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Plant and Asset Engineering

Evaluating the Effectiveness of Chosen Maintenance

Strategies for Dedicated Equipment

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2 Introduction

Effective maintenance is essential to ensuring operational reliability, regulatory compliance, and cost efficiency within wastewater treatment. Process failures can lead to environmental harm and public health risks, which can result in legal penalties. Given the significant ethical and regulatory implications of such failures, maintenance strategies must balance performance, cost, and risk across the entire asset lifecycle (Campbell and Barry, 2024).

This report evaluates the effectiveness of the current maintenance strategy applied to ultraviolet disinfection (UVD) equipment used in the final effluent treatment at Pen-y-Bont wastewater treatment process. UVD systems are critical in ensuring that treated water meets regulatory discharge standards by inactivating harmful microorganisms before discharging into the environment. The reliability and performance of these systems are essential, yet their degradation and maintenance requirements do not always align with traditional time-based maintenance intervals.

This report will critically review the current maintenance practices applied to the UVD system, assessing the strengths, limitations, and underlying rationale. It will then evaluate alternative approaches, including condition-based maintenance, reliability-centred maintenance (RCM), and total productive maintenance (TPM), to determine how the current strategy can be improved. Consideration will also be given to the costs and resource challenges associated with implementing these improvements. Finally, the report will provide conclusions and recommendations to support the development of a more effective and sustainable maintenance strategy.

3 Background: Business & Equipment

Dŵr Cymru Welsh Water operates within the water and wastewater industry, providing services to over three million customers across Wales and parts of England. Its core operations include the collection, treatment, and safe discharge of wastewater back into the environment, ensuring compliance with environmental permits and protecting public health (Dŵr Cymru Welsh Water, n.d.).

Wastewater treatment typically involves preliminary, primary, and secondary processes, followed by final discharge. At environmentally sensitive sites, disinfection is required as a final treatment stage to remove harmful microorganisms before release. This disinfection is now predominantly achieved with UVD systems (Metcalf & Eddy, 2014).

UVD aims to ensure microbiological compliance with regulatory standards as these systems inactivate microorganisms by damaging their DNA, preventing replication and rendering them non-infectious. The UVD systems work by exposing flowing water to ultraviolet light, typically at a wavelength of approximately 254 nm using submerged lamps within a reactor channel. The delivered UV dose (intensity $\times$ exposure time) determines effectiveness (Bolton and Cotton, 2008).

Critical asset selection is guided by the consequence of failure, system impact, and lifecycle risk. Assets such as UVD are classified as critical due to their role as final treatment barriers, where failure results in immediate environmental and regulatory consequences (Moubray, 1991). A criticality scoring matrix helps highlight why the UVD is critical.

Criteria	Score	Reasoning
Safety / Environmental	5	Failure leads to discharge of untreated pathogens: direct environmental and public health risk
Operational Impact	5	Loss of disinfection means loss of compliance function
Economic Impact	4	Potential regulatory fines, reputational damage, and corrective costs
Failure Likelihood	3	Moderate (lamp degradation, fouling, ballast failure)
Detectability	2	Alarms and Data monitored via SCADA (UV intensity sensors, failure alarms)

Table 1 - UVD System Criticality Scoring Matrix

The UVD system at Pen-y-Bont is the Trojan UV3000Plus. It is configured with three parallel banks to provide redundancy and maintain effective UV dose during partial failures. Failure of multiple banks or degradation in performance can still result in loss of disinfection capability and subsequent regulatory non-compliance. This aligns with the principle that criticality is determined by consequence of failure rather than system configuration alone (Moubray, 1991).

4 Critical review of current maintenance practices

4.1 Current Maintenance Strategy

The current maintenance strategy applied to the UV disinfection system is a time-based preventive maintenance, defined as maintenance performed at predetermined intervals regardless of equipment condition (Mobley, 2014). Maintenance is delivered via a supplier contract with quarterly visits made up of two minor and two major service visits, reduced from a previous monthly schedule.

Activities include inspection, cleaning, and component replacement. No internal DCWW operator-led maintenance is undertaken outside of these visits. The approach is therefore a planned but externally dependent model, with reactive interventions for breakdowns between service intervals. Although SCADA data and alarms are available, they are not used to inform maintenance decisions. As a result, the strategy relies on fixed intervals rather than condition-based or predictive principles.

4.2 Strengths of the Current Approach

A key strength of the current maintenance strategy is its structured and consistent approach. Scheduled maintenance ensures that essential tasks are completed at defined intervals, reducing the likelihood of oversight. Planned maintenance is widely recognised for improving reliability compared to purely reactive approaches (Mobley, 2014).

The use of specialist supplier expertise is also beneficial. UVD systems are typically “package plant” systems requiring specific technical knowledge and supplier led maintenance ensures adherence to manufacturer standards, reducing the risk of incorrect intervention. This supports warranty compliance and provides assurance of component compatibility and quality (Campbell and Barry, 2024).

The supplier-led maintenance supports regulatory compliance by demonstrating a structured and auditable maintenance approach. It also provides predictable costs and reduces the need for internal resources and training, improving consistency compared to internally delivered maintenance where competing competencies and priorities can negatively impact the maintenance effectiveness.

4.3 Limitations and Critical Analysis

Despite these strengths, the strategy has significant limitations. The primary issue is the reliance on time-based maintenance, which does not reflect the failure behaviour of UVD components. As identified by Moubray (1991), many failures are not age-related, meaning fixed intervals can lead to unnecessary maintenance while allowing degradation between visits. UVD performance is influenced by factors such as lamp degradation and fouling, which depend on operational and environmental conditions rather than time alone. Consequently, a quarterly interval may allow performance to deteriorate without triggering failure, indicating that the strategy prioritises failure prevention rather

than optimal performance.

Another limitation is the absence of internal DCWW operator led maintenance. This contrasts with the principles of Total Productive Maintenance, which emphasise autonomous maintenance and early fault detection (Borris, 2006). In the absence of operator involvement early indicators of deterioration are not identified or resolved. Site conditions further highlight operator led maintenance Overhanging trees introduce organic debris into the UV channel, particularly during autumnal periods, increasing turbidity and promoting organic build-up on the lamp sleeves.

To emphasise the need for increased operator-led maintenance, site observations highlight the environmental conditions surrounding the UVD system and their impact on performance. Organic debris from overhanging trees accumulates within the UV channel (see figures 1 and 2), alongside filamentous algae originating from the primary settlement stages, where failed spray cleaning systems allow build-up to occur (see figures 3 and 4). Due to its fibrous nature the algae quickly builds up, increasing fouling and maintenance demand. Operational feedback indicates that cleaning of the lamp assemblies constitutes a significant proportion of time during supplier visits (L. Jones, DCWW Operational Supervisor, personal communication, 8 April 2026; G. Rees, Ex-DCWW Operational Supervisor, personal communication, 8 April 2026). Organic fouling of UV lamp sleeves is known to significantly reduce UV intensity and overall system performance (Bolton and Cotton, 2008). This represents condition-driven degradation although it is currently managed through time-based maintenance, highlighting a misalignment within the existing maintenance strategy. In addition to performance degradation, fouling of lamp sleeves reduces UV transmittance, requiring higher energy input to achieve the required UV dose (Bolton and Cotton, 2008). This indicates that the current maintenance approach negatively impacts energy efficiency, as the system operates less effectively under fouled conditions.

The lack of data utilisation is another critical weakness. Although the SCADA systems provides performance data, it is not used to guide maintenance decisions where effective maintenance increasingly relies on condition monitoring to optimise schedules (Moble, 2014). As a result, component failures may not be addressed promptly; faults identified after a service visit may persist until the next scheduled intervention, potentially delaying corrective action by several months. This increases the risk of reduced UV performance and non-compliance.

Overall, the strategy represents a hybrid of planned and reactive maintenance. While structured, it may lead to inefficient resource use, unnecessary interventions, and increased risk of performance-related failures. It also fails to account for seasonal variation, where fouling rates increase during summer and autumn.

4.4 Rationale for the Current Strategy

The current strategy is influenced by organisational, technical, and economic factors. A primary driver is reliance on supplier expertise, as UVD systems require specialist knowledge. Outsourcing reduces the need for internal training and resource allocation (Campbell and Barry, 2024).

Cost predictability is another factor. Time-based maintenance provides a simple and structured approach to planning and budgeting and is often favoured due to ease of implementation (Mobley, 2014). The strategy may also reflect legacy practices, as time-based maintenance has historically been widely adopted despite known limitations (Moubray, 1991).

Risk aversion is also relevant. Given the critical role of UVD in ensuring compliance, supplier led maintenance may be perceived as reducing operational risk. However, this knowledge drain limits the development of internal capability.

4.5 Summary

The current maintenance strategy provides a structured and compliant approach, delivering baseline reliability and predictable costs. However, it is limited by its reliance on time-based maintenance, lack of operator involvement, and ineffective use of available data. Literature indicates that effective maintenance should align with asset condition and failure behaviour rather than fixed intervals (Moubray, 1991; Mobley, 2014), while Total Productive Maintenance highlights the importance of operator engagement (Borris, 2006). The current approach is therefore suitable but with clear opportunities for improvement through data driven and integrated maintenance practices.

5 Improvements to Integrated Maintenance Strategy

To address these limitations, an integrated maintenance strategy is proposed, combining condition-based maintenance, operator involvement, and risk-based decision-making.

The strategy aligns maintenance activities with actual equipment condition and failure mechanisms rather than fixed time intervals. SCADA data will be used to monitor key performance indicators such as UV intensity, transmittance, alarm frequency, and component status. Maintenance interventions, such as lamp sleeve cleaning, will be triggered based on defined performance thresholds to ensure efficient maintenance when required (Mobley, 2014).

SCADA data will also be used to track component failures, such as lamps and ballasts, enabling proactive planning and ensuring replacement parts are available prior to maintenance visits. Analysis of real-time and historical data will identify failure trends, such as increased fouling rates or premature component failure, supporting a transition towards condition-based and predictive maintenance. From a Reliability-Centred Maintenance perspective, this ensures maintenance is targeted at managing specific failure modes and their consequences (Moubray, 1991).

Operator involvement is a key element of the strategy. Drawing on Total Productive Maintenance principles, operators will undertake inspection and basic maintenance tasks, particularly during periods of increased fouling risk. These activities include visual inspection of UV channels, removal of debris, and monitoring and reporting system status and performance. This enables early detection of degradation, reduces reliance on supplier interventions, and allows specialist supplier maintenance to focus on higher value tasks (Borris, 2006).

Environmental and other asset issues contributing to algae and organic build-up must also be addressed. Ensuring effective operation of spray cleaning systems in primary settlement and introducing upstream filtration will reduce fouling within the UVD system. This reflects a systems-based approach, recognising that asset performance is influenced by upstream conditions. Although not a direct maintenance intervention, the installation of a structural cover over the UV banks is proposed to minimise the ingress of organic debris. This represents a proactive approach to reducing failure mechanisms at source, aligning with asset management principles that prioritise the elimination of root causes rather than reactive maintenance.

The strategy incorporates risk-based prioritisation, focusing maintenance on components with the greatest impact on compliance and performance.

5.1 Implementation and Management of Change

The transition to this improved maintenance strategy requires a structured implementation plan supported by effective management of change. Changes to maintenance practices, roles, and

responsibilities introduce operational and organisational risks that must be carefully controlled.

A phased implementation is recommended, beginning with a pilot on Pen-y-Bont UVD system to trial condition-based triggers and operator-led maintenance. Performance should be monitored before wider rollout.

Operator training and the development of standard operating procedures are essential to ensure safe and consistent execution. Effective management of change is critical, as changes to roles and processes introduce operational risks. The Health and Safety Executive (HSE, 2001) highlights the need for controlled change processes, while ISO 55000 emphasises structured change management to maintain asset performance (ISO, 2014). Clear communication and stakeholder engagement are therefore essential.

5.2 Risks and Barriers

Several risks and barriers are associated with implementing the proposed strategy. Cultural resistance may arise due to changes in operator roles and increased responsibility for maintenance tasks.

Resistance to organisational change can limit successful implementation if not effectively managed through training, communication, and stakeholder engagement (Kotter, 1996).

Training is required to ensure operators competence and confidence in undertaking new maintenance tasks (Borris, 2006). This will require supplier support, which may present a barrier if the proposed changes are perceived to reduce future maintenance revenue.

Initial costs associated with training, system development, and process changes may also act as barriers. However, these are expected to be offset by reduced reliance on supplier interventions and improved system performance. Developing a dedicated internal maintenance capability could further reduce long term costs and build organisational expertise.

Finally, the effectiveness of condition-based maintenance depends on the quality and reliability of data. Accurate SCADA and telemetry data are essential to support timely and informed maintenance decisions (Mobley, 2014).

6 A consideration of costs and resources required to implement proposed changes.

Reducing the maintenance frequency from monthly to quarterly has lowered the service contract cost from £23,217.73 to £4,233.07. Combined with renegotiated rates, this represents an approximate cost reduction of 82%, demonstrating the short-term financial benefit of the revised schedule. However, there is currently insufficient data to assess the impact on reactive maintenance costs. For example, a recent quotation for major service parts totalled £29,542.56, and it is unclear whether reduced maintenance frequency may increase component failures over time. This also highlights the high cost of replacement components and the need for more data driven root cause analysis and failure forecasting.

Capital costs are expected to be low, as the strategy primarily utilises existing SCADA infrastructure for condition monitoring. Minor investment may be required to enhance data reporting capabilities, such as configuring dashboards or trend analysis tools. However, higher upfront capital investment may be required to address upstream issues contributing to fouling, including the repair or replacement of primary settlement weir cleaning systems and the installation of screening to reduce organic debris entering the UVD channels. Additional costs may also be associated with installing a structural cover over the UV banks.

Labour and training costs will be more significant. Operators will require supplier provided training to undertake maintenance tasks, including inspection, cleaning, and data reporting. Standard operating procedures will be required in addition to existing workflow. Operational resources on site are already constrained, especially considering maintenance of the primary settlement weir cleaning system has been ineffective. This must be considered before introducing additional workloads.

Improved maintenance practices are also expected to reduce energy inefficiencies associated with fouled or degraded equipment, contributing to lower operational costs over the asset lifecycle.

In the longer term, the strategy is expected to deliver cost savings through reduced unnecessary maintenance and improved fault detection. This is critical given the high cost of failure associated with UVD systems, including regulatory non-compliance and environmental risk. From a lifecycle perspective, aligning maintenance with asset condition improves efficiency and reduces total cost of ownership (Campbell and Barry, 2024).

7 Conclusions/Recommendations.

This report concludes that the current maintenance strategy for the UV disinfection (UVD) system provides a structured and compliant approach but is limited by its reliance on time-based preventive maintenance and supplier-led interventions. While this supports baseline reliability, it does not effectively account for condition-driven degradation such as fouling and algae build-up, nor does it utilise available SCADA data to inform maintenance decisions. As a result, the strategy can lead to inefficient maintenance, delayed fault response, and increased risk of reduced system performance.

The proposed integrated maintenance strategy addresses these limitations by aligning maintenance with actual equipment condition, increasing operator involvement, and adopting a more data-driven approach. This supports improved reliability, better resource utilisation, and enhanced compliance performance.

In the short term, it is recommended to utilise SCADA data for performance monitoring and introduce operator-led inspections and cleaning during peak fouling periods. In the medium term, a pilot programme should be implemented to trial condition-based maintenance, supported by training and standard operating procedures, alongside addressing organic debris fouling. In the long term, the organisation should transition towards a fully integrated, condition-based maintenance strategy aligned with lifecycle asset management principles, reducing reliance on fixed intervals and external suppliers while improving overall system resilience.

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9 Appendix



Figure 1 – UVD System – Overhanging Trees



Figure 2 - UVD System – Organic Debris from Trees



Figure 3 - Primary Settlement - filamentous algae growth.

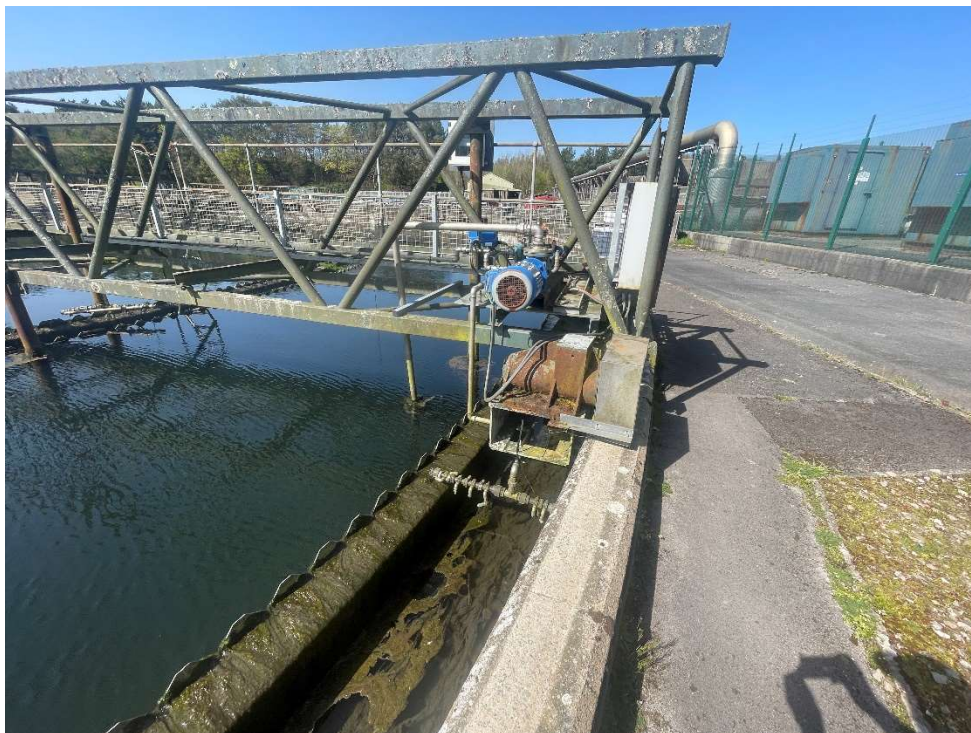


Figure 4- Primary Settlement - weir channel build up / faulty spray system.