CASE STUDY – MASSACHUSETTS WATER RESOURCES AUTHORITY (MWRA), MASS.

a. Category – Application of Reliability Centered Maintenance at their Deer Island Advanced Wastewater Treatment Plant as a Best Practice O&M Strategy

b. Executive Summary

MWRA’s focus on asset management has been on operation and maintenance improvements. The focus is to employ industry best practices to extend equipment life and protect the ratepayer investment in the utility. MWRA completed extensive benchmarking to determine the best practices to adopt from both outside and inside the water and wastewater sectors. An overall Facilities Asset Management Program plan was prepared and implemented using task teams and extensive training and application of best practices. This work on best practices focused on implementation of Reliability Centered Maintenance at MWRA’s Deer Island Wastewater Treatment Plant. A focus on identifying critical assets and implementing predictive and reliability centered maintenance has saved MWRA money as well as enhanced plant reliability. Such approaches that result in change in an organization will take time to implement but will be well worth the effort.

c. Introduction

MWRA provides wholesale water and wastewater services to 2.5 million people and more than 5,500 businesses in 61 communities in central and eastern Massachusetts. MWRA was created as an Authority in 1985. MWRA supplies wholesale water to local water departments in 48 communities: 42 in greater Boston and the MetroWest areas and three in Central Massachusetts. MWRA also provides a back-up water supply in three other communities. MWRA's water comes from the Quabbin Reservoir, about 65 miles west of Boston, and the Wachusett Reservoir, about 35 miles west of Boston. Water is treated at the John J. Carroll Water Treatment Plant at Walnut Hill in Marlborough, Mass., and at the Ware Water Treatment Facility in Ware, Mass., from where it is then stored, conveyed, and distributed.

Wastewater from 5,400 miles of local sewers is transported into 228 miles of MWRA interceptor sewers. The interceptor sewers, ranging from 8 inches to 11 feet in diameter, carry the region's wastewater to two MWRA treatment plants: the Deer Island Wastewater Treatment Plant and the Clinton Wastewater Treatment Plant. Though most of the wastewater flows by gravity, some low-lying areas require pumping.

Since the time of formation of the Authority, MWRA has constructed over $6 billion of new assets, with another $1.6 billion planned for the near future. These facilities are operated by union staff. These assets have helped to clean up Boston Harbor and Massachusetts Bay.
MWRA has a goal of limiting rate increases to its customer communities, which means keeping operating expenses as low as possible without compromising services vital to public health, environmental protection, and the economy. To meet this goal, and as part of its investment in assets, MWRA has established progressive asset management programs to ensure that facilities do not fall into a cycle of disrepair. In particular, MWRA has implemented a state-of-the-practice Reliability Centered Maintenance program at one of its newest, largest facilities, the Deer Island Wastewater Treatment Plant.

d. Background Information

MWRA commissioned the Deer Island Wastewater Treatment Plant in 1997. Designed to treat 1.2 billion gallons per day, the plant provides preliminary, primary, and secondary treatment to wastewater flows. The first phase of secondary treatment began operating in July 1997. Figure 1 shows the major plant process components.

Figure 1 – MWRA Deer Island Wastewater Treatment Plant Major Processes (copyright MWRA. Used by permission.)
After preliminary screening and primary sedimentation, pure oxygen, which is manufactured on site, is added to the wastewater to enhance secondary treatment. Effluent is disinfected before it is discharged to the receiving waters (Massachusetts Bay) through a 9.5-mile Outfall Tunnel bored through solid rock more than 250 feet below the ocean floor. The tunnel's last 1.25 miles includes 54 separate release points or "diffusers." By extending into an area with water depths up to 120 feet, this outfall provides a much higher rate of mixing and/or dilution than is possible with previous discharges locations in the shallow waters of Boston Harbor.

Sludge from primary and secondary treatment is processed further in egg-shaped digesters, where it is mixed and heated to reduce its volume and to kill pathogens. It is then pumped 7.5 miles to the pelletizing plant in Quincy, Mass., where it is dewatered, heat-dried, and converted to a pellet fertilizer for use in agriculture, forestry, and land reclamation.

The Deer Island plant uses computerized systems to assist operations and maintenance management, including a Process Information Control System (PICS) and an Operation Management System (OMS). PICS provides real-time operations data from systems throughout the plant (including system status, flow, etc.). OMS correlates PICS data with laboratory analyses to analyze plant process performance in meeting its discharge permit from the U.S. Environmental Protection Agency and the Massachusetts Department of Environmental Protection.

e. Description of Best Practices including Personnel/Departments (Institutions) Involved

In 2000, 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 FAMP 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 FAMP concentrated on four areas: Maximo (Computerized Maintenance Management System), Maintenance Strategies (which includes the Reliability Centered Maintenance program), Condition Monitoring, and Business Practices. The best practices for each area are presented below.
**Maximo (Computerized Maintenance Management System)**

Deer Island has been using Maximo as its computerized maintenance management software since 1995. This software package is a powerful maintenance management tool that is used by the Work Coordination Group to manage all aspects of the Deer Island maintenance program. MWRA notes that, “Simply buying a CMMS does not constitute an asset management program.” (Maintenance Technology, March 2004)

MWRA conducted a post-implementation audit of Deer Island's Maximo database that included a review of its data quality and its present utilization.

**Data Quality**

The audit concentrated on 1,250 pieces of plant equipment in a specific section of the plant — Primary Clarifier Battery “A.” The review included a three-pronged approach where data was cross-compared between the Maximo database (Equipment, Inventory, Preventive Maintenance, and Work Orders modules), field nameplate data, and technical information (Operation and Maintenance Manuals and Process and Instrumentation Diagrams) located in the on-site technical library. As expected, the audit concluded that the quality of data in Maximo needed to be improved. Equipment was missing from the database, not all equipment data was completed, and data conflicted between Maximo, the field and the library. A corrective action plan was initiated. To date, 95% of the Maximo data has been corrected. To avoid future data quality issues, new procedures have been developed and implemented.

**Utilization of the Maximo System**

The review revealed that Deer Island was utilizing approximately two-thirds of the available Maximo features (termed “functionality”) which reportedly is the case with most other maintenance organizations. To enhance the data quality and support a new asset management initiative, a consultant recommended additional utilization of specific Maximo modules and programming enhancements. A corrective action plan was developed as a result of the audit and the following changes have been implemented to improve Maximo use:

- **Required fields for work orders were established to ensure data quality.**

  Maximo link to the financial software (Lawson) allows equipment costs to be determined, spare part inventory to be viewed in Maximo, kitting of parts for preventive maintenance work orders, and electronic requests for non stock parts.

  Maximo link to distributed control system allows electronic generation of preventive maintenance tasks based on run hours.
New reports were prepared to generate metrics.

- New reports were generated to support scheduling work one week in advance. This effort has been piloted in one area with success and is planned to be rolled out to the rest of the facility in the next two years.

**Maintenance Strategies**

During the construction of the new Deer Island Treatment Plant, each construction contract was required to review the equipment operation and instruction manuals to identify the preventive maintenance tasks to be completed to protect equipment warranties. These preventive maintenance tasks were entered into Maximo and then issued and completed by in-house staff. As a result of this effort, approximately 39,800 preventive maintenance work orders were completed, and 84,000 hours expended in FY99. Completion of preventive maintenance work accounted for 37% of all work hours.

Two maintenance initiatives were undertaken to improve the preventive maintenance program. Reliability Centered Maintenance was selected to review the critical plant systems, and a Preventive Maintenance Optimization Program was undertaken for all other plant components.

**Reliability Centered Maintenance**

In order to ensure that the correct maintenance was being completed for the Deer Island assets, a reliability engineer was hired to begin a Reliability Centered Maintenance (RCM) Program. The RCM program concentrated on the most critical systems, considering both probability and consequence of failure. A criticality analysis was completed that reviewed all systems on Deer Island, which identified that approximately 100 systems should have an RCM analysis completed.

The RCM program was initially piloted on 12 systems in Primary Clarifier Battery A. These systems included the primary sludge pumps, long collectors, cross collectors, primary scum, hot water system, sampling system, electrical power supply, fire protection, influent channel aeration, HVAC, chlorine gas detectors, and sump pumps. The result of the initial pilot was that preventive maintenance hours were reduced by 25% by eliminating low value preventive maintenance. In addition, for the more critical equipment preventive maintenance activities increased, and additional condition monitoring techniques were introduced.

Implementation of asset management involved change, and as is often the case with change, there was initial resistance to the effort. Some employees were concerned that the effort would lead to privatization or staff reductions so initially, there was some
resistance. MWRA took the approach of looking for volunteers to train and implement the RCM program that was being developed. One mechanic volunteered, and he was given two weeks of facilitation training as well as coaching on his first RCM analysis. As an RCM facilitator, his writing skills, presentation skills, and use of Maximo increased dramatically. Due to the skills and experience that he received, he was first promoted to Work Coordination planner and subsequently to Maintenance Manager. As others have seen the opportunities to advance, more individuals have volunteered to be involved.

As of January 2008, MWRA had completed 67 RCM analyses with another 30 planned for completion during the next three years. The RCM program has not only been successful in improving the preventive maintenance program for critical assets but also has improved staff ownership of equipment, improved operations and maintenance interrelations, improved staff knowledge of systems, and increased staff skills.

**Preventive Maintenance Optimization**

Preventive Maintenance Optimization (PMO) is an effort to reduce the workload associated with preventive maintenance of plant equipment without increasing the risk of failure to an undue level. Failure is defined as the inability of a component to perform its function(s) as defined by the users of the equipment.

Machinery will always have some risk of failure regardless of the amount and frequency of preventive maintenance devoted to it. In many cases, performing PM tasks may actually increase the chance of failure. A PM program is “optimized” when the least of amount of resources are devoted to PM that will provide an “acceptable” level of risk of failure. If “acceptable” is defined as the lowest overall costs associated with failure (to include corrective maintenance, safety consequences, loss of operations, environmental damages/fines, etc.), then the PM program is optimized when the total costs (PM costs + Failures/CM costs) are minimized. Consider the following chart:
In many plants, Deer Island Treatment Plant included, the preventive maintenance program has been developed using the recommendations issued by the equipment manufacturer. Since the manufacturer usually issues a warranty with the equipment purchase, the manufacturer benefits by making conservative recommendations for maintenance of its product. To implement the manufacturer’s recommended maintenance to all equipment in a working plant without consideration of its working environment, operational frequency, available work resources, etc., would be extremely taxing on the maintenance department and would waste valuable resources. The intent of PMO is to review the existing maintenance program to:

- Delete maintenance tasks that provide little value.
- Extend or reduce PM interval based on type of task, equipment usage, environment, and industry guidelines.
- Reassign tasks to Operations that would be better served by having the Operations Department perform the task during routine surveillance.

A PMO program was completed for all of the equipment that had not had an RCM analysis previously completed. The result was a significant reduction in the preventive maintenance hours expended. During the four-year period following the PMO implementation, no impacts on plant operation have occurred, as the plant equipment availability has increased, and the maintenance backlog has remained within industry guidelines.
Maintenance resources that were freed up from performing low value PM work orders were reallocated to complete the more valuable Predictive Maintenance (PDM) tasks, supporting the RCM effort, and completing corrective maintenance.

The implementation of the RCM and PMO programs resulted in a reduction of approximately 21,500 PM work orders per year and a reduction of 37,000 hours per year completed by maintenance staff. It should be noted that some of the reduction in PM work orders and hours came from Operators performing light maintenance. Approximately 6,000 hours per year of the reduction is attributed to light maintenance being completed by Operations staff.

**Condition Monitoring**

Two full-time staff completed condition monitoring of critical assets, and more than 50 maintenance technicians have been trained in vibration analysis, lubrication technology, precision laser alignment, and acoustic ultrasonics. Condition monitoring techniques used include vibration monitoring and spectral analysis, lubricating oil sampling, acoustic ultrasonic detection, ultrasonic thickness testing, laser alignment, and infrared thermography.

Acoustic ultrasonic detection provides an indication of a potential equipment problem before the traditional condition monitoring techniques (vibration, oil analysis, heat). The Potential Failure to Function Failure graph in Figure 3 illustrates this point.

![Figure 3 – Ball Bearing Potential Failure to Function Failure Graph](image-url)

Normal corrective actions when vibration or ultrasonic acoustic readings are high include greasing, alignment, or follow-up oil analysis. In some cases, the corrective actions do not result in lower levels, and so planning for equipment replacement is recommended.
The acoustic ultrasonic and vibration results have been very important to keep equipment availability high and extend equipment life. In most cases, the corrective actions extend equipment life by removing the causes of bearing distress. If high levels remain after corrective actions have been made, sufficient time is available to plan for equipment repair or replacement.

**Acoustic Ultrasonic Case Study**

The primary scum pumps, motor, and bearings are monitored using acoustic ultrasonic detection to provide advance warning of potential failures. Using an SDT 170 ultrasonic detector, engineering staff found unacceptable noises and noise levels in 10 of the 14 primary scum pump bearings, indicating potential problems. As a result, samples of lubricating oil were taken from six of the pumps’ gearboxes. Results from National Tribology lab tests showed viscosities that were much too high, indicating that the wrong lubricating oil had been used. Oil in all the pumps was changed to the correct oil and ultrasonic monitoring was repeated. This time, only two pumps had unacceptable noise levels. Maintenance staff conducted an alignment check before considering replacement of the bearings. Laser alignment checking of a machine with an Optalign Plus Laser revealed that a coupling was in poor condition, and the machine was badly misaligned. A new coupling was installed and aligned, and confirmed that the maintenance problem had been solved. These types of analyses and troubleshooting are much less expensive than alternatives such as run-to-failure reactive maintenance, and even more intrusive maintenance such as bearing replacement, if such bearing replacement is not needed. In fact, full analysis showed that, when applied to all 14 primary scum pumps, expending $3,920 in preventive maintenance resulted in cost savings of $43,680 to $74,480. At the same time, equipment availability and reliability has increased. Condition monitoring techniques used at Deer Island have provided many such examples of the benefits and return on investment of proactive maintenance.

**Lubrication Savings Case Study**

The secondary reactors have 36 mixers and 36 aerators that have Lightning triple reduction gearboxes. Twenty gearboxes have failed during the past 10 years, which have required a rebuild. The cost to repair each gearbox is $25,000 to $40,000 depending on the extent of gear damage. Therefore, the oil sampling program is important to extend this equipment life. In 2002, an oil sampling program was initiated for these components. The savings identified are from avoided oil changes that were previously scheduled and completed yearly for all gearboxes. The results of the sampling program follow:

**First Year of Sampling (2002)**

The first round of sampling identified 48 of the 72 gearboxes with oil in good condition, which did not require an oil change. This resulted in cost savings of **$39,610**.

Second Year of Sampling (2003) – **Filtering Oil Introduced**

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The second year of sampling identified 39 gearboxes with oil in good condition and 20 gearboxes that required filtering to remove contaminants and wear particles for a total of 59 avoided oil changes. This resulted in cost savings of $42,545 (~$16,000 from filtering oil).


The third year of sampling identified 43 gearboxes with oil in good condition and 13 gearboxes that required filtering to remove contaminants and wear particles for a total of 56 avoided oil changes. This resulted in cost savings of $41,190 (~$10,000 from filtering oil).

Fourth Year of Sampling (2005) – Started laser alignments of gearboxes

The fourth year of sampling identified 45 gearboxes with oil in good condition and 20 gearboxes that required filtering to remove contaminants and wear particles for a total of 65 avoided oil changes. This resulted in cost savings of $45,225 (~$16,000 from filtering oil).

Fifth Year of Sampling (2006) – Improved breathers added to prevent contamination

The fifth year of sampling identified 34 gearboxes with oil in good condition and 25 gearboxes that required filtering to remove contaminants and wear particles for a total of 59 avoided oil changes. This resulted in cost savings of $40,876 (~$19,000 from filtering oil).

Sixth Year of Sampling (2007) – Sampling Ports installed to improve sample repeatability

The sixth year of sampling identified 45 gearboxes with oil in good condition and 20 gearboxes that required filtering to remove contaminants and wear particles for a total of 65 avoided oil changes. This resulted in cost savings of:

\[
\begin{align*}
\text{Oil savings} &= 65 \times 32 \text{ gallons/gearbox} \times \$23.44/\text{gallon} = \$48,755 \\
\text{Saved labor} &= 4 \text{ hours/oil change} \times 45 \times \$30/\text{hour} = \$5400 \\
\text{Sampling Cost} &= 124 \text{ samples} \times \$30.15/\text{sample} = (\$3739) \\
\text{Sampling Labor} &= 124 \text{ samples} \times 1 \text{ hour/sample} \times \$30/\text{hour} = (\$3720) \\
\text{Total Savings} &= \$46,696 (~\$16,000 \text{ from filtering oil})
\end{align*}
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Therefore, since December 2002, savings of $256,142 have been realized from lower oil usage and saved labor from oil changes. In addition and more important, oil was changed based upon the oil condition as indicated by oil sampling results since 2002, which will result in longer gearbox life.
**Infrared Case Study**

The condition monitoring group tested 21 steam traps in the Deer Island Thermal Plant. Testing of steam traps by the use of an infrared camera as shown in Figure 5 can determine if the steam trap is properly cycling on and off or if the steam trap is not operational.

![Infrared Camera in Use at Deer Island (FLIR Model E-4)](image)

The initial testing of the steam traps found 19 steam traps operating properly and two bucket-type steam traps not operating properly. Figure 4 shows an infrared image of the bucket trap showing a hot temperature on the inlet and outlet of the steam trap. A bucket-type steam trap’s function is to drain condensate formed in steam lines. When sufficient condensate forms in the trap, the bucket lifts, condensate is drained, and the bucket lowers isolating the steam. In the case shown below, the trap remained continuously open. Therefore, steam was always going through the trap. Both bucket-type steam traps were replaced and resulted in reduced steam leakage and energy savings.

![Infrared Camera Images](image)
**Vibration Case Study**

In October 2004, a lube oil pump for the steam turbine generator began to show signs of imbalance on the free end of the motor. A work order was created to clean the cooling fan, and the vibration decreased slightly and then began to increase again.

The vibration spectra for the motor is shown in Figure 6.

![Figure 6 – Sample Motor Vibration Spectra](image)

The condition monitoring staff then viewed the motor cooling fan as shown below and found dry wall screws were used to balance the motor, and it appeared that one screw had backed out as shown in Figure 7.

![Figure 7 – Cooling Fan Motor](image)
The cooling fan was replaced, and the vibration levels returned to acceptable levels. The vibration corrective action extended equipment life by reducing bearing loading from an imbalanced condition.

Overall, the condition monitoring program has been very successful in identifying equipment with potential problems and identifying corrective actions. The program has contributed to improving the plant equipment availability and longer equipment life.

**Business Practices**

**Productivity Improvement Program**

In order to improve the productivity of the maintenance program, several changes to all trades and operations job descriptions were negotiated with the unions. One goal was to implement cross functional crews to break down trade silos to improve teamwork and speed work completion. In addition, light maintenance tasks were included in the job descriptions of all trades and operation staff. Pay increases over a three-year period were provided along with training and testing of staff in the new skills necessary to perform these light maintenance tasks.

**Cross Functional Crews**

In March of 2002, mixed crews were implemented in all plant areas. A mixed crew includes electricians, I&C, M&O Specialists, and plumbers, all lead by a single unit supervisor. The mixed crew format increases efficiency by reducing downtime waiting for specific trades to support a multi-discipline work order. In addition, light maintenance such as HVAC filter changes, light bulb replacements, and lubrication are now assigned to an area maintenance team and/or Operations, not to a specific trade. In the Maintenance Group, this has allowed the unit supervisor flexibility to assign these tasks to any one of a number of staff based upon their availability, the priorities of the week and day. Non-licensed piping and HVAC equipment repairs are not only assigned to the Plumbers and HVAC Technicians but also to M&O Specialists as well. As a result of this flexibility, over 20 % of work is now accomplished by an alternate trade.

**Operations Light Maintenance**

Preventive maintenance (PM) tasks before this program were all completed by maintenance staff. Operations was assigned and provided Maximo work orders for inspection and lubrication tasks. Operations currently completes > 16 % of all PM hours (> 500 hours/month). The best in class goal accepted by the Society of Maintenance and Reliability Professionals (SMRP) is 10-15% of all PM hours and this goal has been met or exceeded at Deer Island since 2003.
**Metrics**

As part of the overall program, metrics were developed to drive change by tracking the implementation of the new maintenance initiatives and to monitor the impact of the new programs on maintenance performance. Monthly and yearly metrics were developed.

A task team was formed to review the existing maintenance metrics and recommend new metrics. Metrics from maintenance text books, papers, and the internet were researched and reviewed for the Deer Island Treatment Plant.

Some key metrics that are used to determine the impact of the maintenance program are maintenance backlog and availability.

**Maintenance Backlog**

Definition - Backlog is determined by totaling the estimated work hours for "in progress" work orders and dividing by the available staff hours each week. To determine this metric, estimated hours are input by planners for all work orders in Maximo.

Benefit - This metric is helpful to gauge whether there is adequate staff to complete the maintenance work. Increasing backlog can be attributed to increased equipment problems or a decline in maintenance efficiency. The industry guideline is to have a backlog of 3 to 6 weeks.

**Availability**

Definition - Availability is the amount of critical plant equipment that is available for service. At Deer Island, operations issues a daily list of approximately 350 equipment items that are available to treat the maximum plant capacity of 1.27 Billion gallons per day. The normal plant flow is 360 MGD.

Benefit - This metric is used to determine if plant equipment is being properly maintained and that operations is not impacted from equipment being out of service. The industry guideline is 97%. Deer Island has met or exceeded this goal since 2003 and in 2007 reached 99.2% availability.

**Summary of Key Lessons and Experiences (Results and Findings)**

A focus on identifying critical assets and implementing predictive and reliability centered maintenance has saved MWRA money as well as enhanced plant reliability. Such approaches that result in change in an organization will take time to implement but will be well worth the effort.