Using a Maintenance Pyramid Concept to:

- Optimise Maintenance
- Target Performance

Paul Soakell
Watercare Services Limited
Contents

• Who is Watercare
  • Assets Maintained

• Framework & Challenges
  • Gaps to Close – Water Services Association of Australia (WSAA)
  • Project MOD
  • Complexity Issues

• Maintenance Pyramid
  • Key Elements
  • History

• Implementation
  • Project Plan
  • Pyramid Targets - RCM influence
  • RCM Project Structure
  • Risk Assessment

• Systems Integration
  • Suite of Applications
  • Integration
  • Key Performance Indicators, Root Cause Analysis (RCA)
  • AvSim - System Modelling

• Summary
  • Savings & Improvements
  • WSAA Benchmarking results 2006
Watercare Services

• New Zealand’s largest Water & Wastewater Company
• Provides bulk water catchment, treatment & distribution of “A” grade quality drinking water to the greater Auckland area
• Provides bulk wastewater collection, treatment & disposal services to Auckland excluding the Northshore
• Governed by an independent Board of Directors appointed by its shareholders
• Its shareholders are the 6 councils of Auckland
• The accountability relationship between Watercare and its shareholders is expressed through the Statement of Corporate Intent
• It operates in a commercial manner
• Committed to improving its value to customers - has a target of 2% cost savings per annum
• Refunded to the shareholders $10M (2004/2005)
## Company Profile

<table>
<thead>
<tr>
<th>Detail</th>
<th>Water</th>
<th>Wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asset Value</td>
<td>$933 million</td>
<td>$690 million</td>
</tr>
<tr>
<td>Turnover</td>
<td>$62 million</td>
<td>$104 million</td>
</tr>
<tr>
<td>No. of Staff</td>
<td>329 Water &amp; Wastewater</td>
<td></td>
</tr>
<tr>
<td>Production</td>
<td>Averages 359,000 M(^3) per day</td>
<td>Treats 274,000 M(^3) per day</td>
</tr>
<tr>
<td>Customers</td>
<td>Auckland, Manukau, North Shore, Papakura, Rodney &amp; Waitakere</td>
<td>Auckland, Manukau, Papakura, Waitakere</td>
</tr>
<tr>
<td>Consumers</td>
<td>Approx 1.2 Million</td>
<td>Approx 911,000</td>
</tr>
</tbody>
</table>
Wastewater Assets

- Treatment Plant, which reuses 14,312,000 M$^3$ of effluent annually

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>299</td>
<td>km of sewers</td>
</tr>
<tr>
<td>51</td>
<td>Pump stations</td>
</tr>
<tr>
<td>13</td>
<td>Siphons</td>
</tr>
<tr>
<td>99</td>
<td>Controlled overflow structures</td>
</tr>
<tr>
<td>1</td>
<td>Treatment Plant, which reuses 14,312,000 M$^3$ of effluent annually</td>
</tr>
</tbody>
</table>
Water Assets

<table>
<thead>
<tr>
<th></th>
<th>Water Assets</th>
</tr>
</thead>
<tbody>
<tr>
<td>79</td>
<td>km of raw water mains</td>
</tr>
<tr>
<td>444</td>
<td>km of treated water mains (size 300mm to 1900mm)</td>
</tr>
<tr>
<td>61</td>
<td>Service reservoirs</td>
</tr>
<tr>
<td>30</td>
<td>Pump stations</td>
</tr>
<tr>
<td>10</td>
<td>Dams</td>
</tr>
<tr>
<td>7</td>
<td>Treatment Plants</td>
</tr>
</tbody>
</table>
Value for Money

Watercare

- Catches
- Treats
- Stores
- Distributes

water for 41 cents a cubic metre after refunding to the shareholders ($10M 2004/2005)
WATERCARE WHOLESALE PRICE AND WATER RETAILERS’ AVERAGE DOMESTIC PRICE PER m³

Value for Money
Types of Assets Maintained

- Largest UV disinfection plant in the world, nearly 8000 UV tubes
- Each tube is roughly $300 each
- 15 minutes exposure will turn you a crispy brown colour!
Types of Assets Maintained
Types of Assets Maintained
Types of Assets Maintained
WSAA M&E Benchmarking 2002 Analysis
Best Practice Companies Demonstrated

- Extensive telemetry installed for condition monitoring and control
- Computerised Maintenance Management Systems (CMMS) used effectively
- CMMS linked to asset management function and KPI’s
- Service Level Agreements used with internal suppliers
- Strong internal communication
- Multiskilled tradesmen used
- Outsourced workshops
WSAA M&E Benchmarking 2002 Analysis
Best Practice Companies Demonstrated

• Move towards portable CMMS - Efficient labour use through mobilised staff
• Use condition information to optimise maintenance
• Statistically analyse failure rates on a failure register and detail probabilities of failure
• Involved asset owners in decision making process by providing hierarchical KPI's showing trade-offs between different service level targets and subsequent investment required to achieve such targets
Gaps to Close

- Different standards across the organisation
- No agreed maintenance strategy
- Not all maintenance activities were documented in the CMMS
- Criticality ratings generally not recorded in the CMMS
- Criticality ratings often recorded in separate databases
- Ratings predominantly based on experience (not a formalised process)
- Importance of individual assets to system performance generally held in people’s heads
- Fragmented capital/revenue expenditure decision making processes
Watercare's Challenge
Implement Project MOD
a continuous improvement project focussed on maintenance & design
Project MOD

- **MOD** – Maintenance Optimisation & Design
- Implemented 2002
- **Driven by**
  - An astute Chief Executive
  - An enthusiastic Operation’s General Manager, 2 Project Sponsors and a Project Manager
  - A hand picked team of dedicated individuals
  - Support extends from the Board of Directors to staff on the shop floor
- **Objectives**
  - Maximise long-term sustainability of Watercare’s assets
  - Set clear improvement targets
  - Develop business rules & standards
  - Implement consistent maintenance practices company wide
  - Appropriate maintenance plans for each asset
  - Increase plant availability & reliability
  - Integrate systems
  - Optimise cost of maintenance Vs. cost of failure - Cost Vs. Risk
  - Train Watercare staff to achieve an understanding of our maintenance strategy company wide
  - Reduce maintenance spend by 10%
Essential to have a Clear Vision

Watercare’s Vision

Deliver the sustainable minimum cost position for asset maintenance and operation that provides the required water & wastewater services to Auckland
Management of complexity

Human Complexity
- Vision
- Values
- Team work
- common goals
- rigour
- visibility of performance
- communication
- Roles & Responsibilities
- ownership
- MRPII
- ERP
- TPM
- QFD

Technical Complexity
- RBM
- Cpk
- FMEA
- RCM
- KPI
- MRPII
- 5s
- BPST
- Kaisen
- KPI
- OEE
- Shainen
- 6 sigma
- WCM

Matching technical expertise with a clear tactical behavioural framework is the essence of effective implementation.
Basic Components of a Maintenance System
“Jigsaw Pieces”

- Critical Equipment
- Work order System
- Process maintenance Teams
- Area Work Teams
- Equipment History
- Risk Based Maintenance
- Computerised maintenance Management System CMMS
- Short Interval Control SIC
- Integrated Score Card
- MTBF MTTR
- Critical Equipment
- Shut down Cycle Time Compression
- FMECA/RCM
- Autonomous Maintenance
- Loss Accounting System
- Planned Corrective Maintenance PCM
- Resource Skills Matrix
- Bill Of Materials BOM
- Maintenance Master Schedule
- Weekly Maintenance Plan
- Daily Maintenance Report
- Maintenance KPI’s
- Planned Maintenance Routines
- Weekly Plan
- Spares Policy Management
- Equipment Numbering System
- Standards & Specifications
- Daily Plan
- Planned Maintenance Routines
- Equipment History
- Multi-Skilling
- Work order System
- MTBF MTTR
- Equipment Master Schedule
- Weekly Maintenance Plan
- Weekly Plan
- Maintenance KPI’s
- Equipment History
- Multi-Skilling
- Work order System

- MTBF MTTR
- Critical Equipment
- Shut down Cycle Time Compression
- FMECA/RCM
- Autonomous Maintenance
- Loss Accounting System
- Planned Corrective Maintenance PCM
- Resource Skills Matrix
- Bill Of Materials BOM
- Maintenance Master Schedule
- Weekly Maintenance Plan
- Daily Maintenance Report
- Maintenance KPI’s
- Planned Maintenance Routines
- Weekly Plan
- Spares Policy Management
- Equipment Numbering System
- Standards & Specifications
- Daily Plan
- Planned Maintenance Routines
- Equipment History
- Multi-Skilling
- Work order System

- MTBF MTTR
- Critical Equipment
- Shut down Cycle Time Compression
- FMECA/RCM
- Autonomous Maintenance
- Loss Accounting System
- Planned Corrective Maintenance PCM
- Resource Skills Matrix
- Bill Of Materials BOM
- Maintenance Master Schedule
- Weekly Maintenance Plan
- Daily Maintenance Report
- Maintenance KPI’s
- Planned Maintenance Routines
- Weekly Plan
- Spares Policy Management
- Equipment Numbering System
- Standards & Specifications
- Daily Plan
- Planned Maintenance Routines
- Equipment History
- Multi-Skilling
- Work order System
Structured Components of a Maintenance System
“Completed Jigsaw” - Maintenance Pyramid

- Integrated scorecard
- Area work teams
- Process maintenance teams
- Risk Based Maintenance (RBM)
- Integrated process maintenance systems
- Computerised maintenance system (CMMS)
- Autonomous maintenance
- Multi-Skilling
- Shut down cycle time compression (CTC)
- Bill of Materials (BOM)
- Maintenance master schedule
- Planned maintenance routines
- FMECA/RCM
- MTBF
- MTTR
- Planned Corrective Maintenance (CBM etc)
- Spares policy management
- Standards & specifications
- Equipment history
- Weekly plan
- Weekly maintenance report
- Maintenance cost report
- Resource skills matrix
- Equipment numbering system
- Critical equipment
- Work order system
- Daily plan
- Maintenance KPI's
- Daily maintenance report
- Loss accounting system
- Short Interval Control (SIC)
Focus on the foundations, first ... building the infrastructure to regain control.

World Class Maintenance

Integrated CMMS
Integrated manufacturing teams multi-skilling
Asset Care policies / maintenance strategy
Advanced condition based monitoring maintenance
RCM/RBM

Increasing Sophistication

Strategic make/buy decisions (contractors)
Maintenance quality standards / specifications / procedures
X-functional FMEA driven routines
Maintenance master schedule
Spares policy
Scope mgmt / prioritisation

Basic Records / Data Collection
Budget Struct / controls & accountability
Loss accounting
Planning / Scheduling
Works order system
Maintenance kpi hierarchy
Skills matrix / policies
Governing policies - approach

It’s not about adding to the complexity, it’s about doing what’s necessary and doing it well.
Pyramid History

- Developed approx 5 years ago
- Initial focus: asset intensive process industries
- Pragmatic approach that can be understood by all levels of an organisation
- Methodology has been used very extensively in Europe and US
- Clients where it has been deployed: ICI, Dupont, Aventis, Bayer, Holcim, BP, Rhodia, Air Products, Rugby Cement, East of Scotland Water, West of Scotland Water, Northumbrian Water, Lyonnaise des Eaux .........
- Combines both maintenance and operations activities that seek to optimise the performance of an asset
- Tells you were you are and helps you define where you need to go. The balance is the gap you set to be achieved.
PHASE 1 Basics
- KPI's
- Equipment numbering
- Critical equipment
- Work order system
- Loss accounting system
- Equipment history
- Resource skills matrix

PHASE 2 Control
- Weekly plan & Weekly report
- Short Interval Control
- Maintenance Strategy
  PPM/CBM/RCM/FMECA/MTBF/MTTR
- Maintenance master schedule
- Spares policy
- Standards & Specifications

PHASE 3 Optimisation
- CMMS
- Autonomous maintenance
- Shutdown cycle compression
- Multiskilling

PHASE 4 Getting Smart
- Risk based maintenance
- Integrated process maintenance systems
  - Bill of Materials (BOM)
  - Area Work Teams
  - Integrated Score Card
Prerequisites for successful change and effect when one is missing ...

<table>
<thead>
<tr>
<th>Pressure for change</th>
<th>Capacity for change</th>
</tr>
</thead>
<tbody>
<tr>
<td>A clear shared vision</td>
<td>Actionable first steps</td>
</tr>
</tbody>
</table>

Bottom of “in-Tray”

Anxiety & frustration

A fast start that fizzles out

Haphazard efforts & false starts
Road Map

- Team Dynamic
  - Programme
    - Purpose
      - Project Launch

- Defined
  - Revise
    - Revise
      - Current Position

- Defined
  - Report
    - Allocate
      - Optimal Position

- Defined
  - Report Success
    - Implement
      - Define
        - Quick Hits

- Report Success
  - Improvements
    - Common Processes
      - Business Rules
        - Define
          - Sustainable Hits

- Define Tasks
  - Project Meetings
    - Workshops
      - Presentation
        - Sign-Offs

- Asset Numbering
  - Critical Equipment
    - Work Order System
      - Daily Plan
        - Maintenance KPI's
          - Daily Maintenance Report
            - Maintenance Cost
              - Structure
                - Short-Interval Control
                  - Production Plan
                    - Spares Policy & Management
                      - Standards & Specifications
                        - Equipment History
                          - Weekly Plan
                            - Weekly Maintenance Report
                              - Maintenance Cost Report
                                - Resource Skills Matrix
                                  - Budget
                                    - B.O.M.
                                      - Parts List
                                        - Maintenance Master Schedule
                                          - Planned Maintenance Routines
                                            - FMEA/RCM
                                              - MTBF
                                                - MTTR
                                                  - MTBCF
                                                    - Predictive Routines / CBM
                                                      - Plant Master Plan
                                                        - Multi-Skilling
                                                          - Shutdown Cycle Time Compression (CTC)
                                                            - Computerized Maintenance Systems
                                                              - Autonomous Maintenance
                                                                - Business Plan
                                                                  - Area Work Teams
                                                                    - Process Maintenance Teams
                                                                      - Risk Based Maintenance (RbM)
                                                                        - Integrated Process / Maintenance System
                                                                          - Best Practice

- Fully installed
  - Process initiated
    - To be addressed
      - input elements

- Pyramid
  - Current
    - Pyramid
  - Optimal
The Analysis Steps

1. Map the Process
   - Maintenance policy
   - Work Selection
   - Work Prioritisation
   - Planning & Scheduling
   - Work Execution

2. Understand the System

3. Identify the gaps
   - “Data availability, management information limited”
   - “Inconsistent practices”
   - “Need for clearer accountabilities”
   - “Some apparent backlogs in maintenance”
   - “Some lost time in execution”

4. Quantify the Benefits
   - Savings
   - Performance visibility
   - Improved management of risk
   - Processes driving cost improvement
   - Value for money

5. Recommendations
   - Implement management control and reporting system in conjunction with pyramids
   - Implement “one system”
   - Implement from “bottom up”
   - Focus on practical behaviours to ensure pace and rigour
# FMECA / RCM

## OBJECTIVE
To proactively identify the optimum maintenance activity

## SCOPE
To systematically establish the failure mode in a process, the effect of the failure and determine what maintenance, if any, should be performed

## OUTPUT
FMECA equipment schedules and analysis

---

### FMEA / RCM

<table>
<thead>
<tr>
<th>Question</th>
<th>0. No / Not Relevant</th>
<th>1. Partially</th>
<th>2. Basic / Minimum</th>
<th>3. Mostly</th>
<th>4. Total / Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are FMECAs and RCMs periodically in use?</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Are the concepts of FMECA / RCM understood by all relevant personnel?</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Are FMECA/RCM techniques used to develop PMR's?</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Are FMECA/RCM techniques used to initiate engineering design improvements?</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Are FMECA/RCM techniques used to modify or upgrade inspection checksheets?</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Are FMECA/RCM techniques used to identify training requirements?</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Are the FMECA/RCM analysis properly documented?</td>
<td></td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>20</td>
</tr>
</tbody>
</table>

- **93% Installed**
  - Color of pyramid element: 0.928571429
Maintenance Pyramid Targets

- Integrated scorecard
- Area work teams
- Process maintenance teams
- Risk Based Maintenance (RBM)
- Integrated process maintenance systems
- Multi-Skilling
- Shut down cycle time compression (CTC)
- Computerised maintenance system (CMMS)
- Autonomous maintenance
- Bill of Materials (BOM)
- Maintenance master schedule
- Planned maintenance routines
- FMECA/RCM
- MTBF
- MTTR
- Planned Corrective Maintenance (CBM etc)
- Plant master plan
- Spares policy management
- Standards & specifications
- Equipment history
- Weekly plan
- Weekly maintenance report
- Maintenance cost report
- Resource skills matrix
- Budget
- Equipment numbering system
- Critical equipment
- Work order system
- Daily plan
- Maintenance KPIs
- Daily maintenance report
- Loss accounting system
- Short Interval Control (SIC)
- Operations/ Maintenance Plan

Targets:
- June 2005
- Dec 2006
- June 2007
- Not required
- Input Data
RCM Influence

RCM software:
- System modelling *AvSim*
- Lifecycle costing *LCCWare*

will help facilitate the RBM process

**Integrated scorecard**

- Area work teams
- Process maintenance teams
- Risk Based Maintenance (RBM) 4.6
- Integrated process maintenance systems

**Multi-Skilling**

- Bill of Materials (BOM)
- Maintenance master schedule
- Planned maintenance routines
- FMEA/RCM

**Computerised maintenance system (CMMS)**

**Autonomous maintenance**

**Business plan**

**Plant master plan**

**Resource skills matrix**

**Spares policy management**

**Standards & specifications**

**Equipment history**

**Weekly plan**

**Weekly maintenance report**

**Maintenance cost report**

**Resource skills matrix**

**Equipment numbering system**

**Critical equipment**

**Work order system**

**Daily plan**

**Maintenance KPIs**

**Daily maintenance report**

**Loss accounting system**

**Short Interval Control (SIC)**

**Operations/Maintenance Plan**

**Input Data**

**> 80% Implemented**

**> 40% <80% Implemented**

**< 40% Implemented**

**Not required**

Current Focus

RCM

Flow on Effect / Potential benefits

### RCM software:
- *AvSim*
- *LCCWare*

Current Focus

RCM

Flow on Effect / Potential benefits
What is Reliability Centred Maintenance (RCM)

- RCM is a procedure for determining maintenance strategies based on reliability techniques and encompasses well-known analysis methods such as Failure Mode Effects and Criticality Analysis (FMECA).
  - IEC 60300-3-11 Nov 1999
  - SAEJ A1011 Aug 1999
- In other words a framework based on international standards that facilitates maintenance plan development
Prime Objectives & Other Benefits

RCM Prime Objectives

• Minimise long-term costs & risks
• Meet safety & environmental goals
• Meet operational goals & customer expectations
• Increase plant availability & reliability

Other Benefits

• Increased rigor applied to asset maintenance
• Identifies over maintained assets “gold plating”
• Identifies under maintained assets “business risk”
• Improved budgeting & forecasting (opex & capex)
• Improved AMP input
• Ability to highlight operational modes not previously considered
• Ability to apply “what if scenario’s”
This is not RCM
Who’s Involved in RCM

- Operations & Maintenance staff (approx 28)
  - Maintenance Planners
  - Operators
  - Trades
  - Asset Specialists “Engineers”
- 4 Teams formed to review
  - Water Networks
  - Wastewater Networks
  - Water Treatment
  - Wastewater Treatment
- Staff will be required to use their knowledge & skills as input into the RCM process - it cannot work without their input
Revised RCM Implementation Structure
August 2006

Notes:
- R Srivastava - RCM trained Sept 2005 - appointed WTP modeller (previously M Dale)
- S Reynolds - RCM trained Sept 2005 - appointed WTP modeller (previously M Dale)
- M Dale - appointed Ardmore modeller (previously J Van Gils)
- J Venter & S Wilcox - appointed Water Networks Ops Specialists to be called upon when required
- R Srivastava no longer RCM team member due Operations limited resource issues
- S Wilcox - appointed to RCM review team I & C (previously K Jose) Dec 2005
- Replacement I & C (A Kennedy replaced S Wilcox) for Water Treatment RCM team member to be trained, S Wilcox to provide support until then
- Recently appointed Western Water maintenance planner A Williams trained & assigned to Water Treatment Western team
- M Bourne - project sponsor replaces D Simpson August 2006
Continued Support

- RCM is now the way we now do business
  - RCM maintenance plans
  - RCM budgets that are zero based every financial year
  - RCM input into the Asset Management Plan “AMP”
- Operations & Maintenance staff will ensure models are kept up to date to deliver the above as part of their day job
  - Maintenance Planners
    Water & Wastewater Treatment, Water & Wastewater Networks
  - Asset Specialists “Engineers”
    Civil, Electrical, Instrument & Control, Mechanical, Reliability & Systems
# RCM Check Sheet for Successful Implementation

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Detail</th>
</tr>
</thead>
</table>
| 1    | Build the current “As Is” model using the library | - Assemble background info e.g. P & ID drawings, asset lists, current maintenance plans, FD’s, photo’s etc.  
- The library is the repository for all our assets such as pumps, motors, instruments etc  
- Start at the top of the hierarchy and question “what happens if?” and follow the tree structure down  
- Do a model then discuss with the team to refine and hone your skills, when satisfied then template out  
- Define boundaries |
| 2    | Review the model for compliance with the current “As Is” model | - Quantities  
- Effects  
- P-F intervals  
- Durations  
- Current maintenance plan  
- Log comments (use a separate XL file if desired) to clarify decisions/assumptions made for such things as redundancy, what are we contracted to pump etc so model review is “simple & user friendly” |
| 3    | Validate the “As Is” model | - Is this what we currently do now  
- Is the model within 10-20% variance of our 5 year average costs |
Critical & Non Critical Assets

- Decision to implement RCM was made using Kepner Tregoe problem solving methodology
- Why was RCM applied to both critical & non critical assets
- Provides an Audit Trail and Increased Rigor by detailing:
  - Why we maintain an asset
  - Who maintains the asset
  - Where we maintain the asset
  - What maintenance is done to the asset
  - How is that maintenance carried out
  - Identifies over maintained assets “gold plating”
  - Identifies under maintained assets “business risk”
- From which informed decisions can be made
### Model Library - Ready for Templating

- **SYSTEM:**
  - 1: Equipment Library 18th October 2005
  - 1.1: Pumps
  - 1.2: Motors
    - 1.2.1: AC Motor, XLarge > 200 KWW
    - 1.2.2: AC Motor, Large 75 - 200 KWW
    - 1.2.3: AC Motor, Medium 11 - 75 KWW
    - 1.2.4: AC Motor, Small < 10 KWW
  - 1.3: Air Compressors
  - 1.4: Fans, Ventilation, Odour Control
  - 1.5: Blowers
  - 1.6: Centrifuges
  - 1.7: Gearboxes
  - 1.8: Valves
  - 1.9: Actuators
  - 1.10: Drives
  - 1.11: Mixers
  - 1.12: Tanks
  - 1.13: Pipework
  - 1.14: Instrumentation
  - 1.15: Electrical
  - 1.16: Building Plant Services
  - 1.17: Buildings and Structures
  - 1.18: Site Works
  - 1.19: Screens / Filters
  - 1.20: Screw Feeders

4 motor types in the library
Model Library - Ready for Templating

1.1: Pumps
- 1.1.1: Centrifugal, Vertical, X Large > 17", Drive Shaft
- 1.1.2: Centrifugal, Vertical, Large 12 - 16", Drive Shaft
- 1.1.3: Centrifugal, Vertical, Medium 6 - 11", Drive Shaft
- 1.1.4: Centrifugal, Vertical, Small < 5", Drive shaft
- 1.1.5: Submersible, Small < 10 kW
- 1.1.6: Submersible, Medium 11 - 20 kW
- 1.1.7: Submersible, Large 21 - 50 kW
- 1.1.8: Submersible, X Large > 50 kW
- 1.1.9: Centrifugal, Horizontal, > 17", Coupled
- 1.1.10: Centrifugal, Horizontal, Large 12 - 16", Coupled
- 1.1.11: Centrifugal, Horizontal, Medium 6 - 11", Coupled
- 1.1.12: Centrifugal, Horizontal, Small < 5", Coupled
- 1.1.13: Centrifugal, Vertical, X Large > 17", Coupled
- 1.1.14: Centrifugal, Vertical, Large 12 - 16", Coupled
- 1.1.15: Centrifugal, Vertical, Medium 6 - 11", Coupled
- 1.1.16: Centrifugal, Vertical, Small < 5", Coupled
- 1.1.17: Sump Pump
- 1.1.18: Progressive cavity, Monopump
- 1.1.19: Dosing, Diaphragm, Wallace Tiernan, Encore 700
- 1.1.20: Vacuum Pump, Busch
- 1.1.21: Small Direct mounted Pump/Motor < 10 kW

1.2: Motors
1.3: Air Compressors
1.4: Fans, Ventilation, Odour Control
1.5: Blowers
1.6: Centrifuges

21 pump types in the library
Model Development

Asset = Pump

Asset Function = Move Water

Asset Functional Failure = Low / No Flow

Asset Failure Cause = Blockage
Previously 6 month check

Chart shows optimum interval for 6 monthly (4380hrs) electrical routine is 1 year (8760hrs) - represents lowest cost and lowest criticality.
Importance of Criticality
## Watercare’s Risk Matrix Applied to RCM

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Description</th>
<th>Risk Register Score</th>
<th>Frequency</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Almost Certain</td>
<td>1 730 Hrs, Monthly</td>
<td>H EE EE EE E E E E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likely</td>
<td>0.7 8760 Hrs, Yearly</td>
<td>M H E E E E E E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Possible</td>
<td>0.4 43800 Hrs, 5 Years</td>
<td>L M H E E E E E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlikely</td>
<td>0.1 262800 Hrs, 30 Years</td>
<td>L L M H E E E E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very Unlikely</td>
<td>0.05 438000 Hrs, 50 Years</td>
<td>L L L M H E E E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remotely Possible</td>
<td>0.01 876000 Hrs, 100 Years</td>
<td>L L L L M H E H</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequence</th>
<th>1</th>
<th>5</th>
<th>15</th>
<th>40</th>
<th>75</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>Negligible</td>
<td>Moderate</td>
<td>Important</td>
<td>Serious</td>
<td>Very Serious</td>
<td>Catastrophic</td>
</tr>
</tbody>
</table>

48
Risk Assessment

Matrix developed for assessing the impact of failures on service delivery

Objective is to reduce either likelihood and or consequence

Move incidents from zone H to zone M to zone L
Reduce likelihood - Reduce Costs

- Eliminate repetition
- Non productive mundane maintenance
- Pareto/Statistical Process Control “SPC”

Perform Root Cause Analysis “RCA”

Run To Failure

Likelihood

Consequence

1 ----------------------------- 100
Risk Assessment

Risk based Maintenance “RBM”

1. How to move from zone L towards zone M, under managed conditions i.e...... cost reduction.

2. Accurate failure information must be available (MTBF, MTTR etc)

3. Structured RCM process has been adhered to resulting in good FMECA development
Risk Assessment
Understand Your Risks
Shifting Expenditure to Critical Assets

Average yearly spend per WW retic pump station over 5 years

- 50% PPM
- 50% UPM

Low proportion of maintenance in relation to operational cost

High proportion of maintenance in relation to operational cost

>70% PPM
Critical Asset ??

Consequence of failure ??
Risk ??
Parachute ??
Alignment of Equipment (Fault/Cause) Codes With RCM

Asset = Pump
Asset Function = Move Water
Asset Functional Failure = Low / No Flow
Asset Failure Cause = Blockage

<table>
<thead>
<tr>
<th>PUS</th>
<th>Pump</th>
<th>Submersible</th>
</tr>
</thead>
<tbody>
<tr>
<td>1220</td>
<td>Airlocked</td>
<td></td>
</tr>
<tr>
<td>1241</td>
<td>Bearing collapsed</td>
<td></td>
</tr>
<tr>
<td>1160</td>
<td>Blocked</td>
<td></td>
</tr>
<tr>
<td>1482</td>
<td>Cable failure</td>
<td></td>
</tr>
<tr>
<td>1541</td>
<td>Faulty mini CAS unit</td>
<td></td>
</tr>
<tr>
<td>1504</td>
<td>Flanged joint failure</td>
<td></td>
</tr>
<tr>
<td>1262</td>
<td>Guide rails / fittings corroded</td>
<td></td>
</tr>
<tr>
<td>1661</td>
<td>Hot joint/termination</td>
<td></td>
</tr>
<tr>
<td>1181</td>
<td>Impeller broken</td>
<td></td>
</tr>
<tr>
<td>2121</td>
<td>Impeller Worn</td>
<td></td>
</tr>
<tr>
<td>1781</td>
<td>Impeller/pulleys loose</td>
<td></td>
</tr>
<tr>
<td>1461</td>
<td>Internal Casing erosion</td>
<td></td>
</tr>
<tr>
<td>1782</td>
<td>Mounting/fittings loose</td>
<td></td>
</tr>
<tr>
<td>1505</td>
<td>Oil seal failure</td>
<td></td>
</tr>
<tr>
<td>2122</td>
<td>Wear ring worn</td>
<td></td>
</tr>
<tr>
<td>2181</td>
<td>Windings Insulation failure</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>No RCM code</td>
<td></td>
</tr>
</tbody>
</table>
## Alignment of Equipment (Fault/Cause) Codes With RCM

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Code</th>
<th>Status</th>
<th>Blocked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grease Lines</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Guides</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Nozzles</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Primary Tank</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Vacuum</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Centrifugal</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Diaphragm</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Centrifugal</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Direct Mounted</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Cavity Progressive</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Submersible</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Sump</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Centrifugal Vertical</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Hydraulic</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Pipe work Liquid</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Troughs</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Valve Penstock</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
<tr>
<td>Weir Troughs</td>
<td>1160</td>
<td>Blocked</td>
<td>blocked</td>
</tr>
</tbody>
</table>

**Query for all blocked pumps**

**Query for 1160 codes**
• NOTE

The software does not decide on which maintenance policy or combination of policies to adopt. Instead it advises the user on the operational data provided.

• The user makes the decision on which maintenance policy to adopt. This decision may include combinations of:
  • Scheduled Preventive Maintenance Tasks
  • Condition Monitoring
  • On-Condition Inspections
  • Inspections for Hidden Failures - Failure Finding Tasks
  • Run To Failure “RTF”
  • Re-Design
System Integration
Suite of Applications in Use

**RCM Cost Maintenance Decision Making**
- Start Up
- Hierarchy design
- Work order reporting code development
- Maintenance plan development through life
- Ongoing maintenance plan optimisation
- Rapid Assessment
- Failure history analysis

**AvSim + System Performance Optimisation**
- Through Life
- Ongoing plant availability, capacity, throughput modelling
- Spares optimisation
- Resource profiles
- Cost profiles
- Capital project prioritisation

**Reality Charting**
- Root Cause Analysis

**Supports Open System Design**
- ODBC Compliant database
- Specific Defined Interface required for live links
- Periodic Data Dump and Upload possible
- Microsoft Access import/export
- Microsoft Excel import/export
- ASCII file import/export
- Inter-program project conversion
- Export diagrams to Microsoft Word in rich text format
- Text, graphs, diagrams

**LCCWare Life Cycle Cost**
- Through Life
- NPV analysis
- Alternative improvement scenario cost profile comparison
- Payback periods
- Economic repair limits

**CMMS MOZAIC - “Oracle Database”**
- AM01 Asset Management
- WO01 Work Orders Maintenance
- Etc
- Job Plans within database - moving to attached word documents - allows easier automation
- Codes currently discipline & equipment specific - to match RCM/FMECA for equipment

**Control Systems “SCADA & DCS”**

**Plant Historians**
- Run hours
- Flow
- Level
- Pressure
- Chlorine/PH/Temp/Vol
- Etc
System Integration
RCM, Work Orders, KPI's & RCA Relationships

Reliability Improvement

Performance Management “KPI’s”

Root Cause Analysis (RCA) “Solutions”

CMMS MOZAIC

Work Data Management

Input Findings “History”

Close Work order

Implement Solutions

Plan Vs. Target

Review History

Failure Parameters

RCM Cost

Maint. Strategy Critical Assets

Maint. Strategy Non Critical Assets

Variance

Solutions

PARETO Analysis

Define Problem

RCM Cost

Plan Vs. Target

Review History

CMMS MOZAIC
KPI's

- KPI’s developed, based on 3 tiers

**Level 3 Strategic KPI’s**
- senior management

**Level 2 Business KPI’s**
- middle management

**Level 1 Team KPI’s**
- measured frequently in real time
- drive real time action
- focused on process
KPI's

Maintenance KPI's are used to:

- Monitor efficiency gains from implementation of maintenance improvement initiatives
- Identify areas presenting opportunities for improvement

1. **Total Cost of Maintenance**
   
   To monitor and measure overall maintenance cost trends and compare it with targets and benchmarks in order to highlight areas where improvements can be made.

2. **Unplanned Maintenance Costs vs. Total Maintenance Cost**
   
   To enable the company to identify activities where focused resource allocation is required to cost effectively minimise the level of unplanned maintenance.
   
   Our target: % Unplanned maintenance costs should be inside a range of +/- 5% around the historical average % unplanned maintenance cost.

3. **Efficiency - Unit Cost of Maintenance**
   
   To monitor, measure and benchmark efficiency gains and to highlight areas where gains could be made through upgrade or other resource allocation.

4. **Work Orders Completed vs. Work Orders Approved**
   
   Monitoring the trend for the number of work orders raised and approved during the period, the number of carryover work orders from previous periods and the number of work orders completed during the period provides the best indicator of effective resource allocation.
Root Cause Analysis
Root Cause Analysis

Problem

The problem will still re-occur unless the Root Cause is established and addressed
Root Cause Analysis
Root Cause Analysis
Welcome to Watercare’s Maintenance Manual

This manual is uncontrolled on printing

Maintenance Manual on the Company’s Intranet
• Waikato Water Treatment Plant Availability model (5000 blocks in size) based on RCM models
• Capacity/production model based on availability model
Process Overview Plant Availability

Availability Results based on 10 simulations over a 10 year period (24/7 Operation)
AvSim Plant Model

Raw Water Pump Station
Max running 2 pumps at any time - one spare

STPWO 20.1
Raw Water Pump System

STPWO 20.2
Air Compressor System

STPWO 20.3
Surge Tank System

STPWO 20.4
Raw Water Well

STPWO 20.6
Sample Instrumentation

STPWO 20.7
Raw Water Pump System

STPWO 20.8
Raw Water Pump System

Cap STPWO 20.3 fail
Capacity if STPWO 20.3 fails

Does not trip plant but reduces capacity from 75 to 30ml/d

Sample valves moved from here to raw water screen block

Fills entire block - means filter system is not monitored

services limited
Pareto Top 10 Downtime Contributors

- Random hidden failure
- Critical item
- No redundancy
Pareto Failure Modes

WaterCare Waikato Treatment Plant Total Down Time Importance

Failure Description

- Membrane Blower Electrically actuated valve Manual Operation fails
- Air Scour System Motor Cable failure
- Membrane Train PH Transmitter Out of calibration
- Membrane Train PH Transmitter Out of calibration
- Air Scour System Motor Hot Joint/Termination
- Backwash Tank Inlet Valve Actuator Seized
- Membrane Train PH Transmitter Sensor Dirty
- Raw water well penstock valve Inlet penstock fractured - corrosion/damage
- Membrane Train PH Transmitter Sensor Dirty
- Backwash makeup valve Valve fails to seal
- Raw water pump 32 10kh complete overhaul
- HFA Dosing system pump 11 10kh complete overhaul
- Treated water storage penstock valve Inlet penstock fractured - corrosion/damage

Importance Rank

0 100 200 300 400 500 600 700
Membrane Filtration - Mean Availability 99.07%

Year 1
14% unavailability of membrane aeration blower electrically actuated inlet valve due to:

• Random hidden failure
• Critical item
• No redundancy
The capacity of the plant is limited to a maximum of 75MLD by:
- The surge tank system
- The splitter box system
- The membrane filtration vacuum pumps.
- Mains power supply
• This chart shows the importance rankings from a capacity perspective. The membrane filtration area assets feature in eight out of the ten items. This indicates that this area should be targeted for capacity improvement activities.
# Summary Of Savings

<table>
<thead>
<tr>
<th>Year</th>
<th>Detail</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002/2003</td>
<td>Budget Project MOD banked maintenance savings prior to full roll out of phases 1 &amp; 2 of the maintenance pyramid</td>
<td>$12.5M</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>$1.2M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$11.3M</td>
</tr>
<tr>
<td>2002/2003</td>
<td>Budget Inflation New Asset Maintenance (additional assets $137M)</td>
<td>$11.3M</td>
</tr>
<tr>
<td></td>
<td>Projected 2005 / 2006 Budget</td>
<td>$0.8M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.5M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$12.6M</td>
</tr>
<tr>
<td>2005/2006</td>
<td>Projected Budget Actual Budget MOD Savings</td>
<td>$12.6M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$11.8M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.8M</td>
</tr>
<tr>
<td>Annual Maintenance Savings</td>
<td>MOD savings prior to full roll out of pyramid phases 1 &amp; 2 ($0.5M + $0.3M some banked in advance)</td>
<td>$1.2M</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>$0.8M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$2.0M</td>
</tr>
</tbody>
</table>
### Impact on AMP 2006 - 2026

<table>
<thead>
<tr>
<th>Year</th>
<th>Detail</th>
<th>$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>AMP Forecast - projected lowest</td>
<td>$12.5M</td>
</tr>
<tr>
<td>2018</td>
<td>AMP Forecast - projected highest</td>
<td>$19.1M</td>
</tr>
</tbody>
</table>

**AMP Based Maintenance Forecast**

- **Phases 1 & 2 completed**
- **Potential Savings $300K** Phases 3 & 4 completed
- **Additional Assets 2003 - 2005 $137M**
- **Prior to phases 1 & 2 full roll out $1.2M**
The 2006 WSAA M&E Program Benchmarking Group consists of utilities from Australia, New Zealand, and United States.

**AUSTRALIA**

QUEENSLAND
Brisbane Water (Brisbane)

SOUTH AUSTRALIA
SA Water (Adelaide)

VICTORIA
Central Highlands Region Water (Ballarat)
City West Water (Sunshine)
Central Gippsland Region Water (Traralgon)
Melbourne Water Corporation (Melbourne)

WESTERN AUSTRALIA
Water Corporation (Perth)

**AUSTRALIA**

NEW SOUTH WALES/AUST CAPITAL TERRITORY
ActewAGL (Canberra)
Hunter Water Corporation (Newcastle)
Sydney Water Corporation (Sydney)

**NORTHERN TERRITORY**
Power and Water Corporation (Darwin)

**TASMANIA**
Hobart Water (Hobart)

**NEW ZEALAND**
North Shore City Council (North Shore City)
Christchurch City Council (Christchurch)
Watercare Services (Auckland)

**USA**
Seattle Public Utilities (Seattle)
San Francisco PUC (San Francisco)
Portland Water District (Portland)
The composite service level score versus composite cost score chart for breakdown and scheduled tasks shows Watercare (WCS) as higher than average service level and lower than average cost, and confirms Watercare is an excellent performer for the activities benchmarked.
Observation: Managerial Areas
Maintenance Policy and Planning

Watercare has developed a sound rigorous approach to maintenance planning which is delivering excellent performance and provides a platform for continuing improvement.

Areas of Strength
- Comprehensive policy developed via maintenance pyramid to support consistent maintenance delivery across Watercare’s facilities. Rollout to all facilities is approximately 50% complete.
- Strong commitment to achieving a transparent system to deliver availability, achieve cost savings and manage risk.
- Comprehensive use of appropriate tools such as RCA, Avisim and particularly RCM, to optimise performance. Modelling of facilities is approximately 50% complete.
- Budgets setting based on outcomes of modelling of maintenance regimes.
- Maintenance strategies supported by sound performance data, condition assessment and knowledge of costs.
- Developing models to better connect maintenance strategies with plant availability using RCM and AUSIM.
- While many assets/components are run-to-fail this is still based on maintenance modelling.
- Attempt to standardise on replacement products where possible, e.g. PLC’s.
- Asset specialist play a crucial role in providing operational support, identifying and implementing improvement and rolling out the maintenance optimisation program.
- Asset modelling can provide support for the corporate budget through prediction of whole of asset life costing.

Areas of Improvements
- Maintaining support for the rollout and continued modelling of RCM etc to facilities.
- Retaining asset specialists and modellers.
- Communicating benefits and maintaining employee support.
Summary of Key Improvement Areas

- Implementation of Risk Based Maintenance Programmes that provide a clear opportunity for:
  - Task optimisation
  - Cost improvement
  - Risk assessment
  - Reduction of downtime

- Implementation of work orders that:
  - Focus & prioritise maintenance activities for maximum gain
  - Provide an audit trail
  - Control spend & implement approval processes
  - Provide for common systems company wide

- Implementation of management control and reporting systems that:
  - Drive maintenance optimisation
  - Facilitate decisions to replace/repair/rehabilitate
  - Establish maintenance performance measurements
Some Good Books to Read

- Overall Equipment Effectiveness
  "A Powerful Production / Maintenance Tool for Increased Profits"
  ISBN 0-8311-3138-1

- Effective Maintenance Management
  "Risk & Reliability Strategies for Optimising Performance"
  ISBN 0-8311-3178-0

- Asset Maintenance Management
  "A Guide to Developing Strategy & Improving Performance"

- Quality Planning & Analysis
  "From Product Development Through Use"

- Developing Performance Indicators
  "For Managing Maintenance"
  ISBN 0-8311-3080-6

- Reliability Centred Maintenance
  "RCM II 2nd Edition"
  ISBN 0-7506-3358-1
Full Steam Ahead - Just Do It
The End

Mangere Wastewater Treatment Plant