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Evaluation and Documentation of Mechanical Reliability of Conventional Wastewater Treatment Plant Components

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EVALUATION AND DOCUMENTATION OF MECHANICAL RELIABILITY OF CONVENTIONAL WASTEWATER TREATMENT PLANT COMPONENTS

by

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Contract No. 68-03-2712

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16. ABSTRACT

This study was initiated to determine the in-service reliability, maintainability and availability of selected critical wastewater treatment plant components. Components were considered critical if their failure caused an immediate impact on effluent quality.

Treatment plant components selected included pumps, power transmissions, motors, compressors, valves, and controls. Components were those from four types of wastewater treatment plants. The four types of plants were air activated sludge, oxygen activated sludge, trickling filter, and rotating biological contactor (RBC). Operation and maintenance data obtained from nine operating plants were used to estimate failure rates, mean-time-between-failures, mean-time-to-repair, and availability for each component. These performance statistics are by component type, size range, and application. Performance statistics were calculated from operating data for 119 pumps, 249 power transmissions, 285 motors, 17 compressors, 13 valves, and 269 controls.

Calculated performance statistics can be utilized by design engineers and plant operators to assist in the selection of new equipment. The development of a performance data base and subsequent proper utilization of the data should result in improvements in treatment plant performance. These data allow estimates to be made of performance to be expected from certain equipment in certain applications.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

In the report, performance statistics for various mechanical components found in four types of secondary wastewater treatment plants are presented. These statistics were derived utilizing equipment service records from nine wastewater treatment plants. Results indicate a wide range of performance characteristics for similar equipment in different applications. Example problems are presented with appropriate solutions to explain how these types of statistics can serve as a valuable design and operations tool.

Francis T. Mayo, Director
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561-775

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This report was submitted in fulfillment of Contract No. 68-03-2712 by Southwest Research Institute under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period September, 1978 to March 1981.

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LIST OF ABBREVIATIONS

Abbreviations

POTW	--	Publicly Owned Treatment Works
EPA	--	Environmental Protection Agency
GAO	--	General Accounting Office
BOD	--	biochemical oxygen demand
MTBF	--	mean time between failure
MTTR	--	mean time to repair
WRAP	--	Wastewater Reliability Analysis Program
PM	--	preventative maintenance
CM	--	corrective maintenance
AVI	--	inherent availability
AVO	--	operating availability

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SECTION 1

INTRODUCTION

There are approximately 21,000 publicly owned municipal treatment plants (POTWs) operating in the U.S. at the present time, with 1000-1200 new plants being constructed each year[1][2]. Since 1957, Federal grants exceeding 20 billion have been awarded to help state and local governments construct these treatment plants. Once constructed, local governments become responsible for plant operation in accordance with effluent discharge permit requirements established by the National Pollutant Discharge Elimination System (NPDES).

Many POTWs are apparently not meeting NPDES permit requirements. The General Accounting Office (GAO) concluded in 1970 that operation and maintenance problems with POTWs had been widespread for many years and had resulted in inefficient plant operations[3]. A 1975 EPA analysis of 954 POTW inspections showed 386 plants had sufficient design and operational performance data to determine whether the plant was meeting design criteria for biochemical oxygen demand (BOD) removal. 40 percent of the 386 plants failed to meet design BOD removal. 49 percent of 305 plants were operating below design criteria for suspended solids removal. Other studies have indicated significant problems of non-compliance by POTWs with NPDES permits[4][5][6].

In recognition of these operational and maintenance problems, the U.S. EPA initiated a national research program dealing with performance and reliability of POTWs. A significant part of the effort involves determining the reliability of various mechanical components used at POTWs.

This study was conducted to quantify the in-service reliability of critical mechanical components found in four types of secondary wastewater treatment plants. The four types of plants included in this study were air activated sludge, oxygen activated sludge, trickling filter, and rotating biological contactor. Component reliability statistics calculated were mean time between failure (MTBF), mean time to repair (MTTR), and availability as a fraction of scheduled operating time.

To determine the in-service reliability of critical mechanical components, the first step was to identify the critical components. The following components were identified as critical (i.e., failure would have an immediate impact on effluent quality):

(1) Pumps
(2) Power transmissions
(3) Motors

(4) Compressors
(5) Diffusers
(6) Valves
(7) Controls
(8) Pressure vessels
(9) Conveyors.

A criticality analysis was then conducted to determine which applications of these components should be included in the study. This effort served to identify the field data collection requirements.

Nine treatment plants were then selected from a candidate list of approximately 40 plants. These nine plants were visited and data collected from plant maintenance records. Reliability statistics were then calculated using these data.

SECTION 2

CONCLUSIONS

Based upon the results of the performance data collection and analysis effort conducted during this project, the following conclusions are made:

(1) Three types of performance statistics (reliability, maintainability, and availability) have been determined for mechanical components of wastewater treatment plants. (p. 25)

(2) These performance statistics were not available in the literature, from manufacturers, or owners of equipment. (p. 31)

(3) These performance statistics can be used by design engineers as a tool to (a) compare and predict performance of generic equipment in various applications, and (b) design reliability into new treatment plants. (p. 33)

(4) These data can be used by operators of wastewater treatment plants to help develop spare parts inventories for new equipment and establish preventative maintenance programs. (p. 37)

(5) The majority of the 200 plants contacted by phone or visited during the screening process did not maintain adequate records necessary for collection of data needed in this study. (p. 14)

(6) This data base does not cover all the size ranges or types of equipment typically found in the 21,000 treatment plants operating in the U.S. Therefore, performance statistics for many of the components found in smaller plants are not available in the data base. It was found that these records are not routinely kept by the smaller plants surveyed during this study. (p. 14)

(7) The quality of data obtained from the nine treatment plants was good. The form of record keeping sometimes required judgments as to appropriateness with respect to project data requirements. (p. 16)

(8) The nine treatment plants from which the data were collected maintained records for equipment for a variety of reasons, including ordering spare parts, scheduling preventative maintenance, and preparing annual budgets.

(9) The nine plants visited had preventative maintenance programs which appeared to be effective.

(10) Performance statistics can provide design engineers and plant operators with additional information to help select and specify equipment. Training will be required to help these people know how to utilize such data. For maximum effect, the data base should be expanded to cover all major types and size ranges of equipment found at treatment plants presently operating in the U.S. The data base should be maintained for at least a five year period.

SECTION 3

RECOMMENDATIONS

Based upon the results of this study, the following recommendations are offered:

(1) EPA should encourage the use of performance results of this study by designers or operators as an additional tool for the selection of equipment and the prediction of performance from mechanical components.

(2) EPA should conduct a series of technical seminars to (1) present the results of this project to design engineers and plant operators, and (2) explain the basic reliability and availability analysis methodologies. Their feedback could be used to help formulate and define future EPA policy regarding the Federal role in the WWTP performance statistic data base management.

(3) EPA should conduct a study to determine the feasibility of implementing a continuous performance data collection program from selected treatment plants representing a sufficient cross section of the nearly 21,000 plants in the U.S. by plant type and design flow. Mechanism and cost should be determined.

(4) Based upon favorable results of recommendations (2) and/or (3) above, EPA should initiate a program to collect performance data on a continuous basis for use by design engineers and treatment plant operators.

SECTION 4

PROJECT OBJECTIVES

Major project objectives were as follows:

(1) Quantify in-service reliability, maintainability and availability on mechanical components used in four types of secondary wastewater treatment plants.

(2) Show how the component application affects its reliability, maintainability and availability.

(3) Quantify in-service reliability, maintainability and availability of the sludge processing unit operations at wastewater treatment plants.

SECTION 5

RESEARCH APPROACH

The research approach utilized to accomplish the objectives of this study involved a series of major tasks which are discussed in detail in the following sections. Briefly, the first step, the Criticality Analysis, involved the identification of the important mechanical components in conventional secondary wastewater treatment plants as defined by their potential impact on effluent quality should they fail. Once these components were identified, the criticality of each component was determined and ranked by conducting a failure mode and effects analysis. From this effort, the desirable information needed from actual operating treatment plant records was identified.

The Plant Selection step involved developing a candidate list of treatment plants to be visited. From this list, nine treatment plants were selected and subsequently visited to collect data. These data were then analyzed to determine the important performance statistics, i.e., mean time between failure, mean time to repair, and availability.

5.1 CRITICALITY ANALYSIS

The objective of the criticality analysis was to determine the mechanical components in conventional wastewater treatment plants which would have the most immediate impact on final effluent quality if they failed.

The procedure used in this phase was to define the conventional secondary wastewater treatment plants - air activated sludge, oxygen activated sludge, trickling filter and rotating biological contactor in terms of the respective flow diagrams. These flow diagrams are presented as Figures 1 through 4.

Sludge processing systems were included in the study. These included vacuum filters, aerobic and anaerobic digestion and dissolved air flotation. Data for components of sludge processing equipment were not collected. Only data for those sludge processing systems found at the treatment plants visited were collected.

The flow diagrams defined the various treatment systems of interest. Each system was then divided into the following unit operations:

- Headworks
- Primary settling
- Secondary treatment (biological units)
- Final settling

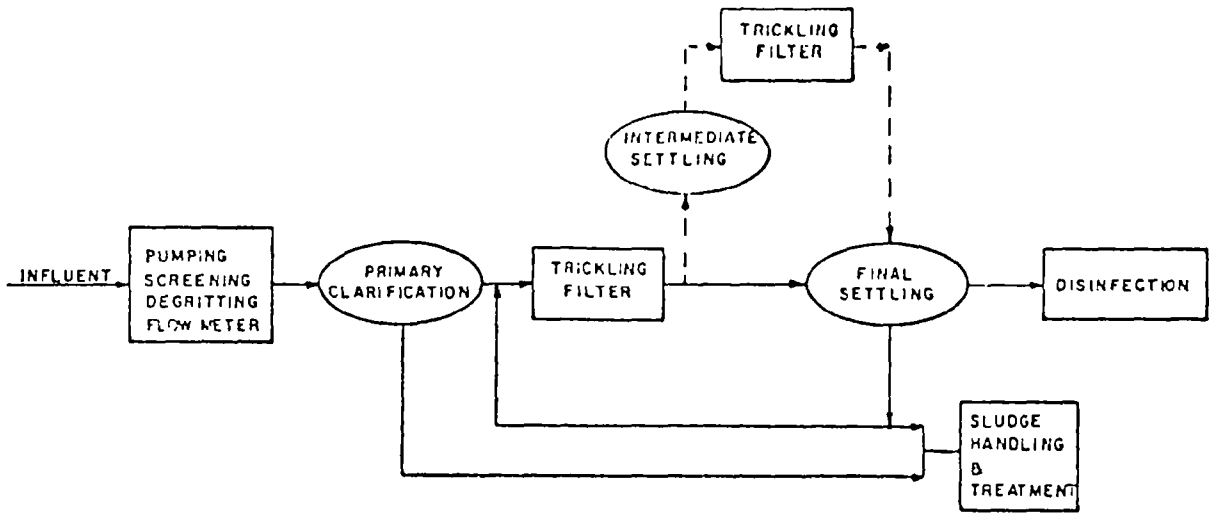


FIGURE 1

FLOW DIAGRAM – TYPICAL TRICKLING FILTER SYSTEM

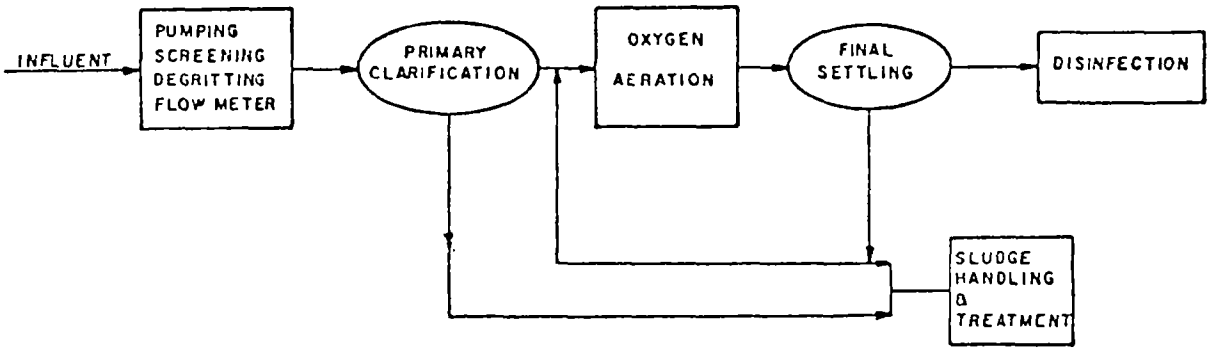


FIGURE 2

FLOW DIAGRAM – TYPICAL OXYGEN ACTIVATED SLUDGE SYSTEM

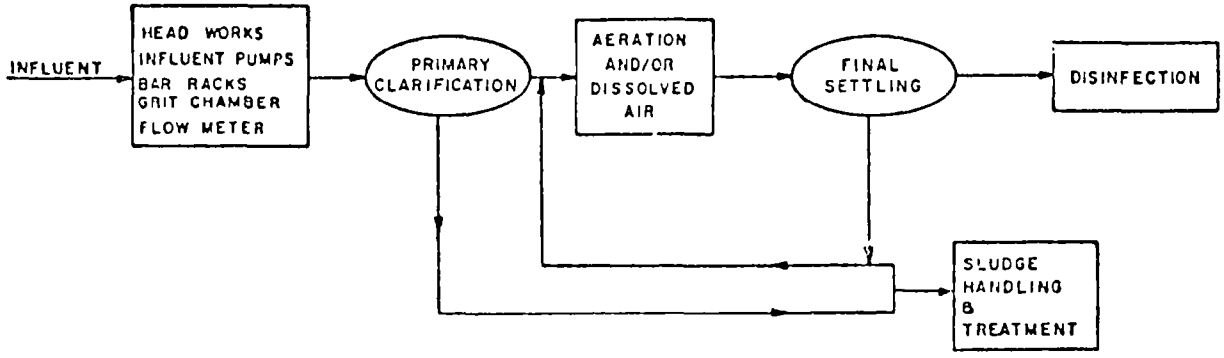


FIGURE 3

FLOW DIAGRAM – TYPICAL ACTIVATED SLUDGE TREATMENT SYSTEM EXAMPLE

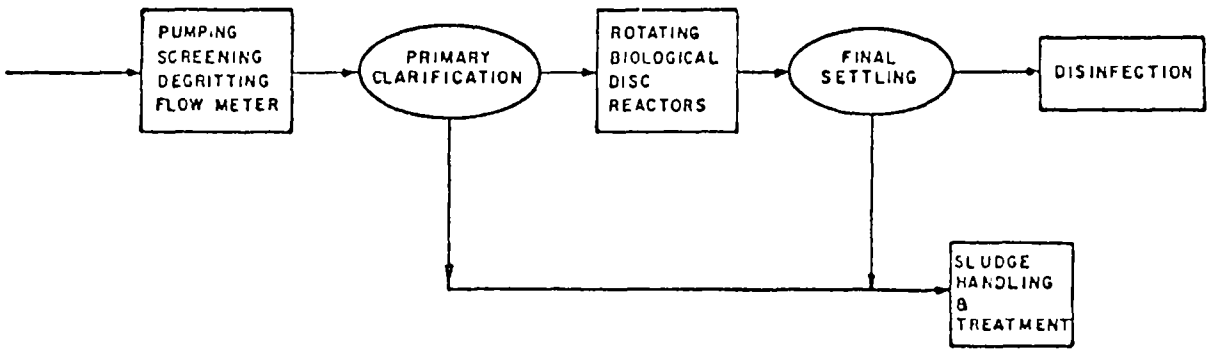


FIGURE 4

FLOW DIAGRAM — TYPICAL ROTATING BIOLOGICAL CONTACTOR TREATMENT SYSTEM

- Sludge processing
- Disinfection

The broad classifications of mechanical equipment that could be identified in each unit operation were then defined. These classifications are:

Pumps
Power transmission
Motors
Compressors
Diffusers (air/water)
Valves
Controls
Pressure vessels
Conveyers (unconfined materials handling)

A numbering system was developed to aid in performing the criticality analysis and data collection. The numbering system is presented in Appendix A. In developing the numbering system, the generic groups, applications, size ranges, subcomponents and other pertinent information were preliminarily identified. Examples of these categories are presented in Appendix A. The system was developed with the flexibility to add additional information during field collection of data. This is the reason for the use of the two, three and four digit columns to identify a specific component. Additionally, to allow for data sorting by computer, it was necessary to eliminate any mixing of equipment type or application between columns.

The following steps were then used in the criticality analysis:

(1) Identification of the broad classification in each plant unit operation for each type of plant.

(2) Identification of the applications for each broad classification defined in step 1 above.

(3) Assignment of a criticality factor as a function of failure on effluent quality and the time of the effect.

In performing the criticality analysis, it was assumed that there was no equipment duplication and the plant was operating at design conditions. For example, it was assumed that there was only one raw wastewater pump in the headworks, only one final clarifier in the final settling unit operation, and no additional hydraulic capacity in either component.

A rating was assigned to each plant type, unit operation, broad classification and application combination. The rating consisted of two parts:

(1) Relationship between Failure and Effluent Quality

- A - Significant impact
- B - Minimal impact
- C - No impact

(2) Time Factor

- 1 - 0-4 hours
- 2 - >4-12 hours
- 3 - >12-24 hours
- 4 - >24 hours

Using this approach, if a combination was rated "A-1," the failure of the mechanical component would likely result in a significant impact on effluent quality within four hours. If the rating was "C," the failure would probably have no impact on effluent quality. The results of the criticality analysis are presented in Appendix B.

The results of the criticality analysis were then reviewed and ranked according to priority by those that would have the most significant impact in the shortest time period. The results of this ranking are presented in Appendix C.

The critical components for inclusion in the study were selected as those with an assigned criticality factor of either A-1, A-2, A-3 or B-1. If the impact of failure of a mechanical component was minimal (i.e., B) and it occurred within four hours, that component was also considered to be critical and included in the data collection effort. The following presents a summary of those mechanical components selected for inclusion in the data collection phase:

- Raw and intermediate wastewater pumps, power transmission and motors for <u>all plant types</u>

- Return activated sludge pumps, power transmission and motors for <u>air</u> and <u>oxygen activated sludge</u>

- Recirculation pump, power transmission and motors for <u>trickling filter</u> and <u>rotating biological contactors</u>

- Motors and power transmission for final clarifiers for all plant types

- Motors, power transmission, compressors, valves, controls and diffusers used in dissolved air production application and mechanical aerators in air activated sludge plants

- Motors, power transmission, recirculation pumps, controls, diffusers and valves used in oxygen generation, application and recirculation in oxygen activated sludge plants

- Liquid application systems for trickling filter plants

- Compressors, motors, power transmission and controls used in rotating biological contactors in RBC plants

- Motors, pumps, power transmission and controls used in primary

clarifiers and primary sludge pumping in trickling filter and RBC plants

- Recirculation pumps controls used in secondary treatment in RBC plants

- Raw and intermediate wastewater pump controls used in all plant types and valves used in raw and intermediate pumps in trickling filter plants

- Controls used in dosing siphon in secondary treatment in trickling filter plants

- Controls used in final clarifiers for all plant types

- Pumps, motors, power transmission and pressure vessels used in disinfection for all plant types.

Having defined the data collection requirements, the next step involved the selection of treatment plants having adequate records from which these data could be collected.

5.2 DATA SOURCE SELECTION

The Criticality Analysis described in Section 5.1 defined the mechanical components for which performance data were needed. The next step was to select the treatment plants where this information could be obtained. This data source selection process involved the following tasks:

- o Develop a list of candidate plants.
- o Select plants for one-day screening visits.
- o Conduct the one-day visits.
- o Select study plants.

A candidate list of approximately 200 treatment plants was developed utilizing information from the U.S. EPA staff, equipment manufacturers and sales representatives, SwRI and subcontractor contacts, treatment plant operators and the literature. The criteria used to develop this list were primarily (1) that the plants satisfied the plant type requirement (i.e., air or oxygen activated sludge, RBC, or trickling filter); (2) there was an indication these plants would be willing to participate in the study; and (3) maintenance records were available.

Using information about these plants, forty-two plants were selected for direct contact by telephone. Project objectives and available maintenance records were discussed with appropriate personnel at each facility. The majority of the plants contacted did not maintain historical records on the plant components by component type. To access these data, extensive on-site time would have been necessary. Other plants did not maintain maintenance records. This was more often the case with smaller plants. Seventeen plants were identified for further consideration. One-day screening visits were then scheduled for each plant. The one-day visits were made to discuss the

project with plant personnel and verify the suitability of plant records for the study.

Following the one-day visits, the treatment plants to be included in the data acquisition effort were selected. Criteria used to make the selection were as follows:

(1) Existence of adequate and complete preventative and corrective maintenance records for all major equipment components at each plant;

(2) Existence of plant equipment typical of the generic equipment found in the four types of treatment plants under consideration;

(3) An indication that plant operations and maintenance personnel were willing to cooperate in the data collection effort.

Table 1 shows the design flow and age of the nine plants included in this study.

TABLE 1. TREATMENT PLANTS INCLUDED IN RELIABILITY STUDY

Plant Type	Design Flow (MGD)	Age (Years)
Air Activated Sludge	98	15
	75	7
	36	8
	60	4
Oxygen Activated Sludge	72	5
	300	7
Trickling Filter	45	20
	150	30
Rotating Biological Contactor	24	2

5.3 DATA ACQUISITION

The objective of the data acquisition phase of this study was to obtain failure and maintenance data on the critical mechanical component/application combinations shown in Appendix C, "Mechanical Equipment Priority Ranking" (see Section 5.1). A schedule was developed for visiting the plant locations identified in Section 5.2. Plant managers/superintendents were contacted to establish the time for the visit and confirm that the appropriate plant employees would be available at that time.

Upon arrival at each plant, the data collection team (engineer/operator and engineering technician) met with the plant staff involved. This meeting

provided an opportunity for the data collection team to further explain the project and discuss possible uses of the project results. The methodology of the data collection effort was discussed. The plant staff was asked to outline the details of their maintenance management system, work order system, spare parts program, contract maintenance, and problems encountered. These discussions were important to facilitate proper collection of the data from plant records. Following this interview, a plant tour was made to familiarize the data collection team with plant layout, sub-processes, equipment, flow patterns, flow rates, and controls.

At this point, data collection was started. Maintenance records for each critical component were reviewed. Data collection forms were used to code all data. An example is shown in Figure 5. Required data elements are shown at the top of this form. All data collected in the field were encoded using the numbering system discussed in Section 5.1 (see Appendix A). These codes are shown in the appropriate columns in Figure 5. For example, column one contains the code number 04-8731. The first two digits, 04, identify the plant location. The second four-digit number represents a record number used to identify that specific piece of equipment. Column two, plant type, shows the number 05, which identified this plant as a combination air/oxygen activated sludge plant. Codes for each of the remaining 23 columns are shown, with a description of what each code means shown below the code. Column 23 was for recording actual down time of sludge processing systems. Data for the sludge processing systems at each facility visited were recorded as shown at the bottom of Figure 5. These data allowed calculation of the mean time between failure and availability of the system.

The data collection from plant records often required a degree of judgment and interpretation. This was especially true when deciding when equipment had actually failed. A mechanical component failure is classified as an event which occurs when a subcomponent ceases to perform its function, and must be repaired or replaced to restore the component to a normal operating condition. An example of a failure is a seized bearing on a pump shaft which must be replaced before the pump can be restored to an operating condition. In contrast, an equipment malfunction was defined as situations where the equipment could be placed back into service by minor cleaning and/or adjustments. Only data for down time considered to be caused by failure were recorded. Malfunctions including pump blockages, reduction in blower capacities due to dirty air filters, and plugging of air diffusers were not recorded. If interpretation of maintenance records was questionable, the data collection team conferred with plant maintenance staff to decide whether a failure had occurred.

5.4 DATA ANALYSIS

A computer program entitled "Wastewater Reliability Analysis Program - WRAP" was written to handle the sorting and analysis of the relatively large data base. Complete details of the logic, fortran listings, and capabilities of WRAP are contained in Appendix E of this report. Reliability, maintainability, maintenance and availability statistics were calculated from the data base across all plants for:

SLUDGE PROCESSING EQUIPMENT		WASTEWATER TREATMENT EQUIPMENT		
PLANT NO 4	04 4321	PLANT NO 4	04 8/31	
UNIT NUMBER		UNIT NUMBER		
COMBINATION AIR/OXYGEN ACT. SL	05	COMBINATION AIR/OXYGEN ACT SL	05	TYPE 2
INCINERATOR	10	SECONDARY TREATMENT	03	UNIT OPERATION 3
		PUMPS	01	IMPACT CLASSIFICATION 4
		PUMP PROPELLER AXIAL	0114	GENERIC GROUPS 5
		INTERMEDIATE WASTEWATER PUMP	03	APPLICATION 6
		100,000 GPM	04	SIZE 7
		BEARING, BALL DOUBLE ROW	023	SUB-COMPONENT 8
		EFFLUENT IMPACT WITHIN 4 HOURS	01	CRITICALITY 9
JULY, 1976	0776	JULY, 1977	0777	DATE INSTALLED 10
100%	99	100 %	99	% OPERATING TIME 11
11 FAILURES	11	1 FAILURE	01	FAILURES 12
		NOT KNOWN	00	FAILURE MODE 13
		NORMAL WEAR	08	CAUSE OF FAILURE 14
		24 - 168 HOURS	04	DOWN TIME 15
		6 HRS - 24 HRS	03	TIME TO REPAIR 16
		DRY BASEMENT	04	ENVIRONMENTAL FACTOR 17
		REPLACED	02	PART DISPOSITION 18
		NOT KNOWN	000	SUBCOMPONENT MFR 19
		ALLIS CHALMERS	016	COMPONENT MFR 20
		NOT KNOWN	00	PART INV INFO 21
		CORRECTIVE MAINTENANCE	02	TYPE OF MAINT 22
DOWN TIME 1584 HOURS	1584			DOWN TIME OF UNIT OR SUB-UNIT 23
AUGUST, 1979	08/79	AUGUST, 1979	08/79	COLLECTION DATE 24
		8 HOURS	008	CLOCK TIME TO REPAIR 25

Figure 5. Sample of a Field Data Collection Form

(1) Components
(2) Components by application
(3) Components by size
(4) Components by generic group
(5) Components by generic group by application
(6) Components by generic group by size.

In addition, failure distribution information by subcomponent type for the first four categories listed above were also calculated. Also, reliability and availability statistics were calculated for sludge processes.

Included in Appendix E is a computer printout by plant, and across all plants of reliability, maintainability, maintenance and availability statistics for components by generic group by application by size.

The statistics calculated from the data serve as the best summary of the data base in terms of the reliability, maintainability, maintenance, availability and subcomponent failure distribution parameters for the nine wastewater treatment plants. This information should be useful to other plant owners and operators, equipment manufacturers, and plant designers.

A description of the algorithms and methods used to calculate the estimates of the parameters which appear in the tables in Appendix D of this report follows.

5.4.1 Number of Units

The number of units in the data base for each category of component groupings was calculated by summing the number of units reported in the data base across the appropriate grouping.

5.4.2 Number of Failures

The number of failures (Column 12 in Figure 5) was calculated in the same manner as the number of units.

5.4.3 Operating Hours (in millions of hours)

The total operating hours (OH) for the units in each category of component groupings was calculated by the following formula:

$$OH = (8760 \sum_{i=1}^{N} Y_i P_i)/1,000,000$$

where

Y_i is the number of years between the installation date (Column 10 in Figure 5) and the date the data were taken or the unit was taken out of service (Column 24 in Figure 5), for the ith unit in the category,

P_i is the percent of the time the unit was operating (Column 11 in Figure 5), and

N is the number of units in the category.

5.4.4 Overall MTBF (in millions of hours)

The point estimate for the overall mean-time-between-failures (MTBF) was calculated by the following formula:[7]

$$MTBF = \frac{2T}{X^2_{0.5;2r+2}}$$

where,

T is the total operating hours (OH) from Section 5.4.3,

r is the number of failures from Section 5.4.2, and

$X^2_{0.5;2r+2}$ is the value of a chi-square distribution[7] with 2r+2 degrees of freedom at the fiftieth percentile.

This method yields a slightly more conservative estimate of the MTBF than the usual method of dividing the operating hours by the number of failures. This method also allows an estimate of the MTBF, even when no failures have occurred.

5.4.5 Minimum MTBF (in millions of hours)

The minimum MTBF for a particular category is the least MTBF calculated in a subcategory of the category. For example, in a grouping of components by generic group by size, there may be several subcategories by application. The smallest value of MTBF from this subcategory is listed as the minimum MTBF. This information serves as a lower bound on the range of the subcategory MTBF's. Where there is only one data point in the subcategory, the entry is left blank.

5.4.6 Maximum MTBF (in millions of hours)

The maximum MTBF is calculated in a similar manner to the minimum value and serves as an upper bound on the range of subcategory values. The difference between the maximum and minimum values can be interpreted as a measure of dispersion about the overall MTBF estimate. If one assumes that these estimates are normally distributed,[8] then an estimate for the standard deviation is one-sixth of the range of the minimum to maximum values. The smaller the ratio of the estimate of the standard deviation to the MTBF, the more precise is the estimate of the MTBF.

5.4.7 Overall 90% Confidence Level (in millions of hours)

The overall 90% confidence level (M(.90)) for the MTBF is calculated

by the formula:[7]

$$M(.90) = \frac{2T}{X^2_{.90;2r+2}}$$

where,

T is the total operating hours (OH) from Section 5.4.3,

r is the number of failures from Section 5.4.2, and

$X^2_{.90;2r+2}$ is the value of a chi-square distribution with 2r+2 degrees of freedom at the ninetieth percentile.

The meaning of the 90% confidence limit is that one can be 90% confident that the true value of the MTBF is at least as great as the calculated 90% confidence limit.

The percent deviation of the confidence limit value from the point estimate value of the MTBF is a function of the number of failures.[7] Figure 6 is a graph showing the percent deviation from the point estimate of the lower confidence limit, as a function of the number of failures. Figure 6 was derived using the following formula:

$$\text{Percent Deviation} = 1 - \frac{x^2(.5);\ (2r+2)}{x^2(CL);\ (2r+2)}$$

From Figure 6, for a lower 90% confidence limit, the following information can be derived as to the approximate percent deviation of the lower 90% confidence limit from the point estimate of the MTBF as a function of the number of failures.

Number of Failures	Approximate Percent Deviation
1	-57%
2	-49%
3	-44%
4	-41%
5	-38%
10	-31%
20	-24%
100	-12%

The percent deviation is also a measure of the precision of the point estimate.

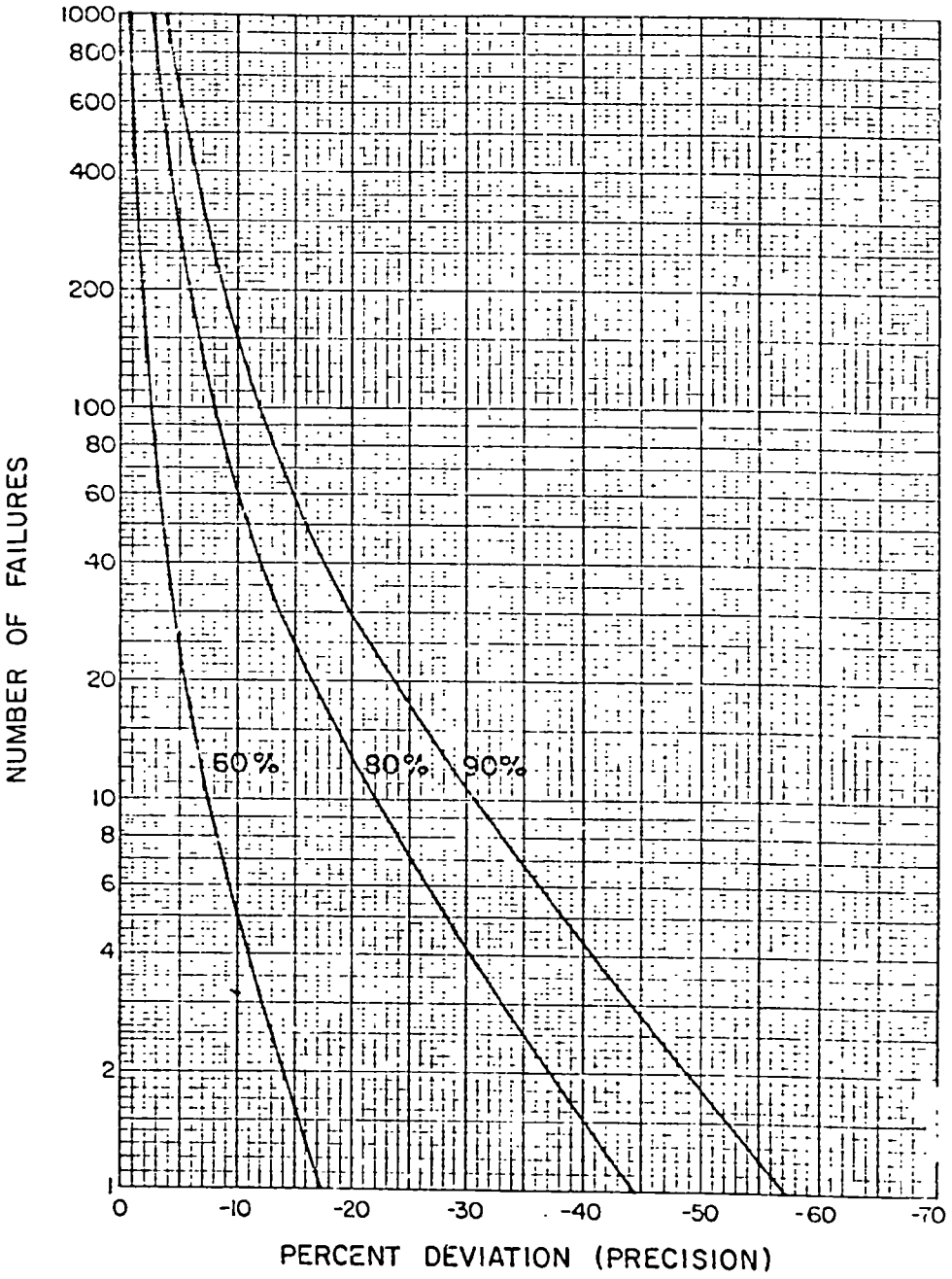


Figure 6. Percent Deviation of One Sided Lower Confidence Limits From Point Estimate of MTBF vs. Number of Failures

5.4.8 Preventative Maintenance Hours per Unit per Year (PM-HRS/UNIT/YEAR)

The preventative maintenance (scheduled maintenance) hours per unit per year (PH) for each unit category are calculated by the formula:

$$PH = \left(\sum_{p=1}^{m} PM_j\right)/[(Y)(m)] \quad ,$$

where,

- m is the number of units in the category, (taken from Section 5.4.1)
- Y is the number of operating years on the m units (taken from Section 5.4.3), and
- PM_j is the number of preventative maintenance hours reported on the jth unit.

5.4.9 Corrective Maintenance Hours Per Unit Per Year (CM-HRS/UNIT/YEAR)

The corrective maintenance (unscheduled maintenance due to failures) hours per unit per year (CH) for each category are calculated by the formula:

$$CH = \left(\sum_{j=1}^{m} CM_j\right)/[(Y)(m)] \quad ,$$

where,

- m is the number of units in the category (taken from Section 5.4.1)
- Y is the number of operating years ($\Sigma Y_i P_i$, taken from Section 5.4.3) on the m units
- CM_j is the man hours spent on corrective maintenance for the jth unit (Column 16 in Figure 5).

5.4.10 Mean-Time-To-Repair (MTTR) in hours

The mean time to repair a unit in a category is calculated by the formula

$$MTTR = \left(\sum_{j=1}^{N} \sum_{i=1}^{nj} C_{ij}\right)/\left(\sum_{j=1}^{N} \sum_{i=1}^{nj} r_{ij}\right)$$

where,

N is the number of units in the category,

n_j is the number of corrective maintenance actions due to failures on the jth unit

C_{ij} is the number of calendar hours during which repair actions were being made (Column 15 in Figure 5) due to the ith failure on the jth unit.

r_{ij} is the ith failure on the jth unit, that is,

$\sum_{j=1}^{N} \sum_{i=1}^{nj} r_{ij}$ is the total number of failures

(or corrective maintenance actions) on the N units in the category.

5.4.11 Inherent Availability (AVI)

The inherent availability for each of the component groupings is calculated by the formula:

$$AVI = \frac{MTBF}{MTBF+MTTR}$$

The inherent availability of a component is a measure of the fraction of time that the component can be expected to be operational, excluding preventative maintenance downtime.

5.4.12 Operating Availability (AVO)

The operating availability for each of the component groupings was calculated by the formula:

$$AVO = \frac{TH-THD}{TH} \quad ,$$

where,

$TH = (\sum_{i=1}^{N} Y_i)(8760)$ = total hours for all units in category, and

THD = total downtime over all units due to corrective and scheduled maintenance.

Thus, the operating availability is calculated from the operating history of the units, and is a measure of the fraction of the calendar time which the unit was operating.

5.4.13 Component Failure Statistics by Subcomponent Type

For each of the first four component groupings listed in Section 5.4, the number of failures of the components due to failures of subcomponents was determined. The relative frequency of failures by subcomponent type was calculated. These frequency distributions for the dominant subcomponent failures are listed in Appendix D, Part 2.0.

5.4.14 Reliability and Availability Statistics for Sludge Processes

Data on the following five sludge process were obtained.

(1) Sludge treatment external to the wastewater treatment process
(2) Anaerobic digestion
(3) Incineration
(4) Sludge Thickening Dissolved Air Floatation
(5) Vacuum filter

Statistics calculated by plant and across all plants are: operating hours, number of failures, MTBF, 90% confidence limits on MTBF and operating availability. These statistics for sludge processes were calculated in a manner similar to their counterparts for components, and are presented in Appendix D, Part 3.0.

SECTION 6

RESULTS AND DISCUSSION

The performance statistics on critical components and sludge processes which were calculated from the data gathered at nine wastewater treatment plants are presented in Appendix D. The statistics which were calculated are as follows:

RELIABILITY STATISTICS

- o Overall mean time between failures (Overall MTBF)
- o Maximum mean time between failure (Max MTBF)
- o Minimum mean time between failure (Min MTBF)
- o Lower limit 90% confidence level for the mean time between failure point estimate (overall 90% CL)

MAINTAINABILITY AND MAINTENANCE STATISTICS

- o Mean time to repair (MTTR)
- o Preventative maintenance man hours per unit per year (PM-HRS/Unit/YR)
- o Corrective maintenance man hours per unit per year (CM-HRS/Unit/YR)

AVAILABILITY STATISTICS

- o Inherent availability (AVI)
- o Operating availability (AVO)

These statistics, presented in Part 1.0 of Appendix D, have been grouped as follows:

- o By component (component is synonymous with broad classification as used in the data numbering system)
- o By component by generic group
- o By component by application
- o By component by size/capacity
- o By component by generic group by application
- o By component by generic group by size/capacity

The definitions and methods used to calculate the performance statistics are presented in Section 5.4 of this report. A discussion of Tables 1.1.1 and 1.1.2 of Appendix D follows.

Table 1.1.1 presents the reliability statistics for the eight components (or broad classifications) included in the data base. The overall point estimate of the mean time between failures for pumps was 32,066 hours, or approximately 3.7 years. This estimate is for all types of pumps of various size ranges in a variety of applications. To obtain the MTBF estimate for a specified type of pump in a certain application, say an open impeller pump being used for raw wastewater pumping, one refers to Table 1.5.1.1. The lower limit 90% confidence level MTBF value for pumps in Table 1.1.1 is 28,630 hours, or approximately 3.3 years. As discussed in Section 5.4, this means there is a 90% chance that the true MTBF value is greater than 3.3 years. The true MTBF value would be that value calculated from operating data for all critical pumps in all wastewater treatment plants throughout the United States. Since this history is not presently available, the 90% value, combined with the overall point estimate, provides a reasonable range for predicting component performance.

The minimum and maximum MTBF values shown in Table 1.1.1 represent the smallest and largest estimated MTBF values calculated for subcategories of pumps. The difference between these values can be interpreted as a measure of the dispersion about the overall MTBF estimate for pumps.

In summary, the estimate of the true MTBF value for pumps based upon data collected is 32,066 hours. The smallest and largest MTBF values calculated were 21,662 hours and 74,191 hours, respectively in the subcategory of generic group. There is a 90% chance that the true MTBF value is at least 28,630 hours. The same conclusions can be made for the other components listed in the tables presented in Part 1.0 of Appendix D.

Table 1.1.2 presents the maintenance statistics for components. For pumps, the preventative maintenance (scheduled) hours/unit/year spent at all the treatment plants included in the study averaged .00227 hours. The corrective maintenance (breakdown) hours per unit per year were .05177 hours. These numbers might appear to be low. However, it must be recognized they are based upon a large number of pumps (119) operating for a combined total of 442 years. Many units operated for ten years with few failures, and required minimal scheduled maintenance. The corrective maintenance value is based upon the active man hours required to disassemble, correct, and reassemble the unit, excluding time parts may have spent in the shop or time spent waiting for a new part to be received.

The AVI, or the inherent availability, is a measure of the fraction of time that the component can be expected to be operational, excluding preventative maintenance downtime. The AVO, or the operating availability, is a measure of the same fraction of time, but is based upon the operating history of the units, including preventative and corrective maintenance.

For pumps, the AVI and AVO fractions from Table 1.1.2 are .99968 and .99116, respectively.

The tables in the other five groups provide a further breakdown of the reliability and maintenance statistics.

Part 2.0 of Appendix D contains tables presenting the number and relative frequency of failures of subcomponents for the eight components or broad classifications. For example, Table 2.1.1 lists the types of subcomponents which caused pump failures, ranked according to the number of failures. There were 17 impeller wear ring or plate failures. The relative frequency was .177. This means one should expect that approximately 17 percent of the subcomponent failures for pumps will be due to impeller wear rings or plates.

Part 3.0 of Appendix D presents reliability and availability statistics for the various sludge processes located at the treatment plants visited during this study. Table 3.1.1 presents for the five sludge processes listed, total operating hours, number of failures of the process, the mean time between failure, the 90% confidence level lower limit and the operating availability. The first process listed, sludge process external to wastewater treatment process, includes primary, secondary, waste activated, and digester gas recirculation pumping. The other processes listed are self-explanatory.

MTBF Comparison Method

In order to select the component type for an application with the highest MTBF, it is necessary to compare the MTBF statistics for the candidate component type. Since one is comparing estimates of the true MTBF, it is useful to derive an estimate of the level at which a given MTBF value is statistically different from another MTBF value.

One method is to utilize an "F" test[8] based on the fact that the statistic

$$\frac{2r^{m}}{m}$$, where

r is the number of failures,

^{m} is the print estimate for MTBF, and

m is the true MTBF,

has a Chi Square distribution with 2r degrees of freedom.[7] The ratio of two of these statistics has an "F" distribution[8] with $2r_1$, $2r_2$ degrees of freedom, and a test of the hypothesis that the true MTBF's of the populations from which the estimates came are equal can be made.

Another less precise method is illustrated in the following paragraphs, using data taken from Tables 1.2.1, 1.5.2.1, and 1.5.2.9.

Generic Group	No. of Failures	MTBF	90% CL
Concentric Reducer	2	122,640	61,898
Belt Drive	5	91,101	55,640

The significance level at which the two MTBF's are statistically different is a measure of the risk that one is wrong in saying that the component with the highest point estimate value MTBF has a true MTBF that is actually higher than the point estimate value MTBF of the other component.

A less precise method (than the F test) for determining the significance level at which the concentric reducer can be judged to have a higher MTBF than the belt drive is outlined below:

Step 1. Compare the 90% confidence limit value MTBF of the concentric reducer to the point estimate value MTBF of the belt drive. If the 90% confidence limit value MTBF of the concentric reducer (61,898 hours) is greater than the point estimate MTBF value of the belt drive (91,101 hours), there is less than a 10% chance of being wrong if one decides that the true MTBF of the concentric reducer is greater than the point estimate value MTBF of the belt drive; the significance level would be less than 10%. However, since the 90% confidence limit value MTBF of the concentric reducer is less than the point estimate value MTBF of the belt drive, one must go on to Step 2 to determine the approximate significance level.

Step 2. Use the graph in Figure 6 to determine the % confidence limit value MTBF of the concentric reducer which is greater than the point estimate value MTBF of the belt drive.

From Figure 6, the deviation from the point estimate for 80% CL with 2 failures is .376, and for 60% CL with 2 failures is .140. The confidence limits are:

$$80\% = (1-.376)(122,640) = 76,520$$

$$60\% = (1-.140)(122,640) = 105,460$$

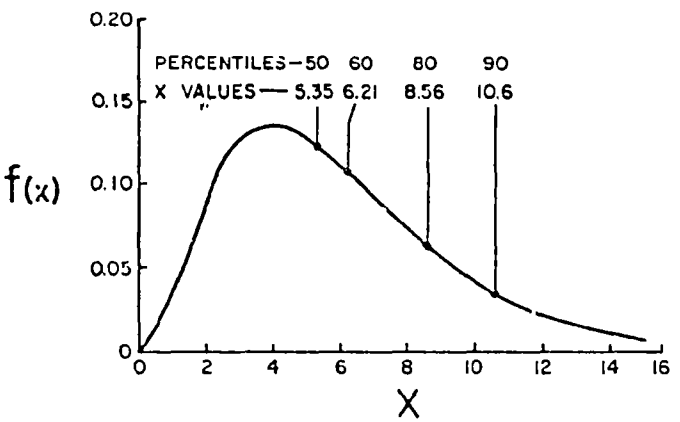
At the 60% CL, the concentric reducer MTBF value is 105,460 hours, which is greater than the point estimate value MTBF of 91,101 hours for the belt drive. However, at the 80% CL, the concentric reducer MTBF value of 76,520 hours is less than the point estimate value MTBF of 91,101 hours for the belt drive.

Thus, there is a risk of greater than 20% and less than 40% of being wrong if one decides that the true MTBF of the concentric reducer is greater than the point estimate value MTBF of the belt drive power transmission.

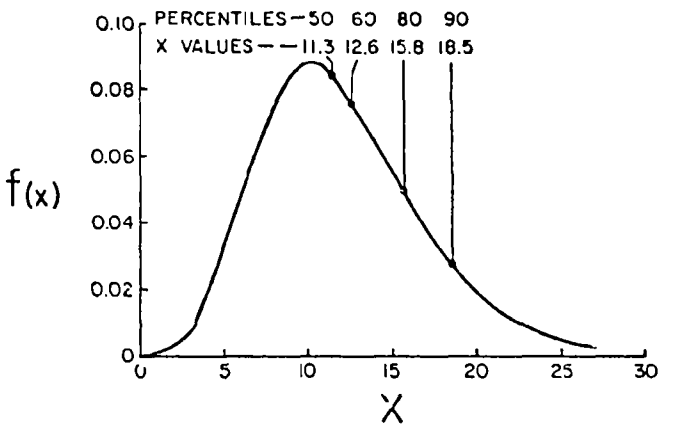
The actual significance level for this example is 32.6% as determined by the "F" test method.

The Chi-Square distributions and the percentiles from which the same calculations could be made are shown in Figure 7, along with a linear graph of the confidence level comparisons. Tables of the appropriate Chi-Square distributions could be used to determine confidence levels for MTBF, using the formula in section 5.4.7.

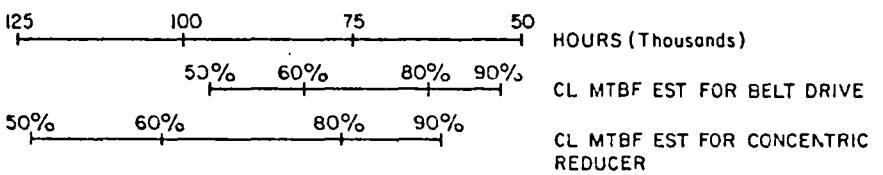
Figure 6 can also be used for this type of determination for any of the MTBF values presented in the tables of Appendix D, Part 1.0. When the 90% Confidence Limit value MTBF of one equipment type is greater than the point estimate value MTBF of another equipment, there is less than a 10% chance of being wrong in deciding that the first equipment type has a higher MTBF than the second.



(a) CHI-SQUARE DISTRIBUTION WITH 6 DEGREES OF FREEDOM



(b) CHI-SQUARE DISTRIBUTION WITH 12 DEGREES OF FREEDOM



(c) CONFIDENCE LIMIT ON BELT DRIVE AND CONCENTRIC REDUCER

Figure 7.
EXAMPLE OF CHI-SQUARE DISTRIBUTIONS; PERCENTILES AND CONFIDENCE LIMITS

SECTION 7

COMPARISON OF RELIABILITY DATA FROM WASTEWATER TREATMENT PLANT STUDY TO DATA FROM TWO OTHER SOURCES

A comparison of reliability data from other sources to the reliability data from the Wastewater Treatment Plant Study is useful in assessing how similar components perform in different applications. Two other data sources were identified which contained data on components that were similar in size and/or generic group to those in the Wastewater Treatment Plant Study. These data sources are, "The Non-Electric Parts Reliability Data",[9] "The Nuclear Plant Reliability Data System" (Edison Electric Institute, operated by Southwest Research Institute, San Antonio, TX).[10]

Pertinent performance data were selected from each of the two sources. Mean time between failure (MTBF) calculations were made, using the same methods as were employed for the Wastewater Treatment Plant Study. The results are shown in Table 2.

For most components, there were many more operating hours contained in each of the other two data sources. The wastewater treatment plant MTBF values were lower than for the other two sources, for all the components listed. This could be expected, since the components reported in the Nuclear Plant Reliability Data System are all in the safety class of the nuclear steam supply system. In addition, many of the components from the Non-Electric Parts Reliability Data were qualified to military specifications and were used in military applications. The added safety and/or reliability requirements for components in these types of applications may have contributed to the higher MTBF values.

Various manufacturers and equipment owners were contacted during the study to solicit reliability/performance data on plant components. These manufacturers indicated they did not calculate these statistics.

TABLE 2. COMPARISON OF MTBF FOR COMPONENTS FROM THREE DATA SOURCES

	Data Source											
	Wastewater Treatment Plant				Nuclear Plant Reliability Data System				Reliability Analysis Center			
Component Type	Operating Hours ($\times 10^6$)	Number of Failures	MTBF ($\times 10^6$)	90% CL ($\times 10^6$)	Operating Hours ($\times 10^6$)	Number of Failures	MTBF ($\times 10^6$)	90% CL ($\times 10^6$)	Operating Hours ($\times 10^6$)	Number of Failures	MTBF ($\times 10^6$)	90% CL ($\times 10^6$)
Pumps, Centrifugal	2.11746	97	.021662	.019105	14.134	314	.04491	.03985	5.176	36	.14123	.1150
Pumps, Axial	1.75462	23	.074191	.057623	.454	1	.27023	.11671	--	--	--	--
Power Transmission	11.10382	311	.03562	.03317	4.124	58	.07020	.05379	37.480	303	.12339	.10563
Motors, Multiphase AC	12.4947	193	.0600	.0620	29.050	112	.2576	.2292	7.290	9	.7592	.5132
Motors, Internal Combustion	.03976	1	.02380	.01023	3.523	102	.03429	.03033	--	--	--	--
Compressors - Centrifugal												
Single Stage	.12666	5	.02242	.01369	3.255	18	.17453	.1315	--	--	--	--
Multi-Stage	.54354	96	.005618	.004952	3.896	22	.17201	.13297	--	--	--	--
Valves												
Ball	.01916	1	.01146	.004927	.1340	1	.0798	.0344	11.192	10	1.084	.7268
Butterfly	.05475	1	.03259	.01408	32.1290	62	.5040	.4319	13.675	18	.7332	.5525
Gate	.10402	11	.00893	.00627	5.2140	26	.1956	.1540	7.484	10	.7027	.4860
Plug	.01916	0	.02952	.00832	1.2880	8	.1489	.09908	5.806	19	.2955	.2242

SECTION 8

PERFORMANCE STATISTICS UTILIZATION

There are a variety of uses for the reliability, maintainability and availability statistics presented in Section 6. For example, design engineers can utilize these data as an additional tool to be used for the selection of equipment, determination of the reliability and availability of unit operations as well as entire treatment systems, and the prediction of operational performance of equipment in various applications. Plant owners/operators can utilize preventative and corrective maintenance data to help refine overall future maintenance budget and staffing projections. Knowledge of equipment failure rates and subcomponent failures can provide input into determining spare parts inventories. The following problems and their solutions are presented to demonstrate how inservice performance statistics can be used in these ways.

AVAILABILITY ESTIMATION

Problem: Determine the expected availability of an existing wastewater pumping station.

Given:	Peak demand	150,000 gpm
	Existing pumps	3 at 55,000 gpm each
	MTBF of each pump	7500 hours
	MTTR of each pump	100 hours

Solution:

Derive the system event tree state-capacity matrix.

Determine the availability versus capacity for each set of states.

Availability (A) for each pump

$$A = \frac{MTBF}{MTBF+MTTR} = \frac{7500}{7500+100} = .9868421053$$

A system event tree is developed showing each operating state, pumping capacity at each state, and the percent of the peak demand flow that can be handled at each state. A_1, A_2 and A_3 define each pump availability. $\bar{A}_1$, $\bar{A}_2$ and $\bar{A}_3$ indicate the pump is unavailable or out of service.

System Event Tree

Operating State	Capacity	% of Peak
$\bar{A}_1\bar{A}_2\bar{A}_3$	0	0
$\bar{A}_1\bar{A}_2A_3$	55,000 gpm	36.67
$\bar{A}_1A_2\bar{A}_3$	55,000 gpm	36.67
$A_1\bar{A}_2\bar{A}_3$	55,000 gpm	36.67
$A_1A_2\bar{A}_3$	110,000 gpm	73.33
$A_1\bar{A}_2A_3$	110,000 gpm	73.33
$\bar{A}_1A_2A_3$	110,000 gpm	73.33
$A_1A_2A_3$	165,000 gpm	110.0

There are 4 capacity states. The percentage of the operating time that the system is in each state can be found using the binomial distribution[7] since:

$$A_1 = A_2 = A_3 \text{ and } \bar{A}_1 = \bar{A}_2 = \bar{A}_3 = 1 - A$$

Let $R = A$ and $Q = \bar{A}$, then

$$(R + Q)^3 = \binom{3}{0} R^3Q^0 + \binom{3}{1} R^2Q^1 + \binom{3}{2} R^1Q^2 + \binom{3}{3} R^0Q^3$$

$$= R^3 + 3R^2Q + 3RQ^2 + Q^3$$

Replacing R by A and Q by $\bar{A}$ and evaluating the binominal expansion yields the state versus time proportion matrix shown below, for each term yields the proportion of the time that the system will be in the respective state. The state capacity is obtained by multiplying the number of available pumps

by the pump capacity.

The state-time proportion matrix is shown below.

State	Time Proportion
165,000 gpm	.9610434283
110,000 gpm	.0384417371
55,000 gpm	.0005125565
0	.0000022781

Thus, in a one year period, on the average, the number of hours in each state would be:

State	Hours per Year
165,000 gpm	8418.740432
110,000 gpm	336.749617
55,000 gpm	4.48999494
0	.019956156

The number of hours in one year is 8760. Therefore, the estimated number of hours per year that this pump station could not be expected to pump at a combined rate of 165,000 gpm would be 8760 - 8419 or 341 hours (14.2 days).

Problem

Determine the state capacity matrix versus probability for the pumping station described in the previous problem with an added pump of 55,000 gpm capacity.

Solution:

The binomial equation for the capacity-probability states is:

$$\binom{4}{0} A^4 \bar{A}^0 + \binom{4}{1} A^3 \bar{A}^1 + \binom{4}{2} A^2 \bar{A}^2 + \binom{4}{3} A^1 \bar{A}^3 + \binom{4}{4} A^0 \bar{A}^4 = 1$$

where

The first term capacity is 4(55,000) = 220,000 gpm

The second term capacity is 3(55,000) = 165,000 gpm

The third term capacity is 2(55,000) = 110,000 gpm

The fourth term capacity is 1(55,000) = 55,000 gpm

The fifth term capacity is 0(55,000) = 0

The matrix below is calculated using the individual pump availability (A) of .9868421053.

State	Time Proportion	Hours per Year
220,000 gpm	.9483981201	8307.967532
165,000 gpm	.0505812331	443.0916017
110,000 gpm	.0010116247	8.861832034
55,000 gpm	.0000089922	.078771672
0 gpm	.0000000299	.000261924

Thus, the addition of a pump has reduced the time that station would be expected to be below the peak demand capability from 341 hours to 8760 - (8308+443) or 9 hours.

There are existing analytical methods[7] to determine the effect of adding new equipment to any existing unit operation, i.e., primary and secondary clarification, aeration, etc. These methods are also useful for determining reliability and availability of the entire treatment plant system. By having access to appropriate performance statistics, designers and operators can develop reliabilities and availabilities for treatment plant designs comprising various types of equipment and identify the design which appears to offer the lowest life cycle cost. This approach to design and equipment component evaluation has been practiced in the electrical and electronics industry since the early 1950's. At the present time, approximately 50 percent of the nuclear power plants in the U.S. participate in a reliability, maintainability and availability data base program. Since Three Mile Island, the industry has begun to evaluate this data base to determine how these data can help prevent similar system failures.

MAINTENANCE COST ESTIMATION

Problem:

Estimate the average maintenance costs for the raw wastewater pumps (excluding motors) in the previous example.

Given:	Number of pumps	3 at 55,000 gpm
	Preventative Maintenance (PM)/ Unit/Year	10 manhours
	Corrective Maintenance (CM)/ Unit/Year	20 manhours
	Labor Costs (average)	$15/hour

Solution:

PM hours/yr = (3 units) 10 manhours/unit/yr
= 30 hours/yr

CM hours/yr = (3 units) 20 manhours/unit/yr
= 60 hours/yr

PM and CM Cost/yr = ($15/hr) 90 hrs/yr
= $1350/yr, or $450/pump/yr

These estimates could be made for all equipment at a planned or existing treatment plant. The results form a base to which the design engineer or owner may apply his own experience, to estimate maintenance costs and staff levels.

SPARE PARTS ESTIMATION

Problem:

Determine the replacement rate for those subcomponents failing most frequently, using the pumps included in the previous example.

Given:	No. of pumps	3 at 55,000 gpm each
	MTBF	81,635 hours

Solution:

The failure rate for each pump is

$$\text{Failure rate} = \frac{1}{\text{MTBF}}$$

$$= \frac{1}{81{,}635 \text{ hours}}$$

$$= 1.23 \times 10^{-5} \text{ failures/hr/pump}$$

For three pumps, the expected number of failures/yr are

$$\frac{\text{No. of failures}}{\text{year}} = 3(1.23 \times 10^{-5})\ 8760$$

$$= 3.23 \times 10^{-1} \text{ failures/yr}$$

The distribution of subcomponent failures from the tables in Appendix D, Part 2.0 are

Impeller wear ring	19.7%
Seal, packing, oil lubricated	18.4%
Bearings, ball, double row	7.9%

The parts needed per year are

Impeller wear rings/yr $= (.197)3.23 \times 10^{-1}$

$= 0.1$

Seals, packing/yr $= (.184)3.23 \times 10^{-1}$

$= 0.1$

Bearings/yr $= (.079)3.23 \times 10^{-1}$
$= 0.03$

Thus, an impeller wear ring and packing should require replacement approximately every ten years. A pump bearing should require replacement only every thirty-three years, due to random failure between scheduled preventative maintenance activity.

These are point estimates of the parts needed per year. Confidence intervals can be placed around this point estimate using the Poisson distribution.[7] The Poisson distribution can also be used to determine the number of spares required for a 90% confidence level of having a spare when needed.

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APPENDIX A
DATA NUMBERING SYSTEM

COLUMN 1 (6 Digits)	PLANT AND RECORD NUMBER
First 2 digits plant ID Number	Last 4 digits component record number
COLUMN 2 (2 Digits)	TYPE PLANT
00	No information
01	Air Activated Sludge
02	Oxygen Activated Sludge
03	Trickling Filter
04	Rotating Biological Contractor
05	Combination Air/Oxygen Activated Sludge
COLUMN 3 (2 Digits)	PLANT UNIT OPERATIONS
00	No information
01	Head Works
02	Primary Settling
03	Secondary Treatment (biological unit)
04	Final Settling
05	Disinfection
06	Sludge Processing outside the Waste Treatment Process
07	Anaerobic Digestion
08	Aerobic Digestion
09	Heat Treatment
10	Incineration
11	Sludge Thickening Gravity
12	Sludge Thickening DAF
13	Centrifuge, Solid Bowl
14	Centrifuge, Basket
15	Centrifuge, Nozzle
16	Vacuum Filter
17	Belt Press
COLUMN 4 (2 Digits)	BROAD CLASSIFICATION OF MECHANICAL COMPONENTS
00	No information
01	Pumps (without motor)
02	Power Transmission
03	Motors
04	Compressors
05	Diffusers air/water
06	Valves
07	Controls
08	Pressure Vessels
09	Conveyor (unconfined materials handling)

COLUMN 5 (4 Digits)	GENERIC GROUPS
Pumps	
0000	No information
0100	No information
0101	Self-priming Centrifugal Pump
0102	Submersible Centrifugal
0103	Screw Pump
0104	Progessing Cavity
0105	Diaphragm
0106	Piston
0107	Gear
0108	Air Operated
0109	Open Impeller Centrifugal
0110	Closed Impeller Centrifugal
0111	Open Impeller Centrifugal Close Coupled
0112	Closed Impeller Centrifugal Close Coupled
0113	Pump with Integral Motor
0114	Propeller Pumps, Axial Flow
Power Transmission	
0200	No information
0201	Concentric Reducer
0202	Parallel Shaft
0203	Right-angle Shaft
0204	Vertical Shaft
0205	Variable Speed Drive Belt Type
0206	Variable Speed Drive Hydraulic
0207	Variable Speed Drive Other
0208	Gear Box
0209	Chain Drive
0210	Cyclo Drive (Wemco Sells)
0211	Belt Drive
0212	Flexible Coupling
Motors	
0300	No information
0301	Single Phase
0302	Multi Phase
0303	Air Drive
0304	Hydraulic Drive
0305	Variable Speed, A.C.
0306	Variable Speed, D.C.
0307	D.C. Exciter
0308	Gas Engine

Compressors

0400	No information
0401	Single Stage Centrifugal
0402	Multi Stage Centrifugal
0403	Rotary, Lobe
0404	Rotary Vane
0405	Rotary Water Seal Ring
0406	Multi Stage High Pressure

Diffusers, air/water

0500	No information
0501	Spargers, Large Bubble, Mechanical
0502	Small Bubble Ceramic
0503	Small Bubble Plastic
0504	Small Bubble Mechanical
0505	Static Tube
0506	Circular (for mechanical aerators)
0507	RBC Shaft
0508	Waste to media

Valves

0600	No information
0601	Gate
0602	Ball
0603	Butterfly
0604	Globe
0605	Needle
0606	Relief (safety)
0607	Check
0608	Sluice Gate
0609	Plug

Controls

0700	No information
0701	Electrical
0702	Mechanical
0703	Pressure (fluid)
0704	Pressure (air)
0705	Chlorinators

Pressure Vessels

0800	No information
0801	Chemical Containers
0802	Reactors

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

Conveyor (Unconfined materials handling)

0900	No information
0901	Belt
0902	Screw
0903	Pneumatic
0904	Bucket
0905	Chain (Bar Screen)
0906	Skimmer
0907	Sludge Collector (includes cross collector)

COLUMN 6 (2 Digits)	APPLICATIONS
Headworks	
00	No information
01	Flow Measurement
02	Raw Wastewater Pumping
03	Intermediate Wastewater Pumping
04	Screening/Communition
05	Grit Removal
Primary and Secondary Settling	
06	Clarifier Circular Center Drive
07	Clarifier Circular Peripheral Drive
08	Clarifier Square/Rectangular Center Drive
09	Clarifier Square/Rectangular Peripheral Drive
10	Scum and Grease Removal
Secondary Treatment	(Biological)
11	Return Activated Sludge Handling
12	Recirculation Pumping
13	Oxygen Generation/Storage
14	Dissolved Air Production
15	Dissolved Air/O Application
16	Trickling Filter Rotary Distributor
17	Dosing Siphon
18	Trickling Filter Fixed Distributor
19	Rotating Biological Contactor
20	Mechanical Aerators

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

Sludge Handling	
30	Primary Sludge Pumping
31	Secondary Sludge Pumping
32	Waste Activated Sludge Pumping
33	Other Sludge Pumping
34	Digester Gas Recirculation Pumping
Disinfection	
50	Chlorine, Gaseous
51	Chlorine, Hypo
52	Other, O_3, UV, Br_2
Mechanical Mixers	
61	High Speed Fixed
62	Low Speed Fixed
63	High Speed Floating
64	Low Speed Floating
65	Submerged Turbine
66	Fixed Rotor
COLUMN 7 (2 Digits)	SIZE (CAPACITY)
00	No information
01	0-10,000 gallons per minute
02	10,001-20,000 gallons per minute
03	20,001-100,000 gallons per minute
04	Over 100,000 gallons per minute
05	0-1 horsepower
06	2-5 horsepower
07	6-25 horsepower
08	26-100 horsepower
09	101-500 horsepower
10	Over 500 horsepower
11	0-10 cfm
12	11-20 cfm
13	20-25 cfm
14	26-100 cfm
15	101-1000 cfm
16	1001-10,000 cfm
17	10,001-20,000 cfm
18	Over 20,000 cfm
19	0-6"
20	7-12"
21	13-24"
22	25-48"
23	Over 48"
24	Under 2000 lbs chemical
25	Over 2000 lbs chemical

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 8 (3 Digits)	SUBCOMPONENT
000	No information
001	Pump Impeller
002	Impeller Wear Ring or Plate
003	Shaft Sleeve
004	Shaft, Drive
005	Shaft Key
006	Seal, Single Mechanical
007	Seal, Double Mechanical
008	Seal, Packed, No Lubricated
009	Seal, Packed, Water, Oil, Grease Lubricated
010	Seal, Other
011	Coupling
012	Drive Belt
013	Pulley, Belt Drive
014	Bearing Ball, Single Row
015	Experimental/Prototype Bearing
023	Bearing, Ball, Double Row
024	Bearing, Thrust
025	Bearing, Needle
026	Bearing, Cast, Pillow
027	Chain, Pintle
028	Gear for Chain Drive
029	Gear, Worm
030	Gear, Spur
031	Gear, Rack
032	Gear, Pinion
033	Gear, Internal
034	Gear, Miter
035	Gear, Bevel
036	Gear, Helical
037	Magnetic Starter
038	Relay
039	Overload Relay
040	Electrical Timer
041	Switch, Electric
042	Motor Armature
043	Motor Windings
044	Case, Motor
045	Case, Pump
046	Case, Gear
047	Case, Blower
048	Case, Electric or Control Device
049	Controller
050	Brushes
051	Cylinder, Piston Pump

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 8 (3 Digits)	SUBCOMPONENT (Con'td)
052	Collector Mechanism
053	Conveyor Belt
054	Skimmer
055	Solenoid Valve
056	Control Valve
057	Shear Pin
058	Rake Guides
059	Cables
060	Tie Rod
061	End Gate
062	Complete Bearing Replacement
063	Replace Piston
064	Plastic Chain and Flights
065	Pipe Broken
COLUMN 9 (2 Digits)	CRITICALITY
00	No information
01	Effluent impact within 4 hours
02	Effluent impact from 4 to 12 hours
03	Effluent impact from 12 to 24 hours
04	Effluent impact after more than 24 hours
COLUMN 10 (4 Digits)	DATE INSTALLED Month and Year (1072)
COLUMN 11 (2 Digits)	ACTUAL PERCENT OF TIME OPERATING Record actual percentage
COLUMN 12 (2 Digits)	FAILURES
00	No information
99	No failures
01	One fialure
02	Two failures
03	Three failures
04	
05	
COLUMN 13	FAILURE MODE
00	No information

COLUMN 14 (2 Digits)	CONTRIBUTORY CAUSE OF FAILURE
00	No information
01	Automatic Lubrication System Failure
02	Misalignment
03	Mechanical Seals
04	Packing Failure/Improper Installation
05	Overload Protection Failure
06	Control System
07	Corrective Maintenance Inadequate or Incomplete
08	Normal Wear
09	Climatic Conditions
10	Unsuitable for Environment
11	Improper Application
12	Preventative Maintenance Inadequate
13	Bad Part
14	Improper Protection from Environment
15	Swapout of Parts trying to cure a problem

UMN 15 (2 Digits)	CALENDAR DOWN TIME OF FUNCTION
00	No information
01	1 hour or less
02	1 to 6 hours
03	6 to 24 hours
04	24 to 168 hours
05	Over 168 to 720 hours
06	Over 720 to 4320 hours

COLUMN 16 (2 Digits)	MANHOURS TO REPAIR
00	No information
01	0 to 1 hour
02	Over 1 to 6 hours
03	Over 6 hours to 24 hours
04	Over 24 to 168 hours

[1]Where more than one failure is shown, times to repair are averaged

COLUMN 17 (2 Digits)	ENVIRONMENTAL FACTOR
00	No information
01	Outdoors, Ambient
02	Outdoors, Heaters
03	Basement, Humid
04	Basement, Dry
05	Subject to Corrosive Splash
06	Subject to Splash

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 17 (2 Digits)	ENVIRONMENTAL FACTOR (Cont'd)
07	Submerged in Water or Sewage
08	Corrosive Atmosphere
09	Submerged in Corrosive Fluid
10	Subject to Freezing
11	Subject to Excessive Heat
12	Indoor Controlled
COLUMN 18 (2 Digits)	PART DISPOSITION
00	No information
01	Repaired in Place
02	Replaced
03	Replaced and Discarded
04	Sent out for Repair
COLUMN 19 (3 Digits)	SUBCOMPONENT MANUFACTURER
000	No information
001	New Departure
002	Hyatt
003	Fafnir
004	Norma Hoffman
005	Falk
006	Fast
007	Thomas
008	John Crane
009	U. S. Varidrive
010	Reeves Varidrive
011	GE Teledyne
012	Dodge
013	Link Belt
014	Rex
015	Dorr Oliver
016	GE
017	Bristol
018	Roots
019	U.S. Electric
020	Marlow
021	Falk
022	Westinghouse
023	Electric Machinery
024	Climax
025	Ideal

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 20 (3 Digits)	COMPONENT MANUFACTURER
000	No information
001	Gorman Rupp
002	PACO
003	HydroMatic
004	Crown
005	Fairbanks Morse
006	Allis Chalmers
007	Worthington
008	GE
009	Roots
010	Door Oliver
011	Komlinc Sanderson
012	U.S. Electric
013	Marlow
014	Hoffman
015	Chicago Pump Co.
016	Marathon Elec.
017	Falk
018	Westinghouse
019	Envirex
020	Dodge
021	Reliance
022	WEMCO
023	FMC
024	Lightnin
025	Clark
026	DeLaval
027	Midland
028	Eimco Envirotech
029	Ralph B. Carter Co.
030	Louis Allis
031	Electric Machinery
032	Wallace and Tiernan Division
033	Autotrol
034	Climax
035	Ideal
036	Fischer and Porter

COLUMN 21 (2 Digits)	INVENTORY INFORMATION
00	No information
01	Stocked at Plant
02	Available Locally (1 to 6 hours)
03	Available within 24 hours
04	Over 24 hours

APPENDIX A
DATA NUMBERING SYSTEM (Cont'd)

COLUMN 22 (2 Digits)	TYPE OF MAINTENANCE
00	No information
01	Preventative Maintenance
02	Corrective Maintenance
COLUMN 23 (5 Digits)	ACTUAL DOWN TIME OF UNIT OP (Sludge Processing Only)
	Record actual time in hours
COLUMN 24 (4 Digits)	COLLECTION OR DECOMMISSIONING DATE
	First 2 digits are month Second 2 digits are year
COLUMN 25 (4 Digits)	ACTUAL ACTIVE CLOCK TIME TO REPAIR
	Record the sum of the clock time (in hours) when someone worked on unit.

APPENDIX B
RESULTS OF CRITICALITY ANALYSIS

Effects
- A—Significant Impact
- B—Minimal Impact
- C—No Impact

TABLE 1. CRITICALITY ANALYSIS

Type Plant—Air Activated Sludge 01
Unit Operation—Headworks 01

Time Factors
- 1—0—4 hrs
- 2—>4—12 hrs
- 3—>12—24 hrs
- 4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	02	A	1
	03	A	1
	05	C	
Power Transmission 02	02	A	1
	03	A	1
	05	C	
	04	C	
Motors 03	02	A	1
	03	A	1
	05	C	
	04	C	
Valves 06	01	C	
	02	B	4
	03	B	4
	05	C	
Controls 07	01	C	
	02	B	1
	03	B	1
	04	C	
	05	C	
Conveyors 09	05	C	

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 2. CRITICALITY ANALYSIS

Type Plant — Trickling Filter 03
Unit Operation — Headworks 01

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	02	A	1
	03	A	1
	05	C	
Motors 03	02	A	1
	04	C	
	05	C	
	03	A	1
Power Transmission 02	02	A	1
	04	C	
	05	C	
	03	A	1
Conveyor 09	04	C	
	05	C	
Controls 07	01	C	
	02	B	1
	03	B	1
	04	C	
	05	C	
Valves 06	02	B	1
	03	B	1
	05	C	
	01	C	

Effects
A— Significant Impact
B— Minimal Impact
C— No Impact

TABLE 3. CRITICALITY ANALYSIS

Type Plant—Rotating Biological Contractor 04
Unit Operation—Headworks 01

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	02	A	1
	03	A	1
	05	C	
Power Transmission 02	02	A	1
	03	A	1
	04	C	
	05	C	
Motors 03	02	A	1
	03	A	1
	04	C	
	05	C	
Conveyor 09	04	C	
	05	C	
Controls 07	01	C	
	02	B	1
	03	B	1
	04	C	
	05	C	
Valves 06	02	B	4
	03	B	4
	05	C	
	01	C	

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 4. CRITICALITY ANALYSIS

Type Plant—Air Activated Sludge 01
Unit Operation—Primary Settling 02

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	22	B	3
	10	C	
Motors 03	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Power Transmission 02	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Valves 06	10	C	
	22	B	4
Controls 07	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 5. CRITICALITY ANALYSIS

Type Plant—OAS 02
Unit Operation—Primary Settling 02

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Power Transmission 02	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Motors 03	06	B	3
	07	B	3
	08	B	3
	09	B	3
	10	C	
	22	B	3
Valves 06	10	C	
	22	B	4
Pumps 01	10	C	
	22	B	3
Controls 07	22	B	3
	10	C	
	06	B	3
	07	B	3
	08	B	3
	09	B	3

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 6. CRITICALITY ANALYSIS

Type Plant — Trickling Filter 03
Unit Operation — Primary Settling 02

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Pumps 01	10	C	
	22	A	3
Power Transmission 02	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Valves 06	10	C	
	22	B	4
Controls 07	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 7. CRITICALITY ANALYSIS

Type Plant — RBC 04
Unit Operation — Primary Settling 02

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	10	C	
	22	A	3
Motors 03	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Power Transmission 02	05	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3
Valves 06	10	C	
	22	B	4
Controls 07	06	A	3
	07	A	3
	08	A	3
	09	A	3
	10	C	
	22	A	3

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 8. CRITICALITY ANALYSIS

Type Plant — Air Act Sludge 01
Unit Operation — Secondary Treatment 03

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	11	A	1
Power Transmission 02	11	A	1
	14 (blower)	A	2
	20	A	2
Motors 03	11	A	1
	14 (blower)	A	2
	20	A	2
Compressors 04	14	A	2
	20	A	2
Diffusers 05	15	A (Subm Turbine)	2
Valves 06	11	B	4
	14	A	2
	15	A	2
Controls 07	11	A	1
	14	A	2
	15	A	2
	20	A	2

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 9. CRITICALITY ANALYSIS

Type Plant — O_2AS 02
Unit Operation — Secondary Treatment 03

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	13	A	2
	15	A	2
	12 Recir. O	A	2
	20	A	2
	11	A	1
Power Transmission 02	13	A	2
	15	A	2
	12	A	2
	20	A	2
	11	A	1
Pumps 01	11	A	1
	12	A	2
Diffusers 05	15	A (Subm Turbine)	2
Pressure Vessels 08	13	B	4
Controls 07	11	A	1
	12	B	4
	13	A	2
	15	A	2
	20	A	2
Valves 06	11	B	4
	13	A	2
	15	A	2

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 10. CRITICALITY ANALYSIS

Type Plant—Trickling Filter 03
Unit Operation—Secondary Treatment 03

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12—24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	A	1
Power Transmission 02	12	A	1
Motors 03	12	A	1
Valves 06	12	B	3
Controls 07	12	A	3
	17	B	1
Diffusers 05	16 (Actual Arm)	A	2
	17	A	2
	18	A	2

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 11. CRITICALITY ANALYSIS

Type Plant — RBC 04
Unit Operation — Secondary Treatment 03

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	A	1
Power Transmission 02	12	A	1
	19	A	2
	14	A	2
Motors 03	12	A	1
	19	A	2
	14	A	2
Compressors 04	14	A	2
Diffusers 05	19	C	
Valves 06	12	B	3
	14	B	4
Controls 07	12	B	4
	19	A	2
	14	B	4

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 12. CRITICALITY ANALYSIS

Type Plant — Air Act Sludge 01
Unit Operation — Final Settling 04

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 13. CRITICALITY ANALYSIS

Type Plant — O_2AS 02
Unit Operation — Final Settling 04

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 14. CRITICALITY ANALYSIS

Type Plant — Trickling Filter 03
Unit Operation — Final Settling 04

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

Effects
A – Significant Impact
B – Minimal Impact
C – No Impact

TABLE 15. CRITICALITY ANALYSIS

Type Plant – RBC 04
Unit Operation – Final Settling 04

Time Factors
1 – 0 – 4 hrs
2 – >4 – 12 hrs
3 – >12 – 24 hrs
4 – >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Motors 03	06	A	1
	07	A	1
	08	A	1
	09	A	1
Power Transmission 02	06	A	1
	07	A	1
	08	A	1
	09	A	1
Controls 07	06	B	1
	07	B	1
	08	B	1
	09	B	1

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 16. CRITICALITY ANALYSIS

Type Plant — Air Act Sludge 01
Unit Operation — Disinfection 06

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	1
Diffusers 05	50	C	
	51		
	52		
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	52	B	1
	51	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 17. CRITICALITY ANALYSIS

Type Plant — O_2AS 02
Unit Operation — Disinfection 06

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	1
Diffusers 05	50	C	
	51	C	
	52	C	
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	51	B	1
	52	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

Effects
A — Significant Impact
B — Minimal Impact
C — No Impact

TABLE 18. CRITICALITY ANALYSIS

Type Plant — Trickling Filter 03
Unit Operation — Disinfection 06

Time Factors
1 — 0 — 4 hrs
2 — >4 — 12 hrs
3 — >12 — 24 hrs
4 — >24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	1
Diffusers 05	50	C	
	51		
	52		
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	52	B	1
	51	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

Effects
A—Significant Impact
B—Minimal Impact
C—No Impact

TABLE 19. CRITICALITY ANALYSIS

Type Plant—RBC 04
Unit Operation—Disinfection 06

Time Factors
1—0—4 hrs
2—>4—12 hrs
3—>12- 24 hrs
4—>24 hrs

Broad Classification of Equipment	Applications	Relationship between Failure and Effluent Quality	Time Factor
Pumps 01	12	B	1
	50	B	1
	51	B	1
	52	B	1
Motors 03	12	B	1
	50	B	1
	51	B	1
	52	B	
Diffusers 05	50	C	
	51		
	52		
Valves 06	50	B	4
	51	B	4
	52	B	4
	12	B	4
Controls 07	50	B	4
	51	B	4
	52	B	4
	12	B	4
Power Transmission 02	50	B	1
	51	B	1
	52	B	1
	12	B	1
Pressure Vessels 08	50	B	1
	52	B	1

APPENDIX C
MECHANICAL EQUIPMENT PRIORITY RANKING
TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
01	01	01	02	A1
01	01	01	03	A1
01	01	02	02	A1
01	01	02	03	A1
01	01	03	02	A1
01	01	03	03	A1
02	01	01	02	A1
02	01	01	03	A1
02	01	03	02	A1
02	01	03	03	A1
02	01	02	02	A1
02	01	02	03	A1
03	01	01	02	A1
03	01	01	03	A1
03	01	03	02	A1
03	01	03	03	A1
03	01	02	02	A1
03	01	02	03	A1
04	01	01	02	A1
04	01	01	03	A1
04	01	02	02	A1
04	01	02	03	A1
04	01	03	02	A1
04	01	03	03	A1
01	03	01	11	A1
01	03	02	11	A1
01	03	03	11	A1
02	03	03	11	A1
02	03	02	11	A1
02	03	01	11	A1
03	03	01	12	A1
03	03	02	12	A1
03	03	03	12	A1
04	03	01	12	A1
04	03	02	12	A1
04	03	03	12	A1
01	04	02	06	A1
01	04	02	07	A1
01	04	02	08	A1
01	04	02	09	A1
01	04	03	06	A1
01	04	03	07	A1
01	04	03	08	A1
01	04	03	09	A1
02	04	02	06	A1
02	04	02	07	A1

TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING (Cont'd)

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
02	04	02	08	A1
02	04	02	09	A1
02	04	03	06	A1
02	04	03	07	A1
02	04	03	08	A1
02	04	03	09	A1
03	04	02	06	A1
03	04	02	07	A1
03	04	02	08	A1
03	04	02	09	A1
03	04	03	06	A1
03	04	03	07	A1
03	04	03	08	A1
03	04	03	09	A1
04	04	02	06	A1
04	04	02	07	A1
04	04	02	08	A1
04	04	02	09	A1
04	04	03	06	A1
04	04	03	07	A1
04	04	03	08	A1
04	04	03	09	A1
01	03	02	14	A2
01	03	02	20	A2
01	03	03	14	A2
01	03	03	20	A2
01	03	04	11	A2
01	03	04	20	A2
01	03	05	15	A2
01	03	06	14	A2
01	03	06	15	A2
01	03	07	14	A2
01	03	07	15	A2
01	03	07	20	A2
02	03	03	13	A2
			15	A2
			12	A2
			20	A2
02	03	02	13	A2
		02	15	A2
		02	12	A2
		02	20	A2
		01	12	A2
		05	15	A2
		07	13	A2
		07	15	A2

TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING (Cont'd)

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
02	03	07	20	A2
		06	13	A2
		06	15	A2
03	03	05	16	A2
		05	17	A2
		05	18	A2
04	03	02	19	A2
		02	14	A2
		03	19	A2
		03	14	A2
		04	14	A2
		07	19	A2
03	02	03	06	A3
		03	07	A3
		03	08	A3
		03	09	A3
		02	06	A3
		02	07	A3
		02	08	A3
		02	09	A3
		07	06	A3
		07	07	A3
		07	08	A3
		07	09	A3
		03	06	A3
		03	07	A3
		03	08	A3
		03	09	A3
		02	06	A3
		02	07	A3
		02	08	A3
		07	08	A3
		07	09	A3
03	03	07	12	A3
01	01	07	02	B1
			03	B1
02	01	07	03	B1
			03	B1
03	01	07	02	B1
			03	B1
03	01	06	02	B1
			03	B1
04	01	07	02	B1
			03	B1
03	03	07	17	B1
01	04	07	06	B1

TABLE 1. MECHANICAL EQUIPMENT PRIORITY RANKING (Cont'd)

Plant Type	Unit Operation	Broad Classification of Equipment	Application	Time and Effect Relationship
01	04		07	B1
			08	B1
			09	B1
02	04	07	06	B1
			07	B1
			08	B1
			09	B1
03	04	07	06	B1
			08	B1
			09	B1
04	04	07	06	B1
			07	B1
			08	B1
			09	B1
01-02	05	01	12	B1
03-04			50	B1
			51	B1
			52	B1
		03	12	B1
			50	B1
			51	B1
			52	B1
		02	12	B1
			50	B1
			51	B1
			52	B1
01-02	05	08	50	B1
03-04			52	B1
01-02	02	01	22	B3
01-02	02	03	06	B3
			07	B3
			08	B3
			09	B3
			22	B3
01-02	02	02	06	B3
			07	B3
			08	B3
			09	B3
			22	B3
01-02	02	07	06	B3
			07	B3
			08	B3
			09	B3
			22	B3
04	03	06	12	B3

APPENDIX D
SUMMARY OF PERFORMANCE STATISTICS CALCULATED ON CRITICAL COMPONENTS

1.0 Reliability, Maintainability and Availability Statistics for Components

1.1 By Component

1.1.1 Reliability (Table 1.1.1)
1.1.2 Maintainability and Availability (Table 1.1.2)

1.2 By Component by Generic Group

1.2.1 Reliability (Table 1.2.1)
1.2.2 Maintainability and Availability (Table 1.2.2)

1.3 By Component by Application

1.3.1 Reliability (Table 1.3.1)
1.3.2 Maintainability and Availability (Table 1.3.2)

1.4 By Component by Size/Capacity

1.4.1 Reliability (Table 1.4.1)
1.4.2 Maintainability and Availability (Table 1.4.2)

1.5 By Component by Generic Group by Application

1.5.1 Pumps (Tables 1.5.1.1 and 1.5.1.2)
1.5.2 Power Transmissions (Tables 1.5.2.1 through 1.5.2.9)
1.5.3 Motors (Tables 1.5.3.1 through 1.5.3.4)
1.5.4 Compressors (Tables 1.5.4.1 through 1.5.4.3)
1.5.5 Diffusers, Air/Water (Tables 1.5.5.1 and 1.5.5.2)
1.5.6 Valves (Tables 1.5.6.1 through 1.5.6.4)
1.5.7 Controls (Tables 1.5.7.1 through 1.5.7.5)
1.5.8 Conveyors (Tables 1.5.8.1 and 1.5.8.2)

1.6 By Component by Generic Group by Size/Capacity

1.6.1 Pumps (Tables 1.6.1.1 and 1.6.1.2)
1.6.2 Power Transmissions (Tables 1.6.2.1 through 1.6.2.9)
1.6.3 Motors (Tables 1.6.3.1 through 1.6.3.4)
1.6.4 Compressors (Tables 1.6.4.1 through 1.6.4.3)
1.6.5 Diffusers, Air/Water (Tables 1.6.5.1 and 1.6.5.2)
1.6.6 Valves (Tables 1.6.6.1 through 1.6.6.4)
1.6.7 Controls (Tables 1.6.7.1 through 1.6.7.5)
1.6.8 Conveyors (Tables 1.6.8.1 and 1.6.8.2)

2.0 Component Failure Statistics by Subcomponent Type

2.1 By Component (Tables 2.1.1 through 2.1.8)
2.2 By Component by Generic Group

2.2.1 Pumps (Tables 2.2.1.1 and 2.2.1.2)
2.2.2 Power Transmissions (Tables 2.2.2.1 through 2.2.2.3)

2.2.3 Motors (Tables 2.2.3.1 through 2.2.3.4)
2.2.4 Compressors (Tables 2.2.4.1 and 2.2.4.2)
2.2.5 Diffusers, Air/Water (Table 2.2.5.1)
2.2.6 Valves (Table 2.2.6.1)
2.2.7 Controls (Tables 2.2.7.1 through 2.2.7.4)
2.2.8 Conveyors (Table 2.2.8.1)

2.3 By Component by Application

2.3.1 Pumps (Tables 2.3.1.1 through 2.3.1.4)
2.3.2 Power Transmissions (Tables 2.3.2.1 through 2.3.2.3)
2.3.3 Motors (Tables 2.3.3.1 through 2.3.3.6)
2.3.4 Compressors (Tables 2.3.4.1 and 2.3.4.2)
2.3.5 Diffusers, Air/Water (Table 2.3.5.1)
2.3.6 Valves (Tables 2.3.6.1 and 2.3.6.2)
2.3.7 Controls (Tables 2.3.7.1 through 2.3.7.8)
2.3.8 Conveyors (Table 2.3.8.1)

2.4 By Component by Size

2.4.1 Pumps (Tables 2.4.1.1 through 2.4.1.4)
2.4.2 Power Transmissions (Tables 2.4.2.1 through 2.4.2.5)
2.4.3 Motors (Tables 2.4.3.1 through 2.4.3.4)
2.4.4 Compressors (Tables 2.4.4.1 through 2.4.4.3)
2.4.5 Diffusers, Air/Water (Table 2.4.5.1)
2.4.6 Valves (Tables 2.4.6.1 and 2.4.6.2)
2.4.7 Controls (Tables 2.4.7.1 through 2.4.7.5)
2.4.8 Conveyors (Table 2.4.8.1)

3.0 Reliability and Availability Statistics for Sludge Processes

3.1 By Sludge Process (Table 3.1.1)

APPENDIX D
PART 1.0
RELIABILITY MAINTAINABILITY AND AVAILABILITY
STATISTICS FOR COMPONENTS

TABLE 1.1.1. MEAN TIME BETWEEN FAILURE (MTBF) FOR COMPONENTS

Component	Overall MTBF ($\times 10^6$ Hrs)	Min MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)
Pumps	.032066	.021662	.074191	.028630
Power transmissions	.03562	.01785	.71091	.03317
Motors	.06670	.01088	.11482	.06122
Compressors	.00714	.00562	.08392	.00631
Diffusers, air/water	.01813	.01263	1.834	.01067
Valves	.01444	.00893	.03259	.01040
Controls	.08358	.00393	.10064	.07569
Conveyor (unconfined materials handling)	.14848	.06175	.35856	.11690

TABLE 1.1.2. MAINTENANCE STATISTICS FOR COMPONENTS

Components	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR (Hrs)	AVI	AVO
Pumps	.00227	.05177	9.541	.99968	.99116
Power transmissions	.00032	.00469	2.273	.99994	.99898
Motors	.00098	.00660	6.854	.99939	.99816
Compressors	.03399	.17843	0.960	.99987	.99306
Diffusers, air/water	.00065	.04664	8.305	.99951	.99875
Valves	.00084	.73845	11.615	.99879	.96446
Controls	.00025	.00261	3.696	.99996	.99870
Conveyer (unconfined materials handling)	.00055	.10086	4.768	.99996	.99930

TABLE 1.2.1. MEAN TIME BETWEEN FAILURES (MTBF) FOR COMPONENTS BY GENERIC GROUP

Component	Generic Group	Overall MTBF ($\times 10^6$ Hrs)	Min MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)
Pumps	Open impeller, centrifugal	.02166	.01530	.03569	.019105
	Propeller, axial flow	.074191	.02415	.7528	.05762
Power transmission	Concentric reducer	.12264	.02814	.3764	.06190
	Parallel shaft	.71091	.01996	1.867	.35881
	Right angle shaft	.01948	.00993	2.512	.01772
	Vertical shaft	.03147	.01925	.06091	.02611
	Variable speed drive, hydraulic	.3495			.1020
	Variable speed drive, others	.01842	.00784	.02689	.01075
	Gear box	.04578	.00982	.6313	.03932
	Chain drive	.01785			.01091
	Belt drive	.09101			.05564
Motors	Multiphase	.0680	.02102	4.[illegible]939	.0620
	Variable speed, AC	.11482	.01081	.4033	.05795
	Gas engine	.02380			.01023
Compressors	Single stage, centrifugal	.02242	.01934	.02173	.01359
	Multi stage, centrifugal	.00562	.00544	.02689	.00495
	Multi stage, high pressure	.08392	.02933	.05459	.02449
Diffusers, air/water	RBC Shaft	1.834			.5352
	Waste to media	.01263			.01160
Valves	Gate	.00893	.00702	.01353	.00627
	Ball	.01146			.00493
	Butterfly	.03259			.01408
	Plug	.02852			.00832
Controls	Electrical	.10064	.01859	4.6849	.03994
	Mechanical	.03123	.01705	.03334	.01282
	Pressure (fluid)	.03578	.03140	.06485	.02676
	Pressure—air	.01869			.01272
	Chlorinators	.00393			.00262
Conveyor (unconfined materials handling)	Chain (bar screen)	.06175			.04688
	Sludge collector	.35856	.2202	1.570	.23345

TABLE 1.2.2. MAINTENANCE STATISTICS FOR COMPONENTS BY GENERIC GROUP

Component	Generic group	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR (Hrs)	AVI	AVO
Pumps	Open impeller centrifugal	.00343	.09477	7.825	.99962	.98955
	Propeller, axial flow	.00627	.11411	16.780	.99975	.98311
Power transmission	Concentric reducer	.01187	.00890	2.000	.99998	.99998
	Parallel shaft	.00224	.01208	32.000	.99995	.99990
	Right angle shaft	.00103	.01244	1.400	.99995	.99989
	Vertical shaft	.00122	.03331	2.023	.99994	.99688
	Variable speed drive, hydraulic	.01865	0.0		1.0	1.0
	Variable speed drive, others	.39460	.61080	2.500	.99976	.99952
	Gear box	.00045	.05956	3.523	.99993	.99952
	Chain drive	0.0	1.3640	8.000	.9996	.9945
	Belt drive	0.0	.03488	1.800	1.0	.9916
Motors	Multiphase	.00068	.00693	6.853	.99989	.99837
	Variable speed, AC	.01258	.05034	8.000	.99996	.99986
	DC exciter	1.62195	1.59810	3.667	.9967	.99035
	Gas engine	10.57	10.57	24.000	.9990	.9342
Compressors	Single stage, centrifugal	.16854	.31990	3.800	.99981	.99541
	Multi stage, centrifugal	.06513	.44723	0.813	.99987	.99179
	Multi stage, high pressure	.07767	0.0		1.0	1.0
Diffusers, air/water	RBC Shaft	.00356	0.0		1.0	1.0
	Waste to media	.00008	.1591	8.305	.9993	.9982
Valves	Gate	0.0	1.40743	3.636	.99947	.95693
	Ball	0.0	43.89	110.000	.905	.8685
	Butterfly	.05999	.12005	1.000	.99997	.99993
	Plug	.2286	0.0		1.0	1.0
Controls	Electrical	.00028	.00211	2.893	.99998	.99922
	Mechanical	.04385	.96717	8.000	.99956	.99839
	Pressure (fluid)	.00405	.12830	8.236	.99975	.98822
	Pressure—air	.00970	.1309	3.556	.9998	.9998
	Chlorinators	0.0	17.82	5.375	.9986	.9982
Conveyor (unconfined materials handling)	Chain (bar screen)	0.0	.1371	0.947	1.0	.9999
	Sludge collector	.00098	.16507	15.14	.99994	.399751

TABLE 1.3.1. MEAN TIME BETWEEN FAILURES (MTBF) FOR COMPONENTS BY APPLICATION

Component	Application	Overall MTBF ($\times 10^6$ Hrs)	Min MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)
Pumps	Raw Wastewater Pumping	.01530			.01303
	Intermediate Wastewater Pumping	.08588	.01727	.09255	.06318
	Return Activated Sludge Handling	.05336	.7528	.03569	.04235
	Recirculation Pumping	.02415			.01759
Power Transmission	Raw Wastewater Pumping	.01884	.00784	.05919	.01303
	Intermediate Wastewater Pumping	.18861	.02689	.1678	.05679
	Clarifier, Circular Center Drive	.01605	.00993	.09101	.01303
	Clarifier, Square/Rectangular Peripheral	.08044	.00982	2.512	.06760
	Return Activated Sludge Handling	.7037	.3495	.3764	.2118
	Oxygen Generation/Storage	.09389			.02740
	Dissolved Air Production	.1763			.08847
	Rotating Biological Contactors	1.867			.5449
	Mechanical Aerators	.06136	.04735	.06091	.04365
Motors	Raw Wastewater Pumping	.02192	.01163	.02380	.01754
	Intermediate Wastewater Pumping	.06523	.006764	.3931	.04380
	Screening/Communition	1.8100			.5283
	Clarifier, Circular Center Drive	.1236			.09442
	Clarifier, Square/Rectangular Peripheral	4.4935	.5650	2.512	1.356
	Return Activated Sludge Handling	.02642	.01081	.4033	.02214
	Recirculation Pumping	.0531			.03362
	Oxygen Generation/Storage	.08392			.02449
	Dissolved Air Production	.02319	.01858	.02282	.01792
	Dissolved Air/O_2 Application	.01353			.006789
	Rotating Biological Contactor	.02215			.01876
	Mechanical Aerators	.6711			.1959
	Secondary Sludge Pumping	.1513	.0216	.3226	.0650
Compressors	Dissolved Air Production	.00575	.00544	02173	.005069
	Dissolved Air/O_2 Production	.02321	.01934	.02689	.01172
	Oxygen Generation/Storage	.08392			.02449
Diffusers, Air/Water	Rotating Biological Contactor	1.834			.5352
	Trickling Filter Rotary Distributor	.01263			.01160
Valves	Raw Wastewater Pumping	.00997	.00702	.02852	.00694
	Intermediate Wastewater Pumping	.01353			.00679
	Oxygen Generation/Storage	.05459			.01593
	Dissolved Air/O_2 Production	.01081			.00465
Controls	Raw Wastewater Pumping	.03898	.03334	.03742	.02834
	Intermediate Wastewater Pumping	.14729	.01705	.1907	.09589
	Screening/Communition	1.810			.5288
	Clarifier, Circular Center Drive	.1144	.01081	.1191	.08795
	Clarifier, Square/Rectangular Peripheral	4.609	.5270	2.512	1.345
	Return Activated Sludge Handling	.01859	.00043	.01895	.01578
	Recirculation Pumping	.04618			.03008
	Oxygen Generation/Storage	.08392			.02449
	Dissolved Air Production	.04871			.03315
	Rotating Biological Contactor	1.867			.5449
	Mechanical Aerators	.05620	.01081	.06116	.03746
	Secondary Sludge Pumping	.09866	.06485	.09497	.05404
	Chlorine, Gaseous	.02193	.01869	.03140	.01772
Conveyor (Unconfined Materials Handling)	Screening/Communition	.06175			.04628
	Clarifier, Square/Rectangular Peripheral	.35856	.2202	1.570	.23345

TABLE 1.3.2. MAINTENANCE STATISTICS FOR COMPONENTS BY APPLICATION

Component	Application	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR Hrs	AVI	AVO
Pumps	Raw Wastewater Pumping	00944	.3178	8.483	.9994	.9845
	Intermediate Wastewater Pumping	.03301	.47335	13 334	99977	99087
	Return Activated Sludge Handling	.00232	03377	6.786	.99987	99987
	Recirculation Pumping	.00353	.5945	14.710	.9994	.9719
Power Transmission	Raw Wastewater Pumping	.01092	.00198	2.800	.99985	99977
	Intermediate Wastewater Pumping	.17227	0.0		1.0	99989
	Clarifier, Circular Center Drive	.00072	.01971	1.775	.99991	.99759
	Clarifier, Square/Rectangular Peripheral	.00058	.03355	2.787	.99998	.99956
	Return Activated Sludge Handling	.00898	0.0		1.0	1.0
	Oxygen Generation/Storage	.06942	0.0		1.0	1 0
	Dissolved Air Production	.00620	.5953	32.000	.9998	.9996
	Rotating Biological Contactors	.00349	0.0		1.0	1 0
	Mechanical Aerators	.00228	.04797	4.833	.9999	.9999
Motors	Raw Wastewater Pumping	.07434	.30876	8 871	.99957	.99061
	Intermediate Wastewater Pumping	.00302	.03782	4.400	.99999	99980
	Screening/Communition	00360	0.0		1.0	1.0
	Clarifier, Circular Center Drive	.00957	.01893	2.600	1.0	.9983
	Clarifier, Square/Rectangular Peripheral	.00140	0.0		1.0	.9999
	Return Activated Sludge Handling	.00202	07879	5.368	.99977	99943
	Recirculation Pumping	.00795	.2385	12 500	.9998	9842
	Oxygen Generation/Storage	.07767	0.0		1.0	1.0
	Dissolved Air Production	.0485	5214	8 455	.9996	9912
	Dissolved Air/O_2 Production	.06061	.2424	1.000	.9999	.9999
	Rotating Biological Contactor	0 0	.1047	7.857	.9996	9993
	Mechanical Aerator	.00971	0.0		1.0	1.0
	Secondary Sludge Pumping	.01608	.00742	2.000	1.0	1.0
Compressors	Dissolved Air Production	.07405	.38760	0.887	.99985	.99108
	Dissolved Air/O_2 Production	.02020	.29631	2.750	.99992	.99967
	Oxygen Generation/Storage	.07767	0.0		1.0	1.0
Diffusers, Air/Water	Rotating Biological Contactor	.00356	0.0		1.0	1.0
	Trickling Filter Rotary Distributor	.00008	.1591	8 305	.9993	.9982
Valves	Raw Wastewater Pumping	.00539	2.15610	13.400	.99800	93513
	Intermediate Wastewater Pumping	0.0	3 6365	4.500	.9993	.99695
	Oxygen Generation/Storage	.1194	0.0		1.0	1.0
	Dissolved Air/O_2 Production	0.0	1.455	1.000	.9999	9998
Controls	Raw Wastewater Pumping	00453	.14466	4 543	.99986	.99953
	Intermediate Wastewater Pumping	00907	.08034	6.571	.99996	99744
	Screening/Communition	.00360	0.0		1.0	1.0
	Clarifier, Circular Center Drive	.00130	.00580	2.000	.99999	99999
	Clarifier, Square/Rectangular Peripheral	.00147	0.0		1.0	.99999
	Return Activated Sludge Handling	.00074	.05812	2.607	99989	99961
	Recirculation Pumping	00795	.07951	5.571	.9999	.9845
	Oxygen Generation/Storage	07767	0.0		1.0	1.0
	Dissolved Air Production	.00155	.1457	1.333	1.0	.9999
	Rotating Biological Contractor	.00349	0.0		1.0	1.0
	Mechanical Aerators	.00069	.03977	1.750	.99998	.99998
	Secondary Sludge Pumping	.01152	.01037	2.667	1.0	.99871
	Chlorine, Gaseous	.00125	.21428	6.425	.99967	98980
Conveyor (Unconfined Materials Handling)	Screening/Communition	0.0	.1371	0.947	1.0	.9999
	Clarifier, Square/Rectangular Peripheral	.00098	.16507	15.14	.99994	.99975

TABLE 1.4.1. MEAN TIME BETWEEN FAILURES (MTBF) FOR COMPONENTS BY SIZE

Component	Application	Overall MTBF ($\times 10^6$ Hrs)	Min MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)
Pumps	1-1,000 Gallons Per Minute	.0358	.03569	.1678	.03146
	10,001-20,000	.081130	.01378	.5377	.02442
	20,001-100,000	.081635	.02602	.1638	.061515
	Over 100,000	.008366	.005068	.2151	.007010
Power Transmission	0-1 Horsepower	.02537	.00993	2.5120	.02341
	1-5	.01101	.00982	.01785	.00912
	6-25	1.3764	.6316	1.867	.59387
	26-100	.05862	.03476	06091	.04176
	101-500	.07838	.00784	.3764	.05420
	Over 500	.20645	.02689	.1763	.10373
Motors	0-1 Horsepower	.2147	.1236	2.512	.1349
	1-5	.5648			.1648
	6-25	.0621	.0222	1.810	.0527
	26-100	.0460	.0210	1.334	.0347
	101-500	.06463	.02380	.4033	.04903
	Over 500	.02058	.01088	.0231	.01685
Compressors	101-1,000 Cubic Feet Per Minute	.05459			.01593
	1,001-10,000	.02744	.01954	.02933	.01602
	10,001-20,000	.01487			.00817
	Over 20,000	.00535	.02173	.00530	.00471
Diffusers, Air/Water	6-25 Horsepower	1.834			.5352
	10,001-20,000 Gallons Per Minute	.01487			.01160
Valves	0-6 Inches	.05459			.01593
	13-24	.01081			.00465
	25-48	.01907	.00812	.02852	.01044
	Over 48	.00750	.00627	.01081	.00510
	Over 48 Inches	.06175			.04688
Controls	0-1 Horsepower	2.0092	.1191	2.512	.15696
	1-5	.50950			.15362
	6-25	4.6849	1.570	1.867	1.41258
	26-100	.026100	.01895	.06116	.02252
	101-500	.09939	.01081	.6144	.07587
	Over 500	.03770	.00434	.08392	.02796
	Over 2000 lbs. Chemical	.02193	.03408	.5232	.01772
Conveyor (Unconfined Materials Handling)	0-1 Horsepower	.2202			.1434
	6-25 Horsepower	1.570			.4583

TABLE 1.4.2. MAINTENANCE STATISTICS FOR COMPONENTS BY SIZE

Component	Application	PM-Hrs/ Unit/Yr	CM-Hrs/ Unit/Yr	MTTR Hrs	AVI	AVO
Pumps	1-1,000 Gallons Per Minute	.00199	.07576	6.786	.99982	99981
	10,001-20,000	.00349	.17403	7.800	.99974	.99831
	20,001-100,000	.00133	17748	26.722	.99964	99925
	Over 100,000	.07379	.83854	9.368	.99931	.96080
Power Transmission	0-1 Horsepower	.00042	.01266	1.815	.99994	.99847
	2-5	.00288	.29455	2.116	.99984	.99789
	6-25	.00187	.00597	25.000	1.0000	.99982
	26-100	.00180	.05849	5.000	.99995	.99989
	101-500	.00490	.00700	2.600	.99996	.99995
	Over 500	.02579	.25385	32.000	.99981	.99959
Motors	0-1 Horsepower	.00522	.01009	2.600	1.0000	.99890
	2-5	.01152	0.0		1.0000	1.0000
	6-25	.00016	.03261	7.857	.99985	.99975
	26-100	.00108	.03098	4 9665	.99987	.99962
	101-500	.01221	.06992	12.685	.99980	.99289
	Over 500	.04174	.20070	7.658	.99959	.98971
Compressors	101-1,000 Cubic Feet Per Minute	.1194	0.0		1.0000	1.0000
	1,001-10,000	.02136	.18805	2.750	.99993	.99972
	10,001-20,000	.03211	1.4450	6.000	.99960	.99930
	Over 20,000	.12567	.58143	0.723	.98388	.99020
Diffusers, Air/Water	6-25 Horsepower	.00356	0.0		1.0000	1.0000
	10,001-20,000 Gallons Per Minute	.00008	.15910	8.305	.9993	.9982
Valves	0-6 Inches	.1194	0 0		1.0	1.0
	12-24	0.0	1.455	1 000	.9999	.9998
	25-48	.01565	3 9437	42.000	.99702	.96357
	Over 48	0.0	2.15075	2.667	.99960	.93850
Controls	0-1 Horsepower	.00083	.00296	2.050	1.0	.99992
	2-5	.01325		0	1.0	1.0
	6-25	.00124	0.0		1.0	1.0
	26-100	.00034	.02615	2.377	.99993	.99988
	101-500	.00258	.01876	5.450	.99995	.99692
	Over 500 Horsepower	.00310	.11783	3.125	.99990	.99551
	Over 2000 lbs. Chemical	.00125	.21428	6.425	.99967	.98980
Conveyor (Unconfined Materials Handling)	Over 48 Inches	0.0	.1371	0.947	1.0	.9999
	0-1 Horsepower	.00097	.4359	15.14	.9999	.9996
	6-25 Horsepower	.00415	0.0		1.0	1.0

TABLE 1.5.1.1. RELIABILITY AND MAINTENANCE DATA FOR PUMPS – OPEN IMPELLER CENTRIFUGAL BY APPLICATION

Application	No of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	34	60	9277	.01530	–	–	.01303	.009442	.3179	8 483	.994	.9845
Intermediate Wastewater Pumping	9	9	.1669	01727	–	–	.01175	.1079	.7871	6.667	.9996	.9548
Return Activated Sludge Handling	27	28	1.023	.03569	–	–	.02835	.001745	.1028	6.786	.9998	9998
TOTAL	70	97	2 1176	.02166	.01530	.03569	.01911	.003428	.094773	7 825	.99962	99955

TABLE 1.5.1.2. RELIABILITY AND MAINTENANCE DATA FOR PUMPS – PROPELLER, AXIAL FLOW BY APPLICATION

Application	No of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Intermediate Wastewater Pumping	7	9	.8947	.09255	–	–	.06298	06364	1.095	20.00	.9998	.9976
Return Activated Sludge Handling	28	0	.5059	.7528	–	–	.2197	.008658	0 0	–	1.0	1.0
Recirculation Pumping	14	14	.3541	02415	–	–	.01759	.003534	.5955	14.71	.9994	9719
TOTAL	49	23	1.7547	.07419	02415	.7528	.05763	.006265	.1140107	16.783	99975	.99311

TABLE 1.5.2.1. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION – CONCENTRIC REDUCER BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Circular Center Drive	4	2	.07516	.02814	–	–	01412	.02914	.1748	2.0	.9999	.9999
Reutrn Activated Sludge Handling	14	0	.2529	.3764	–	–	.1099	01732	0 0	--	1.0	1 0
TOTAL	18	2	.32806	.12264	.02814	.3764	.061898	.01187	00290	2.0	.99998	99998

TABLE 1.5.2.2. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION – PARALLEL SHAFT BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Intermediate Wastewater Pumping	6	0	.1127	.1678	–	–	.04836	.03885	0.0	–	1.0	1.0
Oxygen Generation/ Storage	5	0	.06309	.09389	–	–	.02740	.06942	0.0	–	1.0	1.0
Dissolved Air Production	6	2	.4709	.1763	–	–	.08847	.006201	.5953	32 0	.9998	.9996
Rotating Biological Contactor	56	0	1.255	1.867	–	–	.5449	.003491	0 0	–	1 0	1 0
TOTAL	73	2	1.90169	.71091	.09389	1.867	35881	002241	.012075	32 0	.99995	.99990

TABLE 1.5.2.3. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION — RIGHT ANGLE SHAFT BY APPLICATION

Application	No of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	2	0	.03978	.05919	–	–	.01728	.1101	0.0	–	1.0	1.0
Clarifier Circular Center Drive	41	180	1.793	.009929	–	–	.009035	.001907	.03039	1.4	.9999	9998
Clarifier Square/ Rectangular Peripheral	8	0	1.688	2.512	–	–	.7332	.002594	0 0	–	1.0	1.0
TOTAL	51	180	3.52078	.019479	.009929	2.512	.017747	.001025	.01244	1.4	.99995	.99989

TABLE 1.5.2.4. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION — VERTICAL SHAFT BY APPLICATION

Application	No. of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Circular Center Drive	9	32	.6287	.01925	–	–	01551	.002322	.1455	.9688	1.0	.9931
Mechanical Aerators	42	12	.7762	.06128	.04735	.06091	.04365	.002284	.04797	4.833	.9999	.9999
TOTAL	51	44	1.4049	.031465	.01925	.06128	.026113	.001223	03331	2 023	99994	99686

TABLE 1.5.2.5. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION — VARIABLE SPEED DRIVE, HYDRAULIC BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Return Activated Sludge Handling	13	0	2349	3495	–	–	.1020	01865	0 0	–	1.0	1 0

TABLE 1.5.2.6. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION – VARIABLE SPEED DRIVE – OTHER BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	3	8	.06796	.007841	–	–	.005230	.02148	1.031	2.5	.9997	.9996
Intermediate Wastewater Pumping	1	0	.01807	.02689	–	–	.007847	–	7.273	0.0	1.0	.9992
TOTAL	4	8	.08603	.018422	.007841	.02689	.010754	.3946	.6108	2.5	.99976	.99952

TABLE 1.5.2.7. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION – GEAR BOX BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	2	.09286	.03476	–	–	.01745	.5660	4.0	.9999	.9998	0.0
Clarifier Circular Center Drive	8	21	8.499	.03924	–	–	.03016	.2512	8.19	.9998	.9997	.000921
Clarifier Square/ Rectangular Peripheral	23	42	2.0675	.04848	.000816	.6313	.04008	.0833	2.1666	.999382	.99944	.0004547
TOTAL	32	65	3.1026	.045783	.03476	.04848	.039323	.059560	3.523	.99993	.99952	–

TABLE 1.5.2.8. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—CHAIN DRIVE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Square/ Rectangular Peripheral	4	5	.1012	.01785	–	–	.01091	0.0	1.364	8.0	.9998	.9945

TABLE 1.5.2.9. RELIABILITY AND MAINTENANCE DATA FOR POWER TRANSMISSION—BELT DRIVE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Circular Center Drive	3	5	.5160	.09101	–	–	.05564	0 0	.08488	1.8	1.0	9916

TABLE 1.5.3.1. RELIABILITY AND MAINTENANCE DATA FOR MOTORS

Mean Time Between Failures (MTBF) By Application
Broad Classification — Motors
Generic Group — Multiphase

Application	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)
Raw Wastewater Pumping	25	26	.5997	.02249	.00983	.02795	.01772
Intermediate Wastewater Pumping	14	2	1.050	.3931	.0422	1.334	.1973
Screening/Communition	3	0	1.216	1.810	—	—	.5283
Clarifier, Circular Center Drive	62	20	2.553	.1236	—	—	.09442
Clarifier, Square/ Rectangular Peripheral	23	0	3.1224	4.4935	.5650	2.512	1.356
Return Activated Sludge Handling	27	48	1.0227	.02102	—	—	.01759
Recirculation Pumping	14	6	.3541	.0531	—	—	.03362
Oxygen Generation/ Storage	5	0	.00563	.08392	—	—	.02449
Dissolved Air Production	11	22	.5255	.02319	.01858	.02282	.01752
Dissolved Air/O_2 Application	2	2	.0361	.01353	—	—	.006789
Rotating Biological Contactor	56	56	1.255	.02215	—	—	.01876
Mechanical Aerators	24	0	.4510	.6711	—	—	.1959
Secondary Sludge Pumping	14	1	.2529	.1513	.0216	.3226	.0650
TOTAL	285	183	12.4947	.0680	.02102	4.4935	.0620

TABLE 1.5.3.2. RELIABILITY AND MAINTENANCE DATA FOR MOTORS

Maintenance Statistics By Application
Broad Classification — Motors
Generic Group — Multi Phase

Application	No. of Units	Operating Hrs ($\times 10^6$ Hrs)	No. of Failures	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	25	.59965	26	.01139	.3653	8.885	.9996	.9936
Intermediate Wastewater Pumping	14	1.04999	2	.003575	.01788	6.000	1.0000	.9999
Screening/Comminition	3	1.216	0	.003601	—	—	1.0000	1.0000
Clarifier Circular Center Drive	62	2.553	20	.009573	.01893	2.600	1.000	.9983
Clarifier Square/ Rectangular Peripheral	28	3.1224	0	.001403	—	—	1.0000	.9999
Return Activated Sludge Handling	27	1.022679	48	.001745	.1562	5.313	.9997	.9993
Recirculation Pumping	14	.3541	6	.007951	.2385	12.50	.9998	.9842
Oxygen Generation/ Storage	5	.05639	0	.07767	—	—	1.000	1.000
Dissolved Air Production	11	.52546	22	.04850	.5214	3.455	.9996	.9912
Dissolved Air/O_2 Production	2	.03613	2	.06061	.2424	1.000	.9999	.9999
Rotating Biological Contactor	56	1.255	56	0.0	.1047	7.857	.9996	.9993
Mechanical Aerators	24	.4510	0	.009713	—	—	1.000	1.000
Secondary Sludge Pumping	14	.25293	1	.01608	.007421	2.000	1.000	1.000
TOTAL	235	12.494729	183	.000682	6.85268	.998	.0069	.9999

TABLE 1.5.3.3. RELIABILITY AND MAINTENANCE DATA FOR MOTORS – VARIABLE SPEED, AC BY APPLICATION

Application	No of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Intermediate Wastewater Pumping	1	1	.01807	.0181	–	–	.00465	0.0	7.273	8.00	.9993	.9992
Return Activated Sludge Handling	16	1	.28907	.1729	.01081	.4033	.07432	.01420	.02841	8.00	1.00	.9999
TOTAL	17	2	.30714	.11482	.01081	.1729	.05795	.01257	8.00	999	.0503	9998

TABLE 1.5.3.4. RELIABILITY AND MAINTENANCE DATA FOR MOTORS – DC EXCITER BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	4	4	.05431	.01163	–	–	.006795	2.702	1.452	5.00	9996	.9939
Intermediate Wastewater Pumping	1	2	.01807	.006764	–	–	.003335	0.0	14.55	1.00	.9999	.9947
TOTAL	5	6	.07238	.010884	.006764	.01163	.006861	1.622	1.598	3 66	9903	.9903

TABLE 1.5.3.5. RELIABILITY AND MAINTENANCE DATA FOR MOTORS – GAS ENGINES BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	2	1	.03978	.02280	–	–	.01023	10 57	10 57	24 00	.9900	.9342

TABLE 1.5.4.1. RELIABILITY AND MAINTENANCE DATA FOR COMPRESSORS – SINGLE STAGE CENTRIFUGAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Dissolved Air Production	3	1	.03632	.02173	–	–	.009337	1.487	1.206	8.00	.9996	.9850
Dissolved Air/O_2 Application	5	4	09034	.01934	–	–	.01130	.01939	4267	2.75	.9999	9996
TOTAL	8	5	.12666	.02242	.01934	.021/3	.01369	.16854	.3199	3 80	.9999	.9955

TABLE 1.5.4.2. RELIABILITY AND MAINTENANCE DATA FOR COMPRESSORS – MULTI STAGE CENTRIFUGAL BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Dissolved Air Production	11	96	.52547	.005438	.005030	.01487	004785	.0727	.5040689	.8125375	.99987	.99150
Dissolved Air/O_2 Production	1	0	.01807	.02689	–	–	.007847	.2424	0.0	–	1.0	1.0
TOTAL	12	96	.54354	.005618	.005438	02689	.004952	.0651	.4723294	.8125375	.99987	.99179

TABLE 1.5.4.3. RELIABILITY AND MAINTENANCE DATA FOR COMPRESSORS – MULTI STAGE – HIGH PRESSURE BY APPLICATION

Application	No of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Oxygen Generation/ Storage	5	0	.05639	.08392	.02933	05459	.02449	.0776659	0 0	–	1.0	1 0

TABLE 1.5.5.1. RELIABILITY AND MAINTAINABILITY DATA ON DIFFUSERS, AIR/WATER – RBC SHAFT BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Rotating Biological Contector	55	0	1 232	1 834	–	–	.5352	.003555	–	–	1.0	1.0

TABLE 1.5.5.2. RELIABILITY AND MAINTAINABILITY DATA ON DIFFUSERS, AIR/WATER – WASTE TO MEDIA BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Trickling Filter – Rotary Distributor	40	223	1.2824	.01263	–	–	.01263	.000078	.1591	8 305	.9993	.9982

TABLE 1.5.6.1. RELIABILITY AND MAINTAINABILITY DATA ON VALVES -- GATE BY APPLICATION

Application	No. of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	5	9	06789	007023	.006266	.008123	004779	0 0	2 245	2 667	9996	9356
Intermediate Wastewater Pumping	2	2	03613	01353	.01081	.01081	.006789	0 0	3 636	8 0	.9994	.9969
TOTAL	7	11	.10402	008929	.007023	.01353	.006266	0 0	1.4074	3.6363	.99947	.95693

TABLE 1.5.6.2. RELIABILITY AND MAINTAINABILITY DATA ON VALVES – BALL BY APPLICATION

Application	No of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	1	.01916	01146	–	–	004927	0 0	43 89	110 0	9905	.8685

TABLE 1.5.6.3. RELIABILITY AND MAINTAINABILITY DATA ON VALVES – BUTTERFLY BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Oxygen Generation/ Storage	3	0	.03668	.05459	–	--	.01593	.1194	–	–	1.0	1.0
Dissolved Air/O_2 Production	1	1	.01807	.01081	–	–	004645	0 0	1 455	1 0	9999	.9998
TOTAL	4	1	05475	–	–	–	–	.05999	.12005	1 0	.999967	.999934

TABLE 1.5.6.4. RELIABILITY AND MAINTAINABILITY DATA ON VALVES – GATE BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	0	01916	02652	–	–	008322	2286	–	–	1 0	1.`

TABLE 1.5.7.1. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS

Mean Time Between Failures (MTBF) By Application
Broad Classification—Controls
Generic Group—Electical

Application	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)
Raw Wastewater Pumping	21	14	.5487	.03742	.03268	.03888	.02726
Intermediate Wastewater Pumping	15	5	1.0812	.1907	.01161	.6144	.1168
Screening/Communition	3	0	1.216	1.810	—	—	.5283
Clarifier Circular Center Drive	53	21	2.47907	.1144	.01081	.1191	.08796
Clarifier Square/ Rectangular Peripheral	27	0	3.6971	4.609	.5270	2.512	1.345
Return Activated Sludge Handling	28	56	1.0547	.018585	.000432	.01895	.01576
Recirculation Pumping	14	7	.3541	.04618	—	—	.03008
Oxygen Generation/ Storage	5	0	.05639	.08392	—	—	.02449
Dissolved Air Production	6	9	.4709	.04871	—	—	.03315
Rotating Biological Contactor	56	0	1.255	1.807	—	—	.5449
Mechanical Aerators	26	9	.4871	.05620	.01081	.06118	.03748
Secondary Sludge Pumping	15	2	.2537	.09497	—	—	.04768
TOTAL	259	122	12.35396	.100643	.018585	4.609	.039939

TABLE 1.5.7.2. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS

Maintenance Statistics By Application
Broad Classification — Controls
Generic Group — Electrical

Application	No. of Units	Operating Hrs (× 10^6 Hrs)	No. of Failures	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	21	.5487	14	.004562	.157737	4.643	.993854	.990509
Intermediate Wastewater Pumping	15	1.0812	5	.010805	.084259	6.0	.999975	.997439
Screening/Communition	3	1.216	0	.003601	0.0	—	1.0	1.0
Clarifier Circular Center Drive	53	2.47907	21	.001300	.005902	2.00	.999999	.999999
Clarifier Square/ Rectangular Peripheral	27	3.0971	0	.001468	0.0	—	1.0	.999891
Return Activated Sludge Handling	28	1.05472	56	.000741	.058123	2.60705	.999888	.999809
Recirculation Pumping	14	.3541	7	.007951	.07951	5.571	.9999	.9845
Oxygen Generation/ Storage	5	.05639	0	.07767	0.0	—	1.0	1.0
Dissolved Air Production	6	.4709	9	.00155	.1457	1.333	1.0	.9999
Rotating Biological Contactor	56	1.255	0	.003491	0.0	—	1.0	1.0
Mechanical Aerators	26	.48707	8	.000692	.039774	1.749963	.999974	.999965
Secondary Sludge Pumping	15	.2537	2	.01496	.01381	2.5	1.0	.9982
TOTAL	269	12.35395	122	.000281	.002114	2.893368	.999979	.999225

TABLE 1.5.7.3. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS – MECHANICAL BY APPLICATION

Application	No of Units	No. of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Raw Wastewater Pumping	1	0	.02240	.03334	–	–	.00973	.1955	0 0	–	1 0	1.0
Intermediate Wastewater Pumping	3	2	.04553	01705	–	–	.008554	.06413	1.924	8 0	.9395	.9976
TOTAL	4	2	.06793	.03123	01705	.03334	.012817	.04835	.967169	8 0	.9997	.99839

TABLE 1.5.7.4. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS – PRESSURE (FLUID) BY APPLICATION

Application	No of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Secondary Sludge Pumping	6	1	.1084	.06485	–	–	.02787	.04714	.0404	3 0	1.0	.9999
Chlorine, Gaseous	6	16	.5202	.03140	–	–	.02331	0 0	3014	8 563	9097	.9053
TOTAL	12	17	.6316	.03570	.03140	.06485	.02576	00406	.128303	8.23576	.00975	.988219

TABLE 1.5.7.5. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS – PRESSURE-AIR BY APPLICATION

Application	No of Units	No of Failures	Operating Hrs (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Chlorine, Gaseous	10	9	.1007	.01069	–	–	.01272	.000307	1339	3 656	9008	9028

TABLE 1.5.7.6. RELIABILITY AND MAINTENANCE DATA FOR CONTROLS – CHLORINATORS BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Chlorine, Gaseous	3	8	.03408	.003932	–	–	.002623	0.0	17.62	5.375	9986	.9632

TABLE 1.5.8.1. RELIABILITY AND MAINTENANCE DATA FOR CONVEYORS – CHAIN (EAR SCREEN) BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Screening/Communition	3	19	1.214	06175	–	–	.04008	0 0	1371	9474	1 0	9009

TABLE 1.5.8.2. RELIABILITY AND MAINTENANCE DATA FOR CONVEYORS – SLUDGE COLLECTOR BY APPLICATION

Application	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Clarifier Square/ Rectangular Peripheral	13	7	2.743	.3577	2202	1.570	.2331	.0009025	.1651	15.14	1.0	.9933

TABLE 1.6.1.1. RELIABILITY AND MAINTENANCE DATA ON PUMPS – OPEN IMPELLER CENTRIFUGAL BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-10,000	33	28	1.1357	.03304	.03569	.1678	.03145	.001997	.075762	6.736	.99982	.99900
10,001-20,000	11	22	.3068	.01708	–	–	01319	.00103	.652	4.136	.9908	.9979
20,001-100,000	9	3	.3604	.09819	–	–	.05305	.000452	.7778	73 0	9993	.9957
Over 100,000	17	44	.23472	.00528	.006058	.006607	.00436	090922	1 480809	5 887	.98058	.98208
TOTAL	70	97	2 11742	.021662	.006058	.1678	.019106	.003428	.094773	7.825	.99962	.99055

TABLE 1.6.1.2. RELIABILITY AND MAINTENANCE DATA ON PUMPS – PROPELLER, AXIAL FLOW BY SIZE

Size (Gallons Per Minute)	No. of Units	No of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
10,001 20,000	22	3	.41169	.1123	.01378	.5377	.061478	.01212	–	–	1.0	.99937
20,001-100,000	17	15	1.1621	.074256	.02002	.1838	.064559	.001108	.227077	17.467	99076	.99035
Over 100,000	10	5	.18003	03197	.006374	2161	018528	.237616	1.934614	4.0	.99928	00016
TOTAL	49	23	1.75402	074197	.006374	.5377	067823	.006256	.114107	16 783	.99576	.99311

TABLE 1.6.2.1. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – CONCENTRIC REDUCER BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0–1	4	2	.07516	.02814	–	–	.01412	.02914	.1748	2.0	.9999	.9999
101-500	14	0	.2529	.3764	–	–	.04696	.01732	0 0		1.0	1.0
TOTAL	18	2	.32006	.12264	.02814	.3764	.061098	.01187	.00990	2.0	.99998	.99998

TABLE 1.6.2.2. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – PARALLEL SHAFT BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
6-25	56	0	1.256	1.867	–	–	.6449	.003491	0 0	–	1.0	1.0
101-500	6	0	.1127	.1678	–	–	.04896	.03885	0.0	–	1.0	1.0
Over 500	11	2	.53399	.01998	.09334	.1763	.11075	00671	.2683	32.0	.9998	.9996
TOTAL	73	2	1 90169	.7109	.01998	1.867	3588	.002241	.012075	32 0	.99996	.99990

TABLE 1.6.2.3. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – RIGHT ANGLE SHAFT BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	49	100	3.481	.03057	.009929	2.612	.03305	.001027	.01310	1.4	.99995	.99909
101-500	2	0	.03978	.06919	–	–	.01728	.1101	0 0	–	1.0	1.0
TOTAL	51	100	3.52078	018479	.03657	.06919	.017747	.001023	.01244	1 4	99996	.99909

TABLE 1.6.2.4. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — VERTICAL SHAFT BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^3 Hrs)	Min. MTBF (× 10^3 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	9	32	.6287	01926	–	–	.01551	.002322	.1456	.0693	1.00	.9931
26 100	35	10	6497	.06091	–	–	.04217	002119	.00546	5.2	.9999	.9999
101-500	7	2	.1236	.04735	–	–	.02376	.02968	.05937	3.0	.9999	.9999
TOTAL	51	44	1.4043	.03146	.01926	.06091	.02311	.001223	.03331	2 023	.99994	.99986

TABLE 1.6.2.5. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — VARIABLE SPEED DRIVE, HYDRAULIC BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^3 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	13	0	.2349	3495	–	–	.1020	.01865	0 0	–	1.0	1.0

TABLE 1.6.2.6. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS — VARIABLE SPEED DRIVE, OTHER BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	3	8	.00705	007841	–	–	.00523	.02148	1 031	2 5	9997	.9998
Over 500	1	0	01807	02639	–	–	007847	7.273	0.0	–	1.0	.9982
TOTAL	4	8	.08603	010122	.007841	.02639	010754	.3048	.6108	2 5	.99976	99952

TABLE 1.6.2.7. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – GEAR BOX BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	11	24	1.483	.00016	.03924	.1726	.04393	0.0	.1659	6.04	.99993	.99974
1-5	15	38	.3794	.009816	–	–	.009041	.004818	.3756	1.342	.9999	.9994
6-25	5	1	1.066	.6313	–	–	.2713	.003921	.1594	25.0	1.0	.9996
26-100	1	2	.09206	.03476	–	–	.01746	0.0	.5080	4.0	.9999	.9998
TOTAL	32	65	3.01026	.045783	.000816	.6313	.009323	.000456	.059530	3.523	.99993	.99552

TABLE 1.6.2.8. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – CHAIN DRIVE BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
1-5	4	5	.1012	.01785	–	–	.01091	0.0	1.384	8.0	.9998	.9945

TABLE 1.6.2.9. RELIABILITY AND MAINTENANCE DATA ON POWER TRANSMISSIONS – BELT DRIVE BY SIZE

Size (Gallons Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	3	5	.5160	.09101			.05564	0.0	.00463	1.8	1.0	.9916

TABLE 1.6.3.1. RELIABILITY AND MAINTENANCE DATA ON MOTORS — MULTIPHASE BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	70	20	4.241	.2147	.1236	2.612	.1349	.00522	.01009	2.6	1.0	.99390
1-5	15	0	.3794	.5646	—	—	.1648	.01152	0.0	—	1.0	1.0
6-25	64	56	3.520	.0621	.0222	1.81	.0527	.00015	.03261	7.857	.99986	.99975
26-100	60	59	2.702	.0460	.0210	1.334	.0347	.00108	.03098	4.95651	.99988	.99962
101-500	52	18	.9590	.0540	.0135	3.228	.0332	.00328	.10599	12.05617	.99977	.99332
Over 500	24	30	.6870	.0231	.00083	.09931	.0157	.02683	.24917	8.433	.99960	.98914
TOTAL	285	183	12.4947	.0680	.0231	.5646	.0620	.00068	.00696	6.85601	.99989	.99338

TABLE 1.6.3.2. RELIABILITY AND MAINTENANCE DATA ON MOTORS — VARIABLE SPEED, AC BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	15	0	.2710	.4033	—	—	.1177	.01618	—	—	1.0	1.0
Over 500	2	2	.03614	.01351	.01081	.01081	.00682	0.0	3.6385	8.0	.9993	.9992
TOTAL	17	2	.30714	.11402	.01351	.4033	.05705	.01258	.060340	8.0	.99902	.99991

TABLE 1.6.3.3. RELIABILITY AND MAINTENANCE DATA ON MOTORS — DC EXCITER BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Over 500	5	6	.07238	.010384	.006764	.01163	.006361	1.6219468	1.6930931	3.660587	9936749	.930348

TABLE 1.6.3.4. RELIABILITY AND MAINTENANCE DATA ON MOTORS – GAS ENGINE BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	2	1	.03978	.02300	–	–	.01023	10.57	10.57	24.00	.9990	.9342

TABLE 1.6.4.1. RELIABILITY AND MAINTENANCE DATA ON COMPRESSORS – SINGLE STAGE CENTRIFUGAL BY SIZE

Size (Cubic Feet Per Minute)	No of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
001-10,000	5	4	.09034	.01934	–	–	.01130	.01939	.4267	2.75	.9999	.9990
Over 20,000	3	1	.03632	.02173	–	–	.009337	1.487	1.206	8.0	.9996	.9850
TOTAL	8	5	.12668	.02242	.01934	.02173	.01369	.16354	.319338	3.80	.9998	.9954

TABLE 1.6.4.2. RELIABILITY AND MAINTENANCE DATA ON COMPRESSORS – MULTI STAGE CENTRIFUGAL BY SIZE

Size (Cubic Feet Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
1,001-10,000	1	0	.01609	.02689	–	–	.007847	.2424	0 0	–	1.0	1.0
10,001-20,000	5	3	05457	.01487	–	–	003168	.03211	1.445	6.0	9996	9903
Over 20,000	6	9	.47090	.005030	–	–	.004417	.1457	.8029	0 6452	.9999	9999
TOTAL	12	96	.54354	.005618	.005030	.02689	004952	.06513	.44723	01264	99987	99179

TABLE 1.6.4.3. RELIABILITY AND MAINTENANCE DATA ON COMPRESSORS – MULTI STAGE HIGH PRESSURE BY SIZE

Size (Cubic Feet Per Minute)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-1,000	3	0	.03368	.05459	–	–	.01593	.1194	0.0	–	1.0	1.0
1,001-10,000	2	0	.01971	.02933	–	–	.008550	.2222	0.0	–	1.0	1.0
TOTAL	6	0	.05039	.00392	.01971	.03368	.02449	.07707	0 0	–	1.0	1.0

TABLE 1.6.5.1. RELIABILITY AND MAINTENANCE DATA ON DIFFUSERS, AIR/WATER – RBC SHA· ˙ BY SIZE

Size	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
6-25 Horsepower	55	0	1.232	1.834	–	–	.5852	.01263	–	–	.01160	–

TABLE 1.6.5.2. RELIABILITY AND MAINTENANCE DATA ON DIFFUSERS, AIR/WATER – WASTE TO MEDIA BY SIZE

Size (Gallons per Minute)	No. of Units	Operating Hrs (× 10^6)	No. of Failures	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
10,001-20,000	40	2.824	223	.000078	.1591	8.355	.9993	.9832

TABLE 1.6.6.1. RELIABILITY AND MAINTENANCE DATA ON VALVES – GATE BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
25-48	2	2	.03165	.01183	.01081	.01146	.005972	0.0	4.15224	8.00	.999169	.999064
Over 48	5	9	.07239	.007501	.006266	.01081	.005097	0.0	2.10575	2.6087	.99360	.993500
TOTAL	7	11	.10403	.003929	.007023	.01353	.003268	0.0	1.40743	3.6394	.99947	.05603

TABLE 1.6.6.2. RELIABILITY AND MAINTENANCE DATA ON VALVES – BALL BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs. ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM Hrs/ Unit/ Year	CM Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
25-48	1	1	.01918	.01146	–	–	.004027	0.0	43.89	110.0	.9906	.8086

TABLE 1.6.6.3. RELIABILITY AND MAINTENANCE DATA ON VALVES – BUTTERFLY BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs ($\times 10^6$ Hrs)	Overall MTBF ($\times 10^6$ Hrs)	Min. MTBF ($\times 10^6$ Hrs)	Max. MTBF ($\times 10^6$ Hrs)	Overall 90% CL ($\times 10^6$ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-6	3	0	.03668	.06459	–	–	.01693	.1184	–	–	1.0	1.0
13-24	1	1	.01807	.01081	–	–	.004645	0.0	1.455	1.00	.9999	.9998
TOTAL	4	1	.05475	.032589	.01081	.06459	.014075	.05009	.12005	1.00	.999967	.999934

TABLE 1.6.6.4. RELIABILITY AND MAINTENANCE DATA ON VALVES — PLUG BY SIZE

Size (Inches)	No. of Units	No. of Failures	Operating Hrs. (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
25-43	1	1	.01916	.02052	—	—	003322	.2208	—	—	1.0	1.0

TABLE 1.6.7.1. RELIABILITY AND MAINTENANCE DATA ON CONTROLS — ELECTRICAL BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	60	20	4.143	.20032	.1191	2.512	.16966	.00063	.00258	2.06	1.0	.93332
1-5	14	0	.3541	.50950	—	—	.10362	.01325	0.0	—	1.0	1.0
6-25	64	0	3.528	4.6849	1.570	1.867	1.41258	.00124	0.0	—	1.0	1.0
26-100	56	69	1.8211	.026109	.01805	.06116	.022521	.00035	.02815	2.37672	.99908	.99993
101-500	60	19	1.92154	.09779	.01031	.6144	.07419	.00274	.02215	5.57856	.99572	.99936
Over 500	15	14	.58221	.03374	.004324	.06302	.02889	.00301	.12236	2.99979	.99635	.99993
TOTAL	269	122	12.35395	.100843	.026100	4.6049	099039	.00023	.00211	2.69337	.99998	.99922

TABLE 1.6.7.2. RELIABILITY AND MAINTENANCE DATA ON CONTROLS — MECHANICAL BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10⁶ Hrs)	Overall MTBF (× 10⁶ Hrs)	Min. MTBF (× 10⁶ Hrs)	Max. MTBF (× 10⁶ Hrs)	Overall 90% CL (× 10⁶ Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-500	1	0	.0224	.03334	—	—	00373	.1855	0.0	—	1.0	1.0
Over 500	3	2	.04563	.01706	—	—	.003354	.03413	1.924	8.0	.9955	.9976
TOTAL	4	2	.03783	.03123	.01706	.03334	.012317	.04835	.50717	8.0	.99965	.99939

TABLE 1.6.7.3. RELIABILITY AND MAINTENANCE DATA ON CONTROLS—PRESSURE (FLUID) BY SIZE

Size	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
101-600 (HP)	6	1	.1034	.03185	–	–	.02707	.04714	.0404	3.0	1.0	.9939
Over 2000 Lbs. Chemical	6	16	.5236	.03140	–	–	.02331	0.0	.3014	8.563	.9097	.9658
TOTAL	12	17	.6316	.03578	.03140	.06405	.02576	.00405	.12330	8.23576	.90975	.96322

TABLE 1.6.7.4. RELIABILITY AND MAINTENANCE DATA ON CONTROLS—PRESSURE—AIR BY SIZE

Size (Horsepower)	No of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Over 2000 Lbs. Chemical	10	.1809	9	.01869	–	–	.01272	.009397	.1309	3.556	.9958	.9998

TABLE 1.6.8.1. RELIABILITY AND MAINTENANCE DATA ON CONVEYORS — CHAIN (BAR SCREEN) BY SIZE

Size	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^6 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^6 Hrs)	Overall 90% CL (× 10^6 Hrs)	PM Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
Over 43 Inches	3	19	1.214	.06175	—	—	.04683	0.0	.1371	.8474	1.0	.8999

TABLE 1.6.8.2. RELIABILITY AND MAINTENANCE DATA ON CONVEYORS — SLUDGE COLLECTOR BY SIZE

Size (Horsepower)	No. of Units	No. of Failures	Operating Hrs. (× 10^6 Hrs)	Overall MTBF (× 10^3 Hrs)	Min. MTBF (× 10^6 Hrs)	Max. MTBF (× 10^3 Hrs)	Overall 90% CL (× 10^3 Hrs)	PM-Hrs/ Unit/ Year	CM-Hrs/ Unit/ Year	MTTR (Hrs)	AVI	AVO
0-1	8	7	16.03	.2202	—	—	.1434	.000729	.4359	15.14	.9999	.9996
6-25	5	0	1.055	1.570	—	—	.4583	.004151	—	—	1.000	1.000
TOTAL	13	7	2.743	.35856	.2202	1.570	.23345	.000882	.160075	15.14	.99993	.65975

TABLE 2.1.1. PUMPS—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring, or Plate	17	.177
2	Solenoid Valve	16	.167
3	Bearing, Ball, Single Row	14	.146
4	Bearing, Ball, Double Row	8	.083
5	Controller	8	.083
6	Bearing, Cast, Pillow	5	.052
7	Complete Bearing Replacement	5	.052
8	Seal, Packed, not Lubricated	3	.031
9	Coupling	3	.031
10	Bearing, Thrust	3	.031
11	Pump Impeller	2	.021
12	Drive Belt	2	.021
13	Case, Pump	2	.021

TABLE 2.1.2. POWER TRANSMISSIONS—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	133	.453
2	Bearing, Ball, Double Row	48	.163
3	Shear Pin	39	.133
4	Seal, other	24	.082
5	Bearing, Ball, Single Row	11	.037
6	Shaft, Drive	9	.031
7	Controller	8	.027
8	Coupling	5	.017
9	Chain, Pintle	5	.017
10	Pulley, Belt Drive	4	.013
11	Skimmer	2	.007

TABLE 2.1.3. MOTORS - DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	58	.347
2	Brushes	38	.228
3	Coupling	19	.114
4	Motor Windings	16	.096
5	Bearing, Ball, Double Row	11	.066
6	Controller	4	.024
7	Shaft Sleeve	3	.018
8	Relay	3	.018
9	Motor Armature	3	.018
10	Seal, Packed, not Lubricated	2	.012
11	Bearing, Ball, Single Row	2	.012
12	Bearing, Thrust	2	.012
13	Overload Relay	2	.012
14	Case, Motor	2	.012

TABLE 2.1.4. COMPRESSORS—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Component Type	No Of Failures	Relative Frequency
1	Coupling	3	.231
2	Bearing, Ball, Single Row	3	.231
3	Switch, Electric	3	.231
4	Pump Impeller	2	.154
5	Brushes	1	.077
6	Pipe Broken	1	.077

TABLE 2.1.5. DIFFUSERS, AIR/WATER – DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent	No. of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

TABLE 2.1.6. VALVES – DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Component Type	No. Of Failures	Relative Frequency
1	Seal, Packed Water, Oil, Grease Lubricated	7	.538
2	Control Valve	3	.231
3	Seal, other	1	.077
4	Co .roller	1	.077
5	Solenoid valve	1	.077

TABLE 2.1.7. CONTROLS—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	46	.371
2	Magnetic Starter	26	.210
3	Overload Relay	13	.105
4	Relay	11	.089
5	Switch, Electric	11	.089
6	Seal, Single, Mechanical	3	.024
7	Seal, other	3	.024
8	Complete Bearing Replacement	3	.024
9	Electrical Timer	2	.016
10	Control Valve	2	.016

TABLE 2.1.8. CONVEYOR—DISTRIBUTION OF SUBCOMPONENT FAILURES

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Rake Guides	19	.731
2	Collector mechanism	5	.192
3	Plastic chain and Flights	1	.038
4	Pipe Broken	1	.038

TABLE 2.2.1.1. PUMPS—OPEN IMPELLER CENTRIFUGAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring or Plate	15	.197
2	Seal, Packed, Water, Oil, Grease Lubricated	14	.184
3	Solenoid Valve	14	.184
4	Bearing, Ball, Double Row	6	.079
5	Bearing, Cast, Pillow	5	.066

TABLE 2.2.1.2. PUMPS—PROPELLER, AXIAL FLOW

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	4	.200
2	Complete Bearing Replacement	4	.200
3	Impeller Wear Ring or Plate	2	.100
4	Bearing, Ball, Double Row	2	.100
5	Bearing, Thrust	2	.100
6	Solenoid Valve	2	.100

TABLE 2.2.2.1. POWER TRANSMISSION—RIGHT ANGLE SHAFT

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	127	.706
2	Bearing, Ball, Double Row	45	.250
3	Pulley, Belt Drive	3	.017
4	Coupling	2	.011

TABLE 2.2.2.2. POWER TRANSMISSION—VERTICAL SHAFT

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, other	20	.445
2	Bearing, Ball, Single Row	11	.245
3	Shaft, Drive	8	.178

TABLE 2.2.2.3. POWER TRANSMISSION—VARIABLE SPEED DRIVE, OTHER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	8	.889
2	Brushes	1	.111

TABLE 2.2.2.4. POWER TRANSMISSION—GEAR BOX

Rank	Sbucomponent Type	No. Of Failures	Relative Frequency
1	Shear Pin	38	.826
2	Seal, other	4	.087
3	Coupling	3	.065
4	Complete Bearing Replacement	1	.022

TABLE 2.2.3.1. MOTORS—MULTI-PHASE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	57	.385
2	Brushes	24	.162
3	Coupling	19	.128
4	Motor Windings	16	.108
5	Bearing, Ball, Double Row	10	.068

TABLE 2.2.3.2. MOTORS—VARIABLE SPEED AC

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	1	.500
2	Controller	1	.500

TABLE 2.2.3.3. MOTORS – DC EXCITER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	14	.933
2	Motor Armature	1	.067

TABLE 2.2.3.4. MOTORS – GASOLINE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	1	.500
2	Replaced Piston	1	.500

TABLE 2.2.4.1. COMPRESSORS – SINGLE STAGE CENTRIFUGAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	3	.429
2	Switch, Electric	2	.286
3	Coupling	1	.143
4	Brushes	1	.143

TABLE 2.2.4.2. COMPRESSORS—MULTI STAGE CENTRIFUGAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Pump Impeller	2	.333
2	Coupling	2	.333
3	Case, Motor	1	.167
4	Pipe Broken	1	.167

TABLE 2.2.5.1. DIFFUSERS, AIR/WATER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

TABLE 2.2.6.1. VALVES—GATE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, Packed, Water, Oil, Grease Lubricated	7	.636
2	Seal, other	1	.091
3	Controller	1	.091
4	Solenoid Valve	1	.091
5	Control Valve	1	.091

TABLE 2.2.7.1. CONTROLS—ELECTRICAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	32	.348
2	Magnetic Starter	23	.250
3	Overload Relay	13	.141
4	Switch, Electric	10	.109
5	Relay	9	.098

TABLE 2.2.7.2. CONTROLS—MECHANICAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Switch, Electric	1	.500
2	Motor Windings	1	.500

TABLE 2.2.7.3. CONTROLS—PRESSURE, FLUID

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	5	.385
2	Magnetic Starter	3	.231
3	Complete Bearing Replacement	3	.231

TABLE 2.2.7.4. CONTROLS—CHLORINATORS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, other	3	.375
2	Relay	2	.250
3	Control Valve	2	.250
4	Gear, Rack	1	.125

TABLE 2.2.8.1. CONVEYOR—SLUDGE COLLECTOR

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Collector Mechanism	5	.714
2	Plastic Chain and Flights	1	.143
3	Pipe Broken	1	.143

TABLE 2.3.1.1. PUMPS—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring, or Plate	15	.246
2	Seal, Packed, Water, Oil, Grease Lubricated	14	.230
3	Solenoid Valve	14	.230
4	Bearing, Cast, Pillow	5	.082
5	Seal, Packed, not Lubricated	3	.049

TABLE 2.3.1.2. PUMPS—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	8	.572
2	Seal, other	1	.071
3	Coupling	1	.071
4	Drive Belt	1	.071
5	Relay	1	.071
6	Switch, Electric	1	.071
7	Brushes	1	.071

TABLE 2.3.1.3. PUMPS—RETURN ACTIVATED SLUDGE HANDLING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	5	.714
2	Coupling	2	.286

TABLE 2.3.1.4. PUMPS—RECIRCULATION PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	4	.286
2	Impeller Wear Ring, or Plate	2	.143
3	Bearing, Ball, Double Row	2	.143
4	Bearing, Thrust	2	.143
5	Solenoid Valve	2	.143

TABLE 2.3.2.1. POWER TRANSMISSION—CLARIFIER CENTER CIRCULAR DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	133	.596
2	Bearing, Ball, Double Row	45	.202
3	Seal, other	20	.090
4	Shaft, Drive	9	.040
5	Bearing, Ball, Single Row	5	.022
6	Pulley, Drive Belt	4	.018

TABLE 2.3.2.2. POWER TRANSMISSION—CLARIFIER SQUARE/RECTANGULAR, PERIPHERAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Shear Pin	38	.809
2	Chain, Pintle	5	.106
3	Coupling	3	.064
4	Complete Bearing Replacement	1	.021

TABLE 2.3.2.3. POWER TRANSMISSION—MECHANICAL AERATORS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	6	.461
2	Seal, other	4	.308
3	Seal, Single Mechanical	1	.077
4	Seal, Packed, Water, Oil, Grease Lubricated	1	.077
5	Bearing Ball, Double Row	1	.077

TABLE 2.3.3.1. MOTORS—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	16	.381
2	Motor Windings	13	.310
3	Relay	3	.071
4	Motor Armature	3	.071
5	Controller	2	.048

TABLE 2.3.3.2. MOTORS—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	2	.667
2	Controller	1	.133

TABLE 2.3.3.3. MOTORS—CLARIFIER CIRCULAR CENTER DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	19	.826
2	Bearing, Ball, Single Throw	2	.087
3	Bearing, Ball, Double Throw	2	.087

TABLE 2.3.3.4. MOTORS – RETURN ACTIVATED SLUDGE HANDLING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	9	.500
2	Bearing, Ball, Double Row	5	.278
3	Seal, Packed, not Lubricated	2	.111

TABLE 2.3.3.5. MOTORS – RECIRCULATION PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Shaft, Sleeve	2	.333
2	Bearing, Ball, Double Row	2	.333
3	Bearing, Thrust	1	.167
4	Complete Bearing Replacement	1	.167

TABLE 2.3.3.6. MOTORS – DISSOLVED AIR PRODUCTION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	11	.688
2	Motor Windings	2	.125
3	Case, Motor	2	.125
4	Bearing, Ball, Double Row	1	.062

TABLE 2.3.4.1. COMPRESSORS—DISSOLVED AIR PRODUCTION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	3	.333
2	Pump Impeller	2	.222
3	Switch, Electric	1	.111
4	Case, Motor	1	.111
5	Brushes	1	.111
6	Pipe Broken	1	.111

TABLE 2.3.4.2. COMPRESSORS—DISSOLVED AIR/O_2 APPLICATION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	3	.750
2	Switch, Electric	1	.250

TABLE 2.3.5.1. DIFFUSERS, AIR/WATER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

TABLE 2.3.6.1. VALVES—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, Packed, Water Oil, Grease Lubricated	7	.700
2	Seal, other	1	.100
3	Controller	1	.100
4	Control Valve	1	.100

TABLE 2.3.6.2. VALVES—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Solenoid Valve	1	.500
2	Control Valve	1	.500

TABLE 2.3.7.1. CONTROLS—RAW WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Magnetic Starter	11	.846
2	Switch, Electric	1	.077
3	Solenoid Valve	1	.077

TABLE 2.3.7.2. CONTROLS—INTERMEDIATE WASTEWATER PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Relay	2	.222
2	Overload Relay	2	.222
3	Switch, Electric	2	.222
4	Controller	2	.222
5	Motor Windings	1	.111

TABLE 2.3.7.3. CONTROLS—CLARIFIER CENTER CIRCULAR DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Magnetic Starter	8	.421
2	Overload Relay	5	.263
3	Switch, Electric	4	.211
4	Relay	1	.053
5	Controller	1	.053

TABLE 2.3.7.4. CONTROLS—RETURN ACTIVATED SLUDGE HANDLING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	22	.786
2	Magnetic Starter	4	.143
3	Electrical Timer	2	.071

TABLE 2.3.7.5. CONTROLS—RECIRCULATION PUMPING

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Overload Relay	3	.429
2	Seal, Single, Mechanical	2	.286
3	Switch, Electric	1	.143
4	Controller	1	.143

TABLE 2.3.7.6. CONTROLS—DISSOLVED AIR PRODUCTION

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	4	.445
2	Switch, Electric	3	.333
3	Relay	2	.222

TABLE 2.3.7.7. CONTROLS—MECHANICAL AERATORS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Relay	4	.500
2	Overload Relay	3	.375
3	Switch, Electric	1	.125

TABLE 2.3.7.8. CONTROLS—CHLORINE, GASEOUS

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	13	.448
2	Seal, other	3	.103
3	Magnetic Starter	3	.103
4	Complete Bearing Replacement	3	.103
5	Relay	2	.069
6	Control Valve	2	.069
7	Seal, Single, Mechanical	1	.035
8	Gear, Rack	1	.035
9	Gear, Pinion	1	.035

TABLE 2.3.8.1. CONVEYOR—CLARIFIER SQUARE/RECTANGULAR PERIPHERAL DRIVE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Collector Mechanism	5	.714
2	Plastic Chain and Flights	1	.143
3	Pipe Broken	1	.143

TABLE 2.4.1.1. PUMPS—0 TO 10,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	5	.714
2	Coupling	2	.286

TABLE 2.4.1.2. PUMPS—10,001 TO 20,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Impeller Wear Ring, or Plate	15	.600
2	Seal, Packed, not Lubricated	2	.080
3	Bearing, Thrust	2	.080

TABLE 2.4.1.3. PUMPS—20,001 TO 100,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Complete Bearing Replacement	4	.308
2	Impeller Wear Ring, or Plate	2	.154
3	Bearing, Ball, Double Row	2	.154
4	Solenoid Valve	2	.154

TABLE 2.4.1.4. PUMPS—OVER 100,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Seal, Packed, Water, Oil, Grease Lubricated	14	.269
2	Solenoid Valve	13	.250
3	Controller	8	.154
4	Bearing, Cast, Pillow	5	.096
5	Drive Belt	2	.038

TABLE 2.4.2.1. POWER TRANSMISSION—0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Drive Belt	133	.588
2	Bearing, Ball, Double Row	45	.199
3	Seal, other	20	.088
4	Shaft, Drive	9	.040
5	Coupling	5	.022
6	Bearing, Ball, Single Row	5	.022
7	Pulley, Belt Drive	4	.018

TABLE 2.4.2.2. POWER TRANSMISSION—2 TO 5 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Shear Pin	38	.884
2	Chain, Pintle	5	.116

TABLE 2.4.2.3. POWER TRANSMISSION—26 TO 100 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	6	.600
2	Seal, other	4	.400

TABLE 2.4.2.4. POWER TRANSMISSION—101 TO 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	8	.727
2	Seal, Single, Mechanical	1	.091
3	Seal, Packed, Water, Oil, Grease Lubricated	1	.091
4	Bearing, Ball, Double Row	1	.091

TABLE 2.4.2.5. POWER TRANSMISSION—OVER 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	2	.667
2	Brushes	1	.333

TABLE 2.4.3.1. MOTORS—0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	19	.826
2	Bearing, Ball, Single Row	2	.087
3	Bearing, Ball, Double Row	2	.087

TABLE 2.4.3.2. MOTORS—26 TO 100 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Motor Windings	11	.393
2	Brushes	9	.321
3	Bearing, Ball, Double Row	4	.143
4	Seal, Packed, not Lubricated	2	.071
5	Shaft, Sleeve	1	.036
6	Controller	1	.036

TABLE 2.4.3.3. MOTORS—101 TO 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Double Row	4	.222
2	Shaft, Sleeve	2	.111
3	Bearing, Thrust	2	.111
4	Overload Relay	2	.111
5	Motor Windings	2	.111
6	Brushes	2	.111
7	Complete Bearing Replacement	2	.111

TABLE 2.4.3.4. MOTORS—OVER 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Brushes	27	.643
2	Relay	3	.071
3	Motor Windings	3	.071
4	Controller	3	.071
5	Motor Armature	2	.048
6	Case, Motor	2	.048

TABLE 2.4.4.1. COMPRESSORS – 1,001 TO 10,000 CUBIC FEET PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Bearing, Ball, Single Row	3	.750
2	Switch, Electric	1	.250

TABLE 2.4.4.2. COMPRESSORS – 10,001 TO 20,000 CUBIC FEET PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Coupling	2	.667
2	Pipe Broken	1	.333

TABLE 2.4.4.3. COMPRESSORS – OVER 20,000 CUBIC FEET PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Pump Impeller	2	.333
2	Switch, Electric	2	.333
3	Coupling	1	.167
4	Brushes	1	.167

TABLE 2.4.5.1. DIFFUSERS, AIR/WATER—10,001 TO 20,000 GALLONS PER MINUTE

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Tie Rod	107	.480
2	Seal, Single, Mechanical	49	.220
3	Bearing, Thrust	36	.161
4	Bearing, Ball, Single Row	25	.112
5	End Gate	5	.022
6	Experimental/Prototype Bearing	1	.005

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TABLE 2.4.6.1. VALVES—25 TO 48 INCHES

Rank	Subcomponent Type	No. of Failures	Relative Frequency
1	Seal	1	.333
2	Solenoid Valve	1	.333
3	Control Valve	1	.333

TABLE 2.4.6.2. VALVES—OVER 48 INCHES

Rank	Subcomponent Type	No. of Failures	Relative Frequency
1	Seal, Packed, Water, Oil, Grease Lubricated	7	.778
2	Controller	1	.111
3	Control Valve	1	.111

TABLE 2.4.7.1. CONTROLS—0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Magnetic Starter	8	.444
2	Overload Relay	5	.278
3	Switch, Electric	4	.222
4	Relay	1	.056

TABLE 2.4.7.2. CONTROLS—26 TO 100 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	21	.512
2	Magnetic Starter	11	.268
3	Relay	4	.098
4	Overload Relay	2	.049
5	Electrical Timer	2	.049

TABLE 2.4.7.3. CONTROLS—101 TO 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	6	.300
2	Overload Relay	5	.250
3	Magnetic Starter	4	.200
4	Seal, Single, Mechanical	2	.100
5	Switch, Electric	2	.100

TABLE 2.4.7.4. CONTROLS—OVER 500 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	6	.375
2	Relay	4	.250
3	Switch, Electric	4	.250

TABLE 2.4.7.5. CONTROLS—OVER 2000 POUNDS CHEMICAL

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Controller	13	.448
2	Seal, other	3	.103
3	Magnetic Starter	3	.103
4	Complete Bearing Replacement	3	.103
5	Relay	2	.069
6	Control Valve	2	.069

TABLE 2.4.8.1. CONVEYOR—0 TO 1 HORSEPOWER

Rank	Subcomponent Type	No. Of Failures	Relative Frequency
1	Collector Mechanism	5	.714
2	Plastic Chain and Flights	1	.143
3	Pipe Broken	1	.143

TABLE 3.1.1. WWTP REPORT-RELIABILITY OF SLUDGE PROCESSES

Process	Operating Hours ($\times 10^6$ Hrs)	No. of Failures	MTBF ($\times 10^6$ Hrs)	90% CL ($\times 10^6$ Hrs)	Avail.
Sludge Process External to WW Treat. Process	.780	400	.00195	.00183	.997
Anaerobic Digestion	.678	40	.0167	.0137	1.000
Incineration	.374	454	.000824	.000776	.723
Sludge Thickening DAF	.406	702	.000577	.000583	.994
Vacuum Filter	.697	1150	.000606	.000583	.931

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