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NEW DIMENSION SOLUTIONS

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AWWARF EVALUATION REPORT ON APPLICATION OF RCM AT MASSACHUSETTS WATER RESOURCES AUTHORITY DEER ISLAND TREATMENT PLANT

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Table of Contents

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1 Massachusetts Water Resources Authority

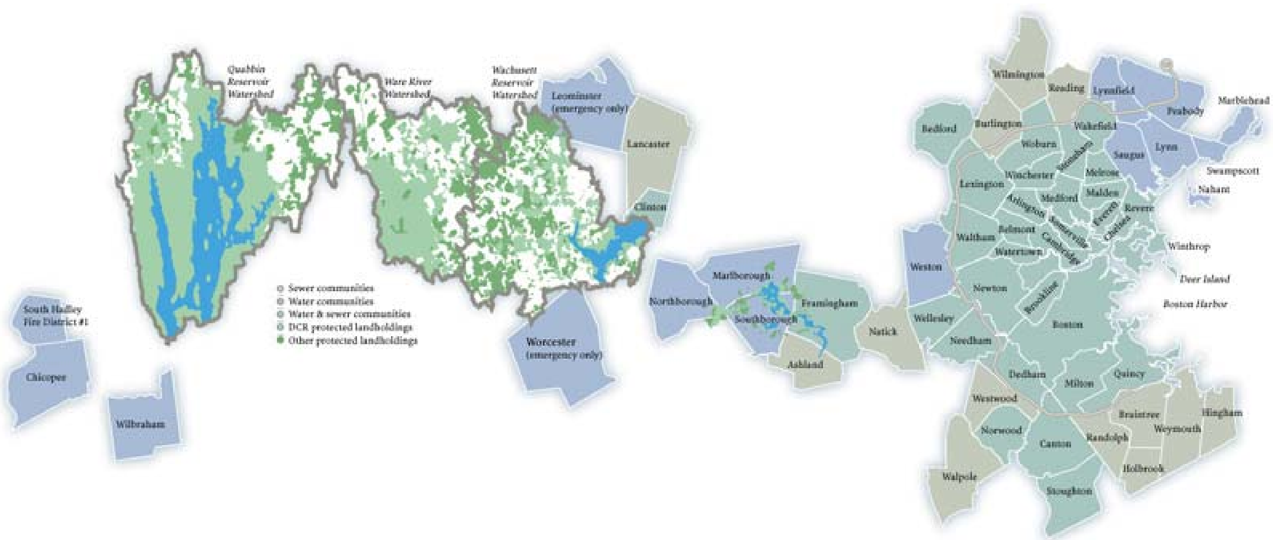
The Massachusetts Water Resources Authority (MWRA) is one of the major public water utilities in the United States. MWRA is a Massachusetts public authority established by an act of the Legislature in 1984 [Chapter 372 of the Acts of 1984] and is empowered to “operate, regulate, finance, and improve the delivery of water and sewerage collection, disposal and treatment systems and services and to encourage conservation”.

The MWRA provides wholesale water and sewer services to 2.5 million people and more than 5,500 large industrial users in 61 metropolitan Boston communities.

Facts and Figures Summary

- **2.5 million people served**
- **890,000 households served**
- **5,500 businesses served**
- **255 million gallons per day of water supplied (average)**
- **390 million gallons per day of waste water/sewage treated (average)**
- **43 sewerage communities**
- **46 water communities**
- **61 metropolitan communities collectively**

<u>MWRA Service Area</u>



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2 Overview of Utility Operations and Assets at the Deer Island Treatment Plant (DITP)

The new Deer Island Sewerage Treatment Plant (DITP) is the centerpiece of the MWRA's $3.8 billion program to protect Boston Harbor against pollution from Metropolitan Boston's sewer systems. The plant's purpose is to remove human, household, business and industrial pollutants from wastewater that originates in homes and businesses in 43 greater Boston communities. Then, complying with all federal and state environmental standards and subject to the precedent–setting discharge permit issued for the plant by EPA and DEP, the treated wastewater can be released to the marine environment. Here are some key facts and figures on the treatment plant:

- The plant serves more than 2 million people. It is the second largest sewage treatment plant in the United States. The plant's peak capacity is 1.27 billion gallons of wastewater per day. Average daily flow is about 380 million gallons per day (mgd).
- The plant has been constructed under a schedule, established and overseen by a federal district court judge to achieve compliance with the Federal Clean Water Act. The Federal Clean Water Act requires that the Deer Island Treatment Plant comply with a permit under the National Pollutant Discharge Elimination System (NPDES). The NPDES permit, issued by EPA with a parallel state permit from the Massachusetts Department of Environmental Protection, sets stringent conditions and limits on the effluent discharges from the plant and establishes many other important requirements.
- About 350 MWRA employees, including plant operators, maintenance trades-people, engineering personnel, management workers and laboratory staff now run the DITP plant.

The primary components of the Plant are laid out as follows:

2.1.1 Pumping

Wastewater "influent" from MWRA customer communities arrives at the plant through four underground tunnels. Pumps then lift the influent about 150 feet to the head of the plant. There are three main pump stations. The North System is served by the North Main Pump Station and the Winthrop Terminal Headworks, containing ten 3,500 hp pumps and six 600 hp pumps. The capacity for the North System is 910 MGD. The Lydia Goodhue Pump Station for the South System can handle an additional 360 MGD of flow, and contains eight 1,250 hp pumps. The pumping capacity at the new Deer Island plant has dramatically increased the volume of wastewater that can be taken into the plant from the conveyance tunnels. This reduces back-ups and overflows throughout the system when wet weather causes peaking of system flows.

2.1.2 Preliminary/Primary Treatment

After pumping, flows pass through grit chambers that remove grit for disposal in an off-island landfill. Next, flows are routed to primary treatment clarifiers that remove about half of the pollutants brought to the plant in typical wastewater (50-60% of total suspended solids and up to 50% of pathogens and toxic contaminants are removed). In this step, gravity separates sludge and scum from the wastewater. The plant uses 48 primary clarifiers each 186 feet long by 41 feet wide by 40 feet deep. The clarifiers have a "stacked" settling surface at mid-depth to double the settling capacity of the tanks that are squeezed into the tight space confines of Deer Island.

2.1.3 Secondary Treatment

Secondary treatment mixers, reactors and clarifiers remove non-settleable solids through biological and gravity treatment. The biological process is a pure, oxygen-activated sludge system, using microorganisms to consume organic matter that remains in the wastewater flow. Secondary treatment raises the level of pollution removal to over 85%. The first and second of three "batteries" of secondary treatment were completed in 1997 and 1998. The third battery of secondary treatment became operational in Fall 2000. Over one hundred tons of pure oxygen are manufactured each day at Deer Island's cryogenic facility to support the biological treatment process.

2.1.4 Sludge Digestion

Sludge and scum from primary treatment are thickened in gravity thickeners. Sludge and scum from secondary treatment are thickened in centrifuges. Polymer is added in the secondary thickening process to increase its efficiency. Digestion then occurs in 12 distinctive egg-shaped anaerobic digesters, each 90 feet in diameter and approximately 130 feet tall. Mimicking the stomach's natural digestion process, microorganisms naturally present in the sludge work to break sludge and scum down into methane gas, carbon dioxide, solid organic byproducts, and water. Digestion significantly reduces sludge quantity. The methane gas produced in the digesters is used in the plant's on-site power generating facility to save operating costs by reducing consumption of purchased energy. Digested sludge leaves

Deer Island by barge for the MWRA Pelletizing Facility at Fore River, where it is further processed into a fertilizer product.

2.1.5 Odor Control

Air scrubbers and carbon adsorbers remove odors and volatile organic compounds from treatment process "off-gases". Odor control is used for primary and secondary treatment process facilities, as well as the sludge processing, plant pumping, and grit removal facilities. Odor control performance is constantly monitored and is governed by a special DEP air quality permit.

2.1.6 Disinfection

After passing through primary and secondary treatment, wastewater is disinfected with sodium hypochlorite to kill bacteria. There are two disinfection basins, each approximately 500 feet long with a capacity of 4 million gallons, in which the effluent is mixed with sodium hypochlorite. Finally, sodium bisulfite is added to dechlorinate the water, so that chlorine levels in the ultimate discharge will not threaten marine organisms. After disinfection and dechlorination, the effluent is ready to be discharged.

2.1.7 Effluent Discharge

A 9.5-mile 24-foot-diameter outfall tunnel transports effluent into the 100-foot deep waters of Massachusetts Bay. Effluent is discharged through more than 50 individual diffuser pipes, each with eight small ports, so that rapid and thorough mixing into surrounding water is achieved and water quality standards are not compromised by the discharge. Extensive environmental monitoring ensures that the environment is properly protected.

3 The DITP RCM Program

The Deer Island Treatment Plant became operational in the mid 1990s. It replaced a plant that had been decommissioned early, largely due to poor maintenance practices. As a result, DITP management was committed to establishing a world-class maintenance program for the new plant. This lead to the Facilities Asset Management Program, or FAMP. The MWRA solicited bids from several consulting firms to assist with the planning and execution of the Facilities Asset Management Program, and selected New Dimension Solutions (formerly Spearhead System Consultants) – a consulting firm based in New York which specializes in driving value from best practice Enterprise Asset Management and Reliability.

3.1 Facilities Asset Management Program

In 2000 the MWRA commenced the Facility Asset Management Program (FAMP) for the Deer Island Treatment Plant and related Residuals and Transport (Pump Stations) facilities to plan, manage, and coordinate the engineering, maintenance, operation, and financing required to maintain these facilities to regulatory requirements. The Facilities Asset Management Program can be further described as having two objectives:

- To cost-effectively replace the less durable capital components of the facilities at the appropriate time to ensure reliable plant operation and preserve the value of the original investment.
- To prolong the equipment life and control the rate of replacement of major asset systems (i.e. to avoid large spending spikes for consolidated retrofit or rehabilitation).

The Authority issued a Request for Qualifications/Proposal (RFQ/P) to secure professional services to develop the most efficient strategy to integrate maintenance, operations, and engineering activities to support the FAMP objectives in October 1999. NDS responded to the RFQ/P and was awarded the contract in March 2000.

In order to implement the FAMP objectives, NDS was required to perform several tasks. These are detailed in Attachment C and included standardization of the maintenance management systems, practices and procedures for the Sewerage Division. NDS also provided uniform maintenance information management standards and condition monitoring capabilities to the Deer Island Treatment Plant (DITP) and its related Residuals and collection system (Transport – Pumping Stations) facilities. Additionally NDS evaluated various maintenance strategy development practices. This study selected RCM as the optimal strategy for the MWRA. RCM was implemented on DITP's Primary Clarifier Battery A as a pilot project. Twelve analyses were completed on Primary Clarifier Battery A, which resulted in significant cost savings. These analyses were then used as templates for the remaining Primary Clarifiers. RCM2 has now been adopted as MWRA's maintenance strategy development tool of choice and has also been rolled out to Field Operations (Waterworks and Transport divisions). NDS was awarded an additional contract to provide additional RCM services to extend the RCM program to additional sections of the DITP facility and other areas of the MWRA.

The pilot program consisted of twelve systems, started on the dates shown, all from Battery A, or A and B combined:

- Primary Sludge Pumps	July 2000
- Primary Scum Removal System	August 2000
- Channel Aeration Blowers	October 2000
- Primary Sludge Longitudinal Collectors	November 2000
- Primary Gallery A/B HVAC System	December 2000
- Influent and Effluent Sample Pumps	January 2001

- Chlorine Gas Detector System	February 2001
- Hot Water (W5) Flush System	March 2001
- EB1 Power Supply	January 2001
- A/B Building Fire Systems	March 2001
- Primary Sludge Cross Collectors	March 2001
- Primary Sump Pumps	April 2001

After the pilots were completed, the RCM program was extended and rolled out to replicate the above for the other three batteries and extend on to other assets as listed below:

- B/C/D Influent and Effluent Sample Pumps	August 2001
- C/D Building Fire Systems	September 2001
- B/C/D Chlorine Gas Detectors	October 2001
- B/C/D Cross Collectors	October 2001
- B/C/D Primary Sludge Pumps	December 2001
- B/C/D Primary Scum Removal System	January 2002
- C/D Primary Gallery HVAC System	January 2002
- B/C/D Primary Sump Pumps	November 2001
- EB2/EB3 Power Supply	May 2002
- RSL Pumps	July 2002
- East Odor Control Scrubber	July 2002
- A Cryogenics Air Compressors	September 2002
- A Digester Gas Compressors	September 2002
- North Main Pumps	November 2002
- A Hypochlorite Feed Pumps	December 2002
- South Main Pumps	February 2002
- A Sodium Bisulfate Dechlorination	January 2003
- W3L Pumps	March 2003
- WSL Centrifuges	April 2003
- A Secondary Collectors	July 2003
- Channel Aeration Review	July 2003
- NMPS HVAC	August 2003
- A Secondary Scum Pumps	August 2003
- Winthrop HVAC System	September 2003
- Winthrop Pumps	September 2003
- NMPS Hydraulics	October 2003
- Hypo Receiving	September 2003
- B/C/D Cryogenic Air Compressors	November 2003
- Digester Flares	December 2003

These assets were selected using the attached criticality matrix (Attachment C) based on utilization of NDS Asset Criticality Analysis tool. NDS and MWRA management reviewed each asset in the plant, noted its consequence and likelihood scores, and then multiplied them together. These products were ranked, and the most critical selected for analysis. After the pilot, the MWRA continued to work down the list. At the present time, this process is still ongoing, at a rate of about twenty analyses per year. Management estimates about 250 more systems will be analyzed.

As mentioned above, DITP is divided into four batteries, each with very similar equipment. Therefore, equipment in Battery A was selected to be analyzed, and then the Battery A analyses were used as ***templates*** and adapted for Batteries B, C and D.

In most cases, there were no major design differences between assets in each Batterybaseline. In several cases, one battery had had some additional ancillary equipment installed, but this seldom required more than one meeting to analyze.

After the audit team had signed off on a new analysis, the group would reconvene with all appropriate drawings and work through the analysis to make the necessary changes for each replication/variant analysis using the initial asset system analysis as a template. This usually took one meeting of three hours, in which time several replications or variants could be made.

The database shows that, in most cases, one analysis was completed and audited, a process that usually took about two months, before the replications/variants were created. Once an original was approved, a period of between three and twelve months elapsed before the replicant/variant analyses were started. The time required to take a replicant/variant analysis to the final sign off point ranged from one to fifteen months.

Few analyses of initial asset systems required less than six or more than ten meetings of 5 hours each. For the pilot projects, meetings were scheduled daily, from 7:30 to 12:30. For the later analyses, meetings were scheduled every other day at the same hours.

A total of twenty three MWRA employees were trained as facilitators as part of the FAMP program. Of these, twelve are associated with DITP, while the other nine work for the Field Operations Division.

Altogether, 290 people from DITP and FOD have been trained to date in the RCM II process. All full review group members were drawn from this list.

Analyses were audited by a group of managers of the appropriate plant. This group consisted of the Director of the plant, the Deputy Director of Maintenance, the Deputy Director of Operations, the Deputy Director of Capital Engineering and the Asset Manager. All members of the review group were also invited, and about fifty percent attended. The auditors were provided with copies of the draft one week before the meeting, and would ask for clarifications or make suggestions based on their experience. A typical audit analysis produced between ten and twenty changes, most of them minor rewording of failure effect descriptions.

NDS provided all the consulting services to the RCM program. This involved training all the above-mentioned personnel, facilitating a number of the initial analyses, reviewing the other analyses, and coaching the MWRA facilitators until they reached a high level of skill.

The group members involved in the RCM program had to divert a certain amount of time from their regular jobs. This was somewhat disruptive to the normal work schedule, but management was able to limit problems by choosing times and participants carefully.

The cost of NDS' services directly related to RCM at Deer Island has been $496,969.32 to date, over a period of several years.

DITP management formed a total of ten task teams to keep control of the various components of the FAMP program. One of these is the RCM group. This group meets regularly, and posts a progress update on the corporate web site every month.

The person most responsible for running the RCM program at DITP is John Colbert, the Asset Manager. He leads the task team. This group works with the appropriate division managers to select members of new analysis teams, and to develop the schedule of analyses.

After an analysis has been signed off by the audit team, the Operations department takes the list of changes to procedures and implements them. The Maintenance department makes all approved PM changes. John Colbert has developed a spreadsheet on which he keeps track of all these, as well as all the one-time adjustments developed by the analyses. It is his job to ensure that the Operations and Maintenance departments remain on track, and that redesigns or training talks occur within a reasonable time.

4 Benefits of the RCM Program at MWRA

The RCM Program conducted at the MWRA has resulted in a significant reduction in fixed-interval tasks (commonly known as PM's). The reductions in fixed-interval maintenance hours generated by RCM2 came from three main sources. Firstly, operators were assigned to perform significantly more of the work in the form of regular monitoring of the equipment under their control. This was often being done informally by the operator in any event, but the RCM2 program has ensured that operator maintenance is properly organized and controlled. Secondly, the RCM2 analyses emphasized how much redundancy is built into the DITP design. As a result, many fixed-interval maintenance tasks could be replaced with a run-to-failure maintenance strategy. Thirdly, as mentioned above, the RCM2 program replaced a maintenance program based on vendor recommendations. Many of these recommendations are unnecessarily conservative, as they have to cover all likely situations.

4.1 Primary Clarifiers

Trade	Annual fixed-interval maintenance hours before RCM analysis	Annual fixed-interval maintenance hours after RCM analysis	Change
Mechanical	21.5	10.6	-10.9
Electrical	18.75	1.5	-17.25
Instrumentation	1	6.5	+5.5
Painter	1	8.5	+7.5
Operations	0	0.7	+0.7
Building & Grounds	0	8	+8
Total	**42.25**	**35.8**	**-6.45**
Change			**-15.3%**

There are twelve Clarifiers in each battery, giving a total of 48. For 48 Clarifiers, the above figures work out to a reduction of 309.6 PM hours per year. MWRA management estimates the average cost per maintenance work hour is $35. Therefore, the RCM2 program saves about $10,836 per year for the Clarifiers.

4.2 Primary Sludge Pumps and Ancillary Equipment

Trade	Annual fixed-interval maintenance hours before RCM analysis	Annual fixed-interval maintenance hours after RCM analysis	Change
Trade	**Annual PM hours before RCM analysis**	**Annual PM Hours after RCM analysis**	**Change**
Mechanical	252	103.2	-148.8
Electrical	584	18.24	-565.76
Instrumental	10	51.88	+41.88
Plumbing	0	9.16	+9.16
Total	846	182.48	-663.52
Change			**-78.4%**

The main reason for the vast reduction in PM hours for this asset was the decision to change the operating context. There are three pumps for each battery, and prior to the RCM2 analysis, all three had been used equally in rotation. After the analysis, one was made a standby, and the other two used together. This allowed a significant number of PM tasks to be removed, as there is now a stand-by pump available full-time. This reduction in PM hours works out to a saving of $22,948 per year.

4.3 Return Sludge Pumps

Trade	Annual fixed-interval maintenance hours before RCM analysis	Annual fixed-interval maintenance hours after RCM analysis	Change
Mechanical	171.5	110.7	-60.8
Electrical	145.6	13.5	-132.1
Instrumental	0	45.9	+45.9
Total	317.1	170.1	-147.1
Change			**-46.3%**

At $35 per hour, the reduction of 147.1 PM hours works out to an annual saving of $5,145. This reduction was achieved almost exclusively by shifting work to operators.

3.4 Cryogenic Facility Compressor 2B

Trade	Annual fixed-interval maintenance hours before RCM analysis	Annual fixed-interval maintenance hours after RCM analysis	Change
Mechanical	59.24	6.6	-52.64
Electrical	6.6	6.5	-0.1
Instrumental	39.56	5.5	-34.06
Painter	0	16	+16
Total	105.4	34.6	-70.08
Change			**-67%**

Removing 70.08 PM hours works out to an annual cost saving of $2,478. As in the above example, this was achieved primarily by transferring work to the operators.

The above tables illustrate some examples of the RCM2 program lowering PM costs. In several cases, the program resulted in significant changes to the operating philosophy of an asset, which often led to significant cost savings. One example of this can be seen above, in the Primary Sludge Pumps, where the decision to turn one pump per battery into a full-time standby allowed a significant drop in PM tasks.

A second example comes from the Primary Sump Pumps. Here, recognition of the high level of redundancy in the system led to a decision to completely stop all PM activity, going from 214 hours to zero for a yearly saving of $7,461.

The third example comes from the Influent and Effluent Sample Pumps. Adopting an approach of flushing them out manually after use instead of a regular PM program, as the pumps are not used very often, allowed a one-time cost of about $5,000 to replace an annual PM cost of $4,665.

5 Hidden Failures : Results Achieved

Reviewing 42 RCM analyses performed to-date, these produced 1,143 hidden failure modes across the 42 analyses, for an average of about 27 per analysis. This is approximately 23.4% of the total failure modes analyzed. Of these, 726, or 64%, are actively managed by fixed-interval tasks (preventive or failure-finding tasks), 259 by "no scheduled (fixed-interval) maintenance", and 158 required redesign due to safety or environmental risks.

Accurate information about how many of these hidden failures were properly managed before the RCM program is not available. Clearly, the 259 for which no task was judged necessary were being adequately controlled previously (although fixed interval tasks were being performed in some cases), but of the others, anecdotal evidence suggests that, at best, approximately 50-60% of hidden failure modes were being managed in a satisfactory manner.

6 Overall Financial Effect of the RCM Program

The best illustration of the overall effect of the RCM2 program on DITP maintenance costs and practices can be seen in the attached charts (**Attachment A – 1998-2003 and Attachment B YTD 2004**). Some of the data from these charts is summarized below:

	2000	2003	Change
PM Work Orders	40,000	24,000	-16,000
CM Work Orders	6,800	4,100	-2,700
CM/Project Hours	120,000	100,000	-20,000
PM Hours	80,000	55,000	-25,000

[**PM** = Fixed Interval Work Orders; **CM** = Corrective Maintenance Work Orders]

All the RCM2 analyses done at DITP included a summary of the predicted benefits. In the later analyses, this incorporated a comparison of the existing PM regime with that recommended by RCM2. On average, this showed a drop of about 130 hours per year per analysis. For 33 completed analyses, this works out to 4290 hours per year, which works out to an annual saving of at least $150,000 from RCM. The rest of the decline in PM hours is the result of other PM consolidation efforts, many also closely involving NDS.

The decline in CM of 20,000 hours works out to a saving of $700,000 per year. How much of this is due to RCM is not possible to quantify. The reduction in CM hours does show that the Fixed Interval (PM) reduction certainly did not result in additional corrective maintenance work. It is indeed apparent that the effective maintenance applied as a result of the RCM analyses, has supported a substantial reduction in corrective maintenance work.

In summary over the three year period from 2000 to 2003, as results of the FAMP project took effect, the hours required for Fixed-Interval PM work reduced from 80,000 hours per year down to 55,000. During the same period, Corrective Maintenance and project hours also declined from 120,000 to 80,000 hours. This means that maintenance hours in total declined by 45,000 hours per year during this period (c 25%). Plant availability was consistently maintained in the upper nineties (%) during the same period.

One of the motivators for MWRA management regarding the FAMP project was the concern that maintenance costs would start to rise as the plant aged (DITP was commissioned in the mid nineties). The FAMP project, using RCM as its foundation stone, has instead accomplished a major increase in maintenance productivity.

7 Intangible Benefits

7.1 Knowledge of the Assets

The greatest intangible gain from the RCM2 program in the opinion of DITP management was knowledge of the assets on the part of operators and maintainers. Working through the details of each system in what is still a fairly new plant, resulted in all group members learning much about the inner workings of the systems they work with, as well as a clearer view of how each fits into the overall plant design and process flow. These gains are illustrated by the following quotations from DITP employees:

"*I thought I knew everything about this system, but after a few RCM analysis sessions, I realized I only knew about 10%. Now, through the knowledge transfer that occurred during RCM, I could teach a course.*"

Operator's comment

"This is more than I ever wanted to know about this system."

Mechanic's comment

As is implied in the first quotation, all the knowledge gathered from the different members of the review groups is kept within the utility to a much greater degree than before, reducing the impact of the staff losses DITP is currently experiencing.

7.2 Communication and Teamwork

In the opinion of DITP management, the next most significant intangible effect of the RCM program was the improvement it generated in communication, both between Operations and Maintenance and between management and the workforce. Over the last couple of years, DITP has reduced its workforce considerably, and this generated some expected suspicion from the workers about the real intent behind the RCM2 initiative. This was eventually dispelled, as shown in the following quotation:

"*I was very skeptical. I thought this would be another tool for cutting the workforce. Now I am impressed with the level of detail that RCM actually goes into. The people that actually do the work are the ones making the decisions on how the equipment is maintained.*"

HVAC Technician's comment

7.3 Ownership of the Maintenance Program

One effect of the involvement of the blue-collar input in the development of maintenance strategies that the RCM2 process encourages is a greater feeling of ownership on the part of the technicians who actually perform the maintenance. The best demonstration of this is, as can be seen in the attached charts, the fact that the PM completion rate has risen from 82% to 92% since the RCM program began in 2001.

"I'll do more analyses. I'm sold. I think we're creating something good here."

-Mechanic's comment

7.4 Drawings

As DITP is a relatively new plant, a reasonably complete and current set of drawings was in place before the RCM analyses began. However, the close attention paid to the drawings by the analysis teams often revealed a number of small changes to be made to bring drawings up-to-date with the real-world configuration.

8 Safety Benefits

Safety was not a significant problem at DITP before the RCM2 program began. However, a number of RCM2 analyses have produced significant recommendations to improve safety. Many of these recommendations have been simply to add extra warning signs or lights in areas that may have been overlooked by the initial builders of the site. Other recommendations have reworked some operating procedures to eliminate unnecessary risks, or led to the replacement of outdated or obsolete safety equipment, such as an old model Chlorine monitor in one Battery.

The most interesting safety enhancement resulting from the RCM2 initiative resulted from the decision to apply the RCM Review Group approach to revising a confined-space work procedure that had caused considerable friction between management and maintenance workers. This led to the creation of a new procedure that ended the often sharp debate, and was completely acceptable to all sides. This also contributed to the improvement in corporate communications created by RCM2.

9 Conclusions on the DITP RCM2 Program

The RCM2 program was launched with two main purposes in mind. The first was to conserve money, the second to ensure the plant will remain in service for at least its intended life of fifty years. The optimization of the site's maintenance programs (fixed-interval tasks) and reworking of operating procedures resulting from the initiative have indisputably accomplished the first objective. Ultimate success or failure with regard to the second cannot be definitively determined now, but the decline in Corrective Maintenance observed since the beginning of the initiative bodes well for the future.

The intangible benefits illustrated above were not specified in the initial reasons for launching the initiative, but they have been gratefully appreciated, and are one of the reasons for the push to now expand RCM2 to the Field Operations Division.

9.1 Management Comments on RCM Program at Massachusetts Water Resource Authority

The following comments on the RCM program have been provided by key management personnel at the MWRA with involvement with the RCM program or its effects/results.

RCM has provided us with a new tool with which to optimize our preventive maintenance program. It has taken us from a time-based approach to more of a failure mode and effects approach. We now look at our equipment with a different view of system operation including considerations for maintenance of standby equipment to effectively use plant redundancy.

Mark Johnson, Director, Metropolitan, Water Operations and Maintenance

RCM has helped MWRA to build a detailed O&M plan that considers safety and efficiency. This program represents a huge agency-wide commitment, including staff from all MWRA locations and job groups.

Rick Trubiano, Director of Field Operations

Equipment on Deer Island has been maintained from plant startup in accordance with original equipment designer's recommendations. Although this was a good starting point, the use of RCM has significantly improved our maintenance program. The operators and maintainers that have day to day hands on knowledge of the equipment operating context, maintenance and past failures are our experts that have helped designed a stronger maintenance program based upon RCM principles. Management's role has been to audit each analysis to ensure proper emphasis is focused on safety, environmental permit requirements, and operational standards.

John Vetere, Director, Deer Island Treatment Plant

"The use of RCM and other maintenance improvements, will help us stay within the best in class spending of 1-1.5% of Replacement Asset Value (RAV) as the plant ages by reducing overall O&M current expense and extending equipment life by better PM practices or operations."

John Colbert, Asset Manager, Deer Island Treatment Plant

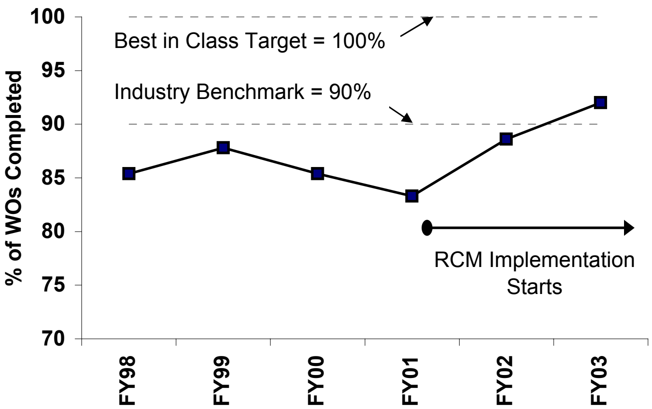
10 Attachment A - Results Achieved – 1998-2003

10.1 Chart 1

a. % of Preventive WO's Completed
b. % Light PM's performed by Operators
c. % of PM's Kitted
d. % of PDMs / PM's [PDM = On-condition tasks using PDM technology]

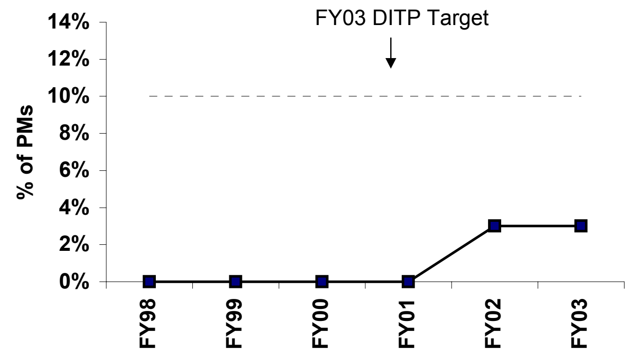
Yearly Maintenance Metrics
Proactive and Productivity Measures

Preventive Maintenance



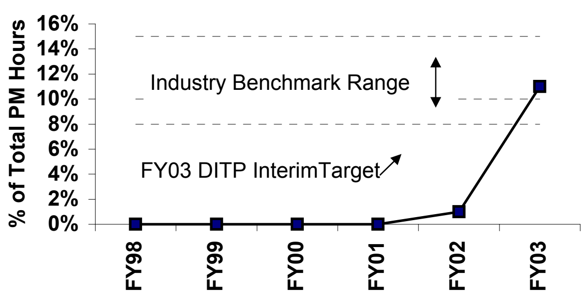
The industry benchmark is 90% PM completion. Upon reaching the 90% goal in FY02, the goal was raised to the best of class standard of 100% PM completion. The trend is continuing upward as RCM and PM Optimization efforts continue. In FY03 the PM completion increased by 6% from 86% to 92%.

Preventive Maintenance Kitting



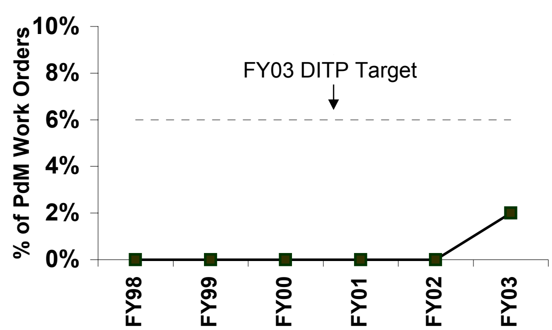
In an effort to increase wrench time, staff have been developing a process to "kit" all preventive maintenance work orders. Kitting is considered a best practice by maintenance and reliability professionals, and entails staging parts necessary to complete maintenance work. Kitting allows maintenance staff to spend more time turning the wrench rather than waiting for parts at the stockroom window. Work Coordination, Procurement and MIS are also working together on this initiative. In FY03, the process to kit parts was developed. Inventory items are now loaded into Maximo monthly so parts can be assigned to work orders. The Lawson Maximo interface is a critical component to kitting parts. The interface has been undergoing pilot testing at Deer Island since July 03. Many issues need to be resolved prior to full implementation of the interface. An aggresive goal of 10% was set in FY03; this goal was re-established for FY04. There is no water/wastewater industry benchmark for this goal.

Operations Light Maintenance PMs



The percentage of preventive maintenance work order hours completed by Operations has increased from less than 1% to 11% since January 2002. DI surpassed its FY03 target of 8% and reached the industry benchmark range of 10-15% in April 2003.

Predictive Maintenance



We plan to increase predictive maintenance activities through expansion of the existing lubrication and vibration programs. In FY03 staff training was completed in vibration analysis, acoustic ultrasonic analysis, and a lubrication task team was formed. Our goal is to increase predictive maintenance work from 2% to 6% of the total maintenance work hours by the end of FY04. Currently all scheduled predictive work is completed each month. Both the kitting and predictive maintenance goals are aggresive and motivate staff to implement these best in class maintenance initiatives. Staff will still continue to set high goals in these areas to facilitate implementing these new programs.

10.2 Chart 2

a. Overtime as % of maintenance wages and salary cost
b. Numbers of outstanding work-orders by task type
c. Maintainer hours by task-type

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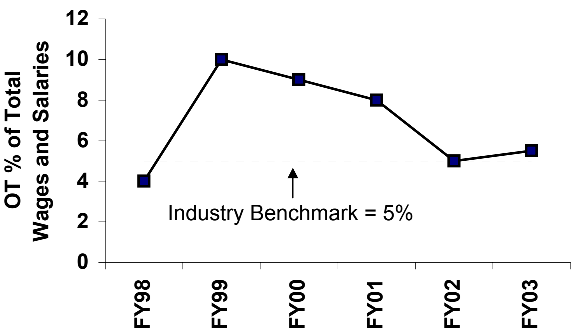
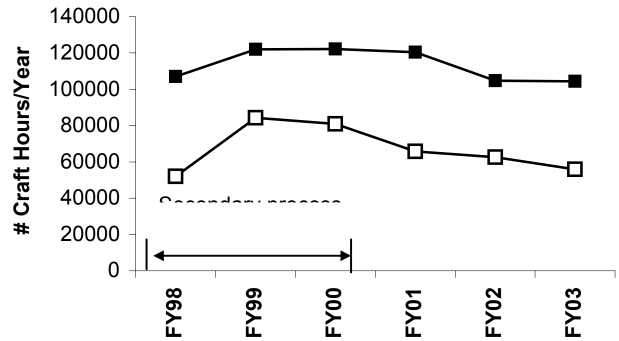
Yearly Maintenance Metrics
Overall Maintenance Program Measures

Overtime Percentage



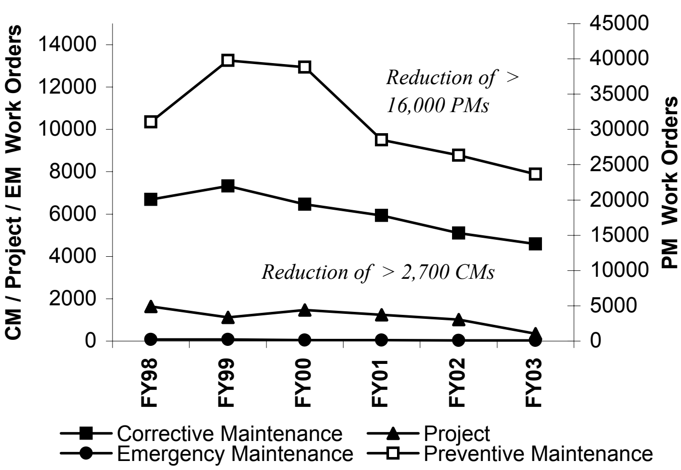
Overtime has decreased steadily from FY99 to FY02. The slight increase in FY03 is attributed to a loss of staff to early retirements and internal transfers which increased maintenance backlog. Additional OT expenditures into FY04 will be required until existing vacancies are backfilled.

Craft Hours Distribution



Optimization of the preventive maintenance program through the transfer of some light maintenance to Operations (11% of the PM hours at the end of FY03), elimination of duplicate work orders, decreasing PM frequency due to equipment history and performance, and Reliability Centered Maintenance recommendations has resulted in a significant decrease (28,300) of PM craft hours from FY99 to FY03

Craft Work Orders



The number of PMs has been significantly decreased due to a concerted effort to optimize the PM program based upon staff input, elimination of duplicate PMs, and implementing Reliability Centered Maintenance recommendations. The number of CMs and Project work orders have decreased as startup issues and initial design issues are resolved. The number of EM work orders continues to be very low showing that staff continue to maintain the appropriate level of equipment to support the NPDES permit. In upcoming years as the plant ages, it is expected that a leveling out and eventually an increase in CM and project work will occur.

10.3 Chart 3

a. Maintenance Budget and FTE's
b. Maintenance Cost as a % of Replacement Asset Value
c. Replacement Asset Value/ maintainer
d. Maintenance Backlog and % Availability

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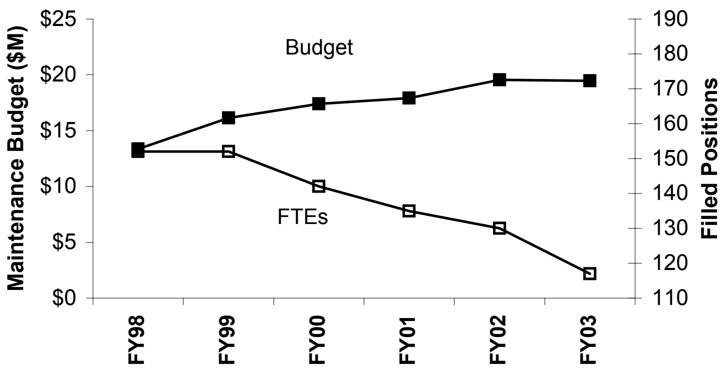
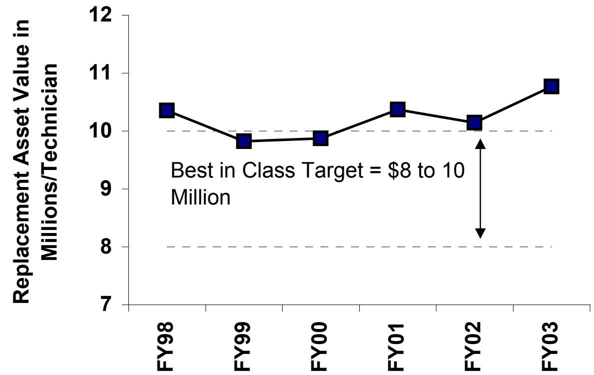
Yearly Maintenance Metrics
Overall Maintenance Program Measures

Maintenance Budget and FTEs



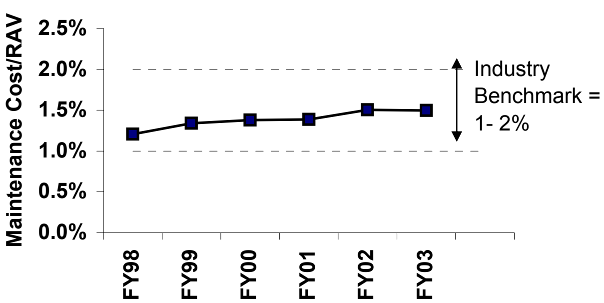
The number of FTE's has steadily decreased through staff attrition. Maintenance has been successful in meeting a number of its goals despite the decrease in staffing through implementation of numerous maintenance efficiencies including operations performing light maintenance, cross functional flexibility, and Reliability Centered Maintenance. Recent staff losses due to retirements and transfers to Walnut Hill have brought the maintenance staffing level below the level in certain trades necessary to support the maintenance program.
The maintenance budget has and will continue to increase in order to ensure proper maintenance of the plant assets as they age and as necessary to replace obsolete components.

Replacement Asset Value / Maintenance Technician



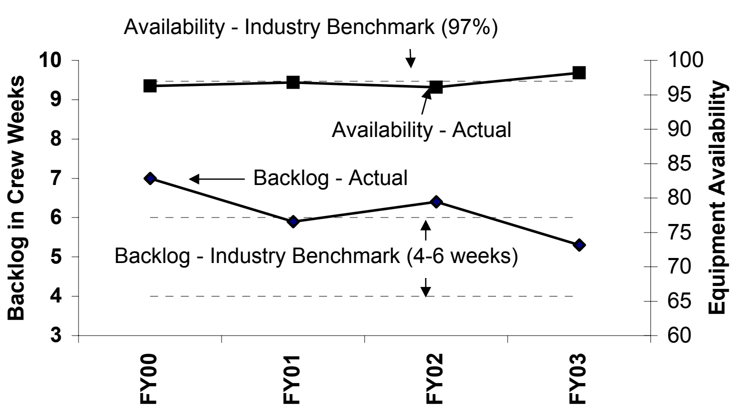
This metric is used to benchmark maintenance staffing. DITP has adopted the world class target of $8-10 Million/Technician. DITP exceeds the target at this time further justifying the need to backfill vacancies in certain key trades.

Maintenance Cost / Replacement Asset Value



This metric is used to determine if annual maintenance spending is within the industry benchmark adopted by DITP of between 1 to 2.0%. The current DITP maintenance spending is within the target range.

Backlog and Availability



The industry benchmarks for availability and maintenance backlog are 97% and 4 to 6 weeks respectively. Deer Island has attained both of these benchmarks in FY03. Although the average backlog in FY03 was within the industry average, it is important to note that the backlog in the last two months of FY03 exceeded the industry average. The backlog increased due to technician vacancies due to early retirements and transfers which will need to be addressed by using overtime in the short term until the vacancies are filled.

10.3.1 Notes on Figure on Maintenance Cost as % of Replacement Asset Value

If you look at the Maintenance Cost and number of FTE chart, the maintenance budget has increased as the plant has aged. The RAV increased as the plant was built, but now is a fixed value of $1.4 billion. The maintenance budget that is used in the RAV chart is the O&M current expense budget plus any Capital projects that are for equipment replacements. The overall O&M current expense budget has decreased but the capital budget for equipment replacement has increased. The reason for the increase is that the plant was built from 1996 to 2002. As with any new plant, there is a grace period where the new equipment does not require replacement and spending on maintenance is lower. As the plant ages, equipment wears out and more spending on maintenance is required. One example, is the drive chains for the primary clarifiers. The chain has a normal life of 5 years, and was replaced as it started to fail at a cost of $ 250,000. The use of RCM and other maintenance improvements, will help us stay within the best in class spending of 1-1.5% / RAV as the plant ages by reducing overall O&M current expense and extending equipment life by better PM practices or operations."

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11 Attachment B - Results Achieved – YTD FY04

11.1 Chart 1

a. % Light PM's performed by Operators YTD04
b. % of PM's Kitted YTD04
c. Maintenance Backlog in Crew Weeks YTD04
d. % of PM Work-orders Completed YTD04
e. % of PDMs / PM's YTD04[PDM = On-condition tasks using PDM technology]
f. Wage/salary cost and overtime cost performanceYTD 04

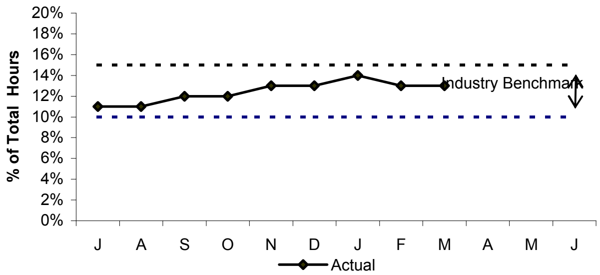
Deer Island Maintenance

3rd Quarter - FY04

Productivity Initiatives

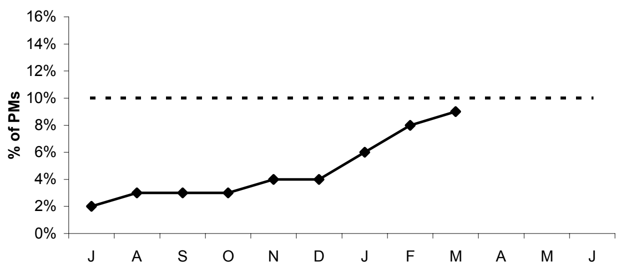
Productivity initiatives include Operations staff performing light maintenance and preventive maintenance kitting. Accomplishing these initiatives should result in a decrease in the overall maintenance backlog.

Operations Light Maintenance PMs



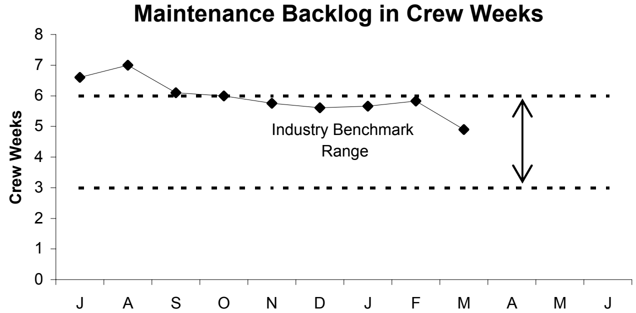
The percentage of preventive maintenance work order hours completed by Operations has increased from less than 1% in January 2002 to 13%. The total number of PMs issued each month varies due to the timing of quarterly, semi-annual, and yearly PMs. The decrease from 14% to 13% in the past months is from a higher number of total PMs issued. The industry benchmark is 10-15% of the total PM hours. This goal has been met.

Preventive Maintenance Kitting



The first step to increasing wrench time is to kit all preventive maintenance work orders. The FY04 aggressive goal is 10% of all PM work orders. This quarter kitting increased from 4% to 9%. The materials kitted to date include lubricants and HVAC materials.

Maintenance Backlog in Crew Weeks

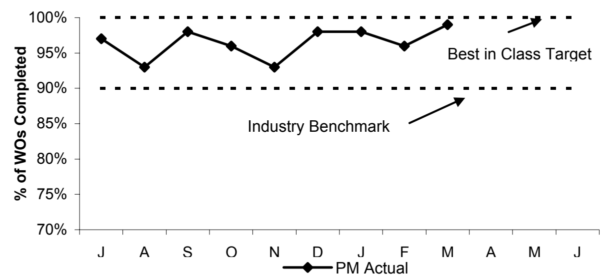


Backlog decreased to 5 weeks while overtime spending was under the monthly budget for the quarter. Management's goal is to control the overtime budget and stay within the industry benchmark backlog of 3 to 6 weeks. The decrease in backlog is due to completing high labor projects such as the gravity thickener rehabiliation.

Proactive Initiatives

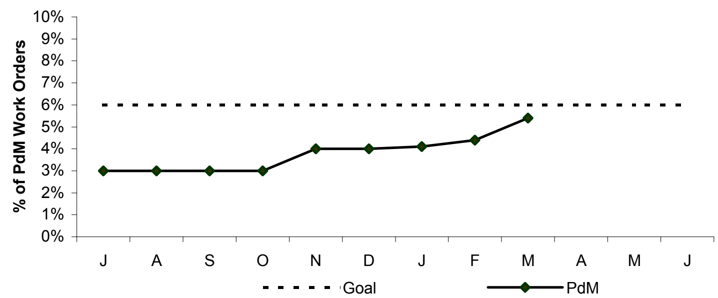
Proactive initiatives include completing 100% of all preventive maintenance tasks and increasing predictive maintenance tasks. These tasks should result in lower maintenance costs for emergencies, corrective maintenance, and overtime.

Preventive Maintenance

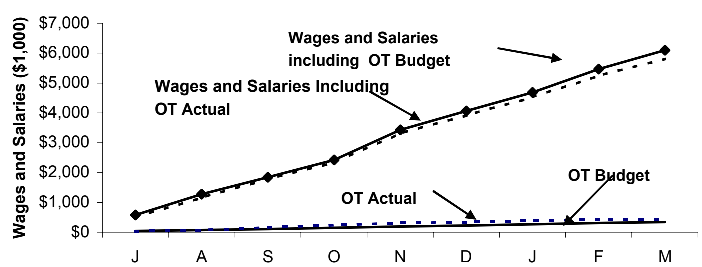


Preventive maintenance goals include completion of 100% of all PM work orders from Operations and Maintenance. Deer Island completed an average of 98% of its PMs this quarter. This is the highest PM percentage this fiscal year.

Predictive Maintenance



DI's FY04 aggressive goal is 6%. PDM tasks for vibration, oil analysis, and acoustic ultrasonics are currently being added to Maximo monthly to reach the year end goal. This quarter Pdm work orders have increased from 4% to 5.4%.



Although overtime is over budget by $74K at the end of March, Regular wages and salaries are under budget by $381K, for a net of $307K under budget for wages and salaries and overtime. Overtime spending for the last quarter is under budget. Overtime spending is expected to remain at budgeted levels or below for the remainder of the fiscal year.

12 MWRA Hidden Failures Data

System Name	*Analysis Status*	*Total Failure Modes*	*Hidden Failures*	*Hidden Failure with Tasks*	*Redesigns*
1. Primary Sludge	Commenced 7/6/00	89	31	12	0
2. Primary Scum	Commenced 8/17/00	127	29	16	0
3. Channel Aeration	Commenced 10/16/00	113	14	12	2
4. Upper Collector/ Lower Collector	Commenced 11/13/00	121	29	19	4
5. HVAC	Commenced 12/5/00	174	149	128	19
6. Sample Pumps	Commenced 1/17/01	108	35	20	0
7. Power Supply	Commenced 1/29/01	209	27	21	2
8. Chlorine Gas Detectors	Commenced 2/21/01	52	26	22	0
9. Hot Water Flush (W5)	Commenced 3/7/01	118	10	4	4
10. Building Fire Systems	Commenced 3/26/01	157	23	19	3
11. Cross Collectors	Commenced 3/28/01				
12. Primary Sump Pumps	Commenced 4/17/01	73	36	0	27
Total		1341	409	273	61

RCM TEMPLATING HIDDEN FAILURES

System Name	*Analysis Status*	*Total Failure Modes*	*Hidden Failures*	*Hidden Failure with Tasks*	*Redesigns*
13. Sample Pumps/Grinders - B/C/D	Commenced 8/20/01	18	2	2	0
14. Building Fire Systems - C & D	Commenced 9/19/01	159	23	19	3
15. Chlorine Gas Detectors - B & C	Commenced 10/01	59	23	18	5
16. Sludge Collectors - B/C/D	Commenced 10/1/02	121	29	19	4
17. Primary Sludge Pumps – B & C	Commenced 12/5/01	80	30	12	0
18. Primary Scum - B&C and D	Commenced 1/2/02	125	23	10	2
19. HVAC - C & D	Commenced 1/7/02	148	121	112	19
20. Sump Pumps - C & D	Commenced 11/1/01	73	36	0	6
21. Power Supply - EB2 and EB3	Commenced 5/7/02	209	27	21	2

Total		992	314	213	41

RCM ROLLOUT HIDDEN FAILURES

System Name	***Analysis Status***	***Total Failure Modes***	***Hidden Failures***	***Hidden Failure with Tasks***	***Redesigns***
22. Confined Space Primary	Commenced 3/1/02	--	--	--	--
23. RSL Pumps	Commenced 7/15/02	99	22	14	2
24. East Odor Control Scrubber	Commenced 7/16/02	212	41	20	17
25. Cryogenics Air Compressors	Commenced 9/8/02	199	28	24	0
26. Digester Gas Compressors	Commenced 9/4/02	115	34	24	3
27. North Main Pumps	Commenced 11/13/02	213	23	14	2
28. Hypochlorite Feed Pumps	Commenced 12/13/02	106	13	10	2
29. South Main Pumps	Commenced 2/3/03	191	61	27	11
30. Sodium Bisulfate Declorination	Commenced 1/27/03	116	15	**11**	**3**
31. W3L Pumps	Commenced 3/3/03	133	24	4	3
32. WSL Centrifuges	Commenced 4/7/03	203	3	1	0
33. Secondary Collectors - Template	Commenced 7/7/03	86	14	8	1
3. Rev. 1 - Channel Aeration Annual Review	Commended 7/29/03	125	12	12	0
34. NMPS HVAC - Template	Commenced 8/12/03	81	3	2	0
35. Secondary Scum - Template	Commenced 8/19/03	105	21	9	3
36. Winthrop HVAC - Template	Commenced 9/9/03	-	-	-	-
37. Winthrop Pumps - Template	Commenced 9/23/03	-	-	-	-
38. NMPS Hydraulics	Commenced 10/6/03	99	33	16	1
39. Hypo Receiving	Commenced 9/29/03	99	3	2	0
40. Cryo Air Compressors - Template	Commenced 11/3/03	193	26	22	0
41. Digester Flares	Commenced 12/29/03	114	38	18	8
42. Digester Mixers	Commence 3/1/04	50	6	2	0
Total		2539	420	240	56

		Total Failure Modes	***Hidden Failures***	***Hidden Failure with Tasks***	***Redesigns***
Pilot		1341	409	273	61

Pilot Template		992	314	213	41
Rollout		2539	420	240	56
		4872	1143	726	158
			23.4% of total failure modes identified have hidden failures	64% of the hidden failures have identified a scheduled task	14% of the hidden failures require a redesign to address an environmental or safety issue.

13 Attachment C – FAMP Program Detail and Project Structure

13.1.1 Task 1- Project Administration and Management

NDS administered, managed and coordinated all work on the project on a daily basis. NDS reviewed and prepared management information, progress reports, project requirements and provided management action needed to maintain budgets and schedules, as well as maintaining the highest standard for quality of all work.

13.1.2 Task 2 - Residuals and Transport Facilities Equipment Inventory and Computerized Maintenance Management Setup

13.1.2.1 Management Setup

The MWRA Sewerage System (excluding DITP) consists of 29 facilities located in Boston and the metropolitan area. A total of 28 facilities are managed by the Transport Department and are referred to as "Transport" facilities. Transport is comprised of three facility types: Head-works, Pump Stations and Combined Sewer Overflows. Of these facilities, 18 were the subject of this task. NDS' objective was to carry out the following:

- Gather and record all available technical data (performance, maintenance, etc.) on the Residuals and Transport plant equipment. Tag all plant and equipment utilizing the same protocols and nomenclature as DITP. NDS developed a software program for a Palm Pilot to automate the equipment tagging process. The condition of the plant and equipment was also assessed during the tagging and data gathering activities.

- Review, organize and adapt existing Residuals and Transport preventive maintenance tasks to the Maximo computerized maintenance management system (CMMS).

- Enter the all the technical data and preventive maintenance tasks into the Maximo CMMS.

- Develop all the business process models for the efficient use of MAXIMO.

- Provide various levels of training for the use and support of MAXIMO.

NDS has completed the following activities to date:

- Gathered and recorded all available technical data, tagged all plant and equipment for seven of the Residuals and Transport facilities
- Developed the relevant business process models for the efficient use of MAXIMO.

13.1.3 Task 3 - Condition Monitoring System Evaluation and Design

The MWRA has identified, in advance of the plant wide maintenance optimization effort to be carried out under Task 4 sixty-seven pieces of rotating equipment as critical or of sufficient capital cost to warrant a dedicated vibration monitoring system. NDS' objective was to carry out the following:

- Inspect the sixty-seven pieces of rotating equipment, along with all relevant technical information and prepare a concept design report and design criteria for a new condition monitoring system
- Prepare a detailed design for the installation of the new condition monitoring system
- Provide engineering services during construction and supervise, inspect and test the installation of the new condition monitoring system. The condition monitoring system shall be provided and installed by a contractor under a separate contract.

- Provide vibration analysis training
- Establish baseline vibration signatures for all 67 pieces of equipment
- Review technical specifications for existing vibration analysis service contract and offer recommendations for improvement.

NDS has completed the inspection of all sixty-seven rotating pieces of equipment and a concept design report for the new condition monitoring system. NDS is in the process of developing the detailed design for installation.

13.1.4 Task 4 – DITP MAXIMO Survey and Maintenance Optimization Pilot Study

DITP previously utilized a calendar-based preventive maintenance program. All the maintenance tasks and frequencies were based on OEM recommendations as required by the Boston Harbor Project. NDS' task has been to:

- Conduct a maintenance management assessment of DITP maintenance systems, including the MAXIMO computerized maintenance management system and determine the status of its data quality, its present utilization, and its suitability to support a maintenance optimization process.
- Evaluate various maintenance optimization strategies such as Reliability-Centered Maintenance (RCM), Total Productive Maintenance (TPM), Root Cause Analysis (RCA), etc. and various equipment life cycle costing methodologies and recommend the best combined strategy for implementation on DITP, Primary Clarifier Battery A.
- Implement the recommended strategy and write a report on the results.

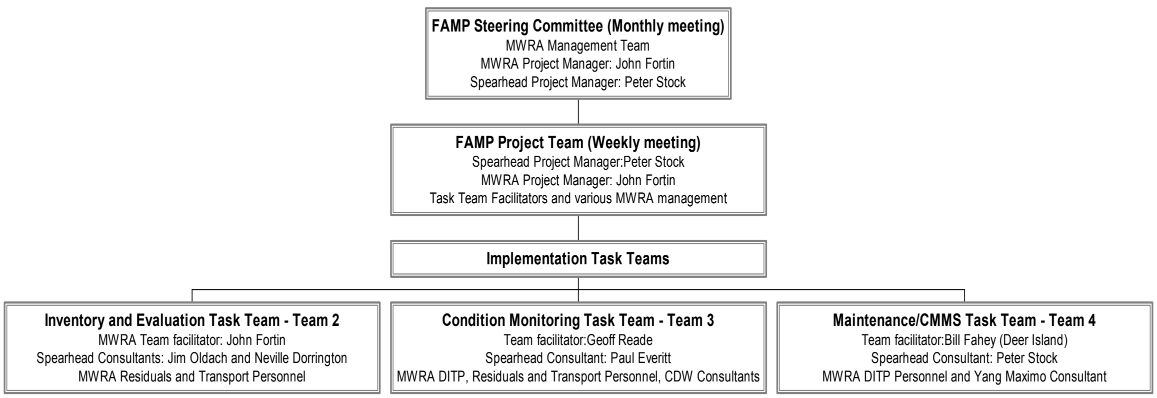
NDS has completed the following activities to date:

- Maintenance management assessment and the MAXIMO survey
- Maintenance optimization strategy evaluation, recommending RCM
- RCM analyses of equipment of Primary Clarifier Battery A.

13.1.5 Project Team Structure

See the figure below

Facilities Asset Management Program (FAMP)
Initial Project Organizational Structure 2000



The FAMP project organizational structure was made up of the following groups:

- FAMP Steering Committee was made up of MWRA management from DITP, Residuals and Transport as well MWRA's and NDS' project managers. The steering committee reviewed recommendations put forward by the task teams, project progress and resolves any issues that may need attention.
- FAMP Project Team was made up of the two project managers from MWRA and NDS and the Task Team facilitators. This team reviewed work completed, activities to be addressed that week and any issues that need immediate attention on a weekly basis.
- The task teams carried out the activities of their respective task teams.

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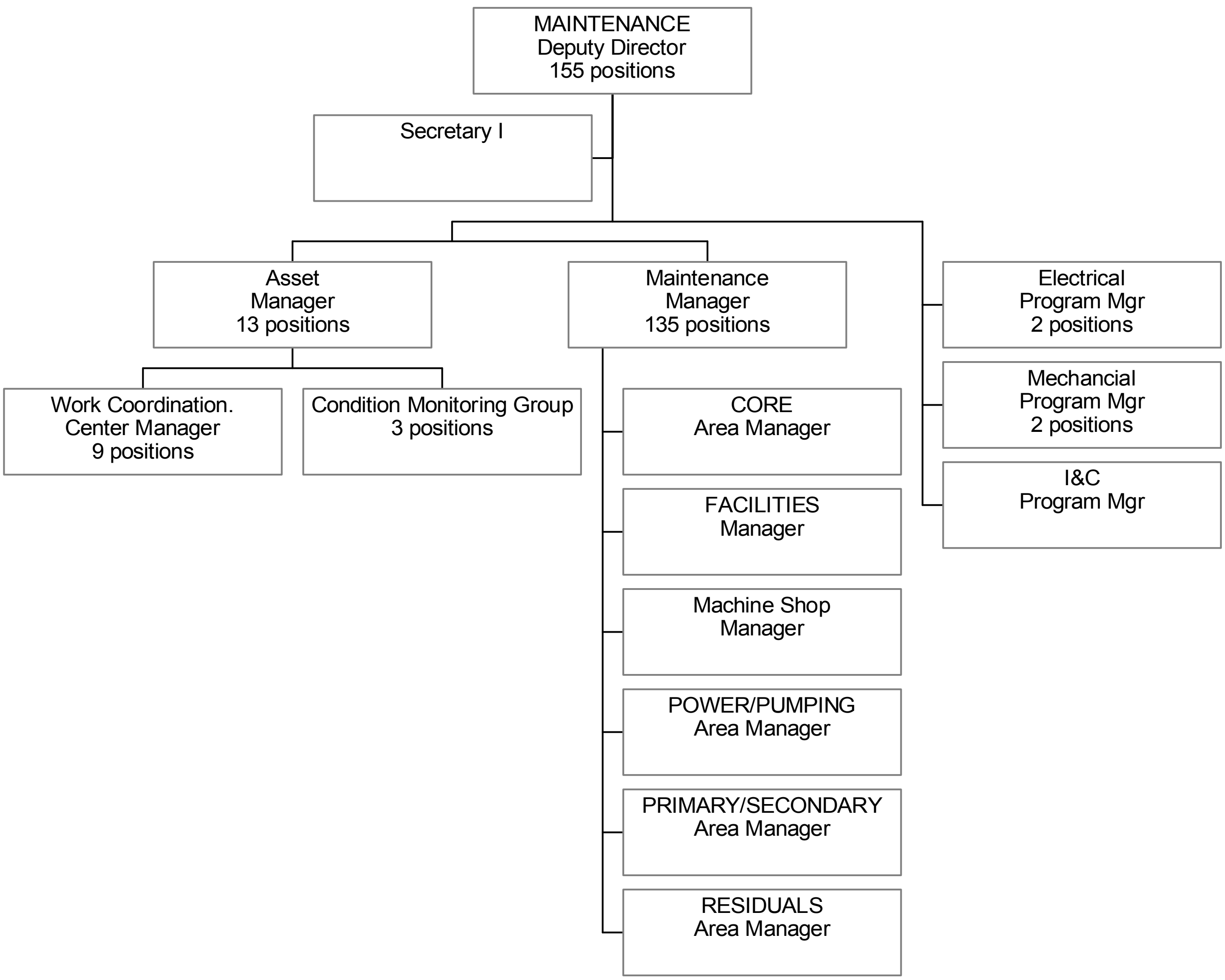
14 MWRA Maintenance Organization Structure

Deer Island Maintenance Organization



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