive than air activated sludge treatment. Oxygen plant selection has often been predicated on land use and air emissions restrictions.
- Increased process stability can be achieved with deeper (>20 feet) clarifiers and decreased surface overflow rates of 400 to 600 gallons per day per square foot.
- High efficiency blowers with adjustable inlet and outlet guide vanes and full bottom fine-bubble membrane diffusers provide the most efficient air transfer system.
- Separate selector zone and aeration zone applications improve process stability and secondary settleability.
- Surface aerators are more energy efficient than submerged turbine aeration devices for high pure oxygen facilities.
- Trickling filters should be considered, but balanced with land availability and the level of treatment required. At one agency, the O&M costs are 25% those of aeration costs, based on flow.

### Residuals Processing and Handling

- Disposal costs and quantities of grit and screenings vary considerably.
- Co-digestion of secondary and primary sludges is the preferred method of operation.
- Digester O&M costs are reduced if grit is removed from the treatment stream prior to digestion.
- Use of sludge screens and grinders upstream of the digesters will decrease plugging problems in pipelines and the digesters, minimizing O&M cleaning costs and improving biosolids quality.
- Controlling *Nocardia* in secondary treatment processes can reduce some digester foaming.
- Fixed covers reduce the nuisance of digester foaming.
- Centrifuges are not cost-effective for sludge thickening.
- Dewatered biosolids dryness should be based upon minimizing the total costs of dewatering and disposal/reuse.
- Dewatering cake pumps are recommended when there is a concern for odors, elevation, and long transport distances.

- If transporting high solids sludge, special consideration should be made for the conveyance and discharge methods to account for the higher solids characteristics. For example, the chute slope into the sludge storage hoppers should be steep enough to prevent bridging. Minimize conveyance length and use gravity where available.
- Regulations and agency policy, responding to public perceptions/reactions, have an impact on biosolids processing, disposal and reuse systems.
- Risks of contractor non-performance is reduced by having diverse and multiple disposal/reuse contractors. There must be a balance between risk and the cost of diversity.
- Some agencies reduce costs by seeking competitive bids from multiple contractors for hauling, applying, and reusing biosolids.
- Agencies should perform complete and detailed pilot testing of new biosolids disposal/reuse options and technologies prior to committing to a full scale and long term commitment.
- Some agencies use sludge lagoons to reduce biosolids mass, increase quality, and allow seasonal land application.
- Low costs agencies incinerate or use biosolids on-site.

## Odor Control

- Air emission control and treatment costs can vary significantly due differences in regional permitting requirements, site locations, and public acceptance (agency policy).
- All agencies perform some form of odor or emissions control within the collection system and at the wastewater treatment facility.
- There is no dominant odor control technology. Odor control methods are very much agency and site specific.
- Odor control costs are increasing at a greater rate than inflation.

## Disinfection/Dechlorination

- Investments in instrumentation may be offset by savings due to improved chemical dosing.
- Many agencies have converted, or are planning to convert, from chlorine to other disinfection alternatives in order to mitigate the safety, public perception, and risk management issues associated with storing and handling chlorine.
- Disinfection/dechlorination costs are heavily impacted by NPDES permit requirements.
- Chemicals or energy for ultraviolet treatment are the major components of disinfection/dechlorination costs. Opportunities for improved cost efficiency include 1) Competitive bidding that may include joint contracts with others, and 2) Optimization of chemical dosing through better monitoring, improved mixing, and better instrumentation.

### Computer Systems and Automation

- Standardization of control systems simplifies both operation and maintenance of the control system.
- Standardization of control systems saves costs in training, maintenance, spare parts, reliability, and troubleshooting.
- Critical systems for facility operation should have a hot back up to ensure continuous operation.

### Power Generation/Energy Systems

- Operations staff can perform light maintenance on the power generation systems.
- Opportunities exist for cost savings through better energy management; this includes peak purchasing, negotiated power costs, load shedding (demand management), and electrical monitoring in unit processes.

### Maintenance Conclusions

- For most agencies capital support by maintenance staff for project startup and design work is difficult to capture and separate from the O&M budget.
- Most computerized maintenance management users do not adequately differentiate among preventive, predictive, corrective, or reactive work.
- The lowest cost agencies have dedicated staff who plan preventative and corrective work.
- Run to failure is the most efficient way to maintain non-critical equipment with low replacement costs.
- Predictive maintenance (condition monitoring) can realize the greatest potential when used on critical equipment or equipment that is expensive to replace or repair.
- Agencies who have the greatest workforce flexibility realize the lowest maintenance costs.
- Regulatory licensing requirements, multiple unions, or stringent trade lines appear to have a significant impact on workforce flexibility and may increase maintenance costs.
- The lowest cost agencies perform the highest percentage of preventative maintenance (greater than 30%; see Table 71).

## RECOMMENDATIONS

The recommendations of the O&M Work Group are as follows:

- Implement Asset Management programs that incorporate: life cycle replacement, equipment criticality, spare parts inventory, standardization and purchasing.
- Dedicate maintenance staff for planning preventative maintenance, as well as equipment breakdowns for non-critical equipment.
- Maintenance work should be coordinated across all crafts and with operations to make the best use of equipment down time.

- Utilize precision maintenance technologies such as Vibration Analysis, Thermal Imaging, Laser Alignment, and Dynamic Balancing to improve equipment reliability and efficiency.
- Contract out specialty and non-core maintenance activities when it makes good business sense.
- Invest and commit to programs that provide Safety Training, Technical Training, Cross Training, and Business/Cultural Training.
- Assign the highest priority to preventative maintenance activities.
- Evaluate optimization of unit processes on a plant-wide basis. For example, evaluate the applicability of coagulant addition in the front end of the plant to improve process operation and costs throughout the facility.
- Focus optimization efforts on the higher cost unit process, e.g., secondary treatment and biosolids reuse, and the primary cost centers of energy and chemicals.
- Change the number of in-service units to match flow/load conditions.
- Convert to high efficiency blowers and equipment to reduce energy costs.
- Steam turbine technology is more reliable and requires lower maintenance than internal combustion engine-driven technology.
- Continue to develop alternative methods of biosolids disposal/reuse that balance risk with cost in order to provide a safe, acceptable alternative to current methods.
- Encourage competition for biosolids service providers and bulk purchase of other commodities, such as chemicals and energy, to force market competition through multiple bidders.
- Be active in the development of new regulations effecting the wastewater industry.
- Install hot back up to computer systems for critical facilities.
- Joint multiple agency input into WERF projects

Areas of recommended study and development are:

- Minimally attended systems,
- New biosolids technology and research options considering costs, risks, markets, regulations/permitting, technology, and marketing,
- Joint multiple agency commodity contracts, and 4) Joint multiple agency research

Continued efforts for future benchmarking projects should include:

- Develop standard and uniform definitions among the agencies for maintenance activities such as wrench on bolt time, planned maintenance, predictive maintenance, reactive maintenance, and preventative maintenance.
- Establish maintenance standards for optimum efficiency such as ratio of preventative to breakdown work etc.
- Implement O&M friendly Financial Management Systems consistent with O&M templates
- Modify/improve templates for future years, to include other areas such as collection systems, training, water reclamation etc.

- Update benchmarking data annually
- Commit adequate time to unit processes not fully analyzed in this phase of the study, such as odor control, water reclamation/conservation, tertiary treatment/water reclamation, information technology, labor-management relations, and capital projects and O&M.
- Continue to refine the benchmarking tools. Refine the process benchmarking surveys and analysis and develop tools to assess the effects of changes implemented as a result of this study.
- Expand the number of agencies in the Multi-Agency study by targeting agencies with similar capacities.

When considering new or refurbished facilities, the following suggestions should be considered:

- Consider methods to reduce operations labor, such as increased automation and operating partial systems.
- Design and install efficient grit removal system at the front end of the plant.
- Consider life cycle costs, including maintenance requirements, for any new equipment.
- Evaluate the specific application to choose between chain and flight materials. A capital cost savings now may drive operations and maintenance costs higher and prevents the process from operating at peak performance.
- Consider primary circular clarifiers.
- Design secondary clarifiers with some reserve capacity to provide operational stability. (The clarifiers should be 18-20 feet deep, and operate at an overflow rate of 400 to 600 gallons per day per square foot.)
- Evaluate membrane technology in lieu of secondary clarifiers.
- Evaluate possible application of “low tech” processes where possible, such as fixed film reactors or sludge lagoons.
- Install high efficiency blowers with inlet and outlet guide vanes to help decrease energy usage where blowers are used.
- If operating a pure oxygen-activated sludge process, evaluate the cost of generating the oxygen on site using plant staff.
- Use surface aerators for pure oxygen dissolution to help decrease energy usage.
- Choose digester technologies that minimize life cycle costs.
- Use mechanical seals (as opposed to packing) wherever applicable.
- Consider using pumps for conveyance of dewatered biosolids to aid odor control and reduce maintenance costs especially when elevations and long distances are involved.

# Appendices