

University of Wales Trinity Saint David

School of Engineering



Six Sigma Green Belt

Combined Sewer Overflow & Storm Overflow Event

Reduction and Enhanced Monitoring

ACMA5005

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2 Introduction

Combined Sewer Overflows (CSO) and Storm Overflows (SO) associated with pumping stations and wastewater treatment works represent critical challenges for water utility companies such as Welsh Water. Aging infrastructure, urban expansion, and rising environmental standards necessitate the adoption of effective and resilient management strategies. CSOs typically occur when excessive rainfall overwhelms combined sewer systems, causing untreated wastewater to discharge into local water bodies. Similarly, storm overflows at pumping stations and treatment works arise when the hydraulic capacity of these assets is exceeded, resulting in emergency discharges that can have significant environmental impacts. These events not only lead to environmental pollution but also threaten regulatory compliance, customer confidence, and public health. Addressing these interconnected challenges demands a systematic, data-driven approach, making Six Sigma an ideal methodology.

According to Pyzdek (2018), Six Sigma offers a comprehensive framework for process improvement by minimising defects and variability through the DMAIC (Define, Measure, Analyse, Improve, Control) methodology. Welsh Water leveraged this approach to systematically identify, analyse, and mitigate the root causes of both CSO and SO events. The structured nature of Six Sigma, as outlined by Muroe (2007), enables organisations to apply statistical tools effectively, thereby achieving measurable improvements in operational and environmental performance.

The primary objective of the Six Sigma project at Welsh Water was to reduce the frequency and environmental impact of discharges from both CSO and SO events, while ensuring compliance with statutory requirements and increasing transparency to stakeholders. Utilising the principles of operations management described by Russell (2009), the project involved comprehensive data collection, root cause analysis, and the implementation of targeted, evidence-based solutions to improve system reliability and resilience across all major asset types.

This report explores the application of Six Sigma in managing both CSO and SO events, detailing each phase of the DMAIC process, the statistical tools used, and the resulting impact on environmental performance and regulatory compliance. By examining this case, valuable insights are gained into how Six Sigma can be effectively deployed within the water utility sector to tackle complex and multifaceted operational challenges.

3 Define

3.1 Problem Statement

Welsh Water has been experiencing frequent CSO and SO events, particularly during periods of heavy rainfall, leading to the discharge of untreated or partially treated wastewater into nearby rivers, coastal areas, and sensitive environments. These occurrences pose significant environmental risks, threaten compliance with increasingly stringent regulatory standards, and could potentially result in financial penalties, enforcement actions, and reputational damage.

Current operational practices have proven insufficient in managing the volume and variability of inflows effectively across sewer networks, pumping stations, and treatment facilities. Key contributing factors include aging infrastructure, limited ability to handle large flows and storm storage, increasing urban development, and the impacts of climate change, which together increase the pressure on the wastewater system during storm events.

With the recent deployment of near real-time monitoring systems, where storm overflow data is now available to the public, scrutiny over the management of CSO and SO events is intensifying. Customers, regulators, and environmental groups expect water companies to demonstrate continuous improvement in minimising the frequency, duration, and environmental impact of discharges. Without a systematic, data-driven approach to identify and address the root causes of both CSO and SO events, Welsh Water risks ongoing environmental degradation, loss of customer trust, and potential regulatory breaches.

Therefore, this Six Sigma project aims to apply the DMAIC (Define, Measure, Analyse, Improve, Control) methodology to systematically identify the issues which are contributing to CSO and SO events at targeted assets, reduce the frequency of such events by at least 30%, and improve compliance with environmental standards within a 12-month period. This initiative seeks to enhance the overall efficiency, resilience, and reliability of the wastewater management system, ensuring sustainable operations, strengthened regulatory adherence, and improved environmental performance.

3.2 Voice of the Customer

Understanding the Voice of the Customer (VoC) is essential in aligning the Welsh Water CSO and SO event reduction project with the expectations and concerns of stakeholders. Key stakeholders include environmental organisations, recreational water users, and the customers. Insights from these stakeholders help identify critical requirements for the project.

3.2.1 Environmental Organizations:

Surfers Against Sewage (SAS) are an environmental group who have raised concerns and campaigned against frequency and impact of CSO and SO events across water companies in England, Scotland

and Wales. SAS emphasises that such discharges, intended only for exceptional circumstances, are occurring regularly, leading to environmental degradation and health risks. They advocate for water companies to prioritise; high risk pollution where storm overflows are causing the most serious consequences to bathing waters and high priority nature sites. To show transparency by providing accessible and accurate real time discharge information. Empower a nature led approach, for government to remove barriers to promote adoption of nature-based solutions that can ease pressure on sewage systems and help resolve water quality issues (Ross et al., 2023).

3.2.2 Recreational Water Users:

Surfers Against Sewage (SAS) also highlight that individuals engaging in activities like surfing, swimming, and angling are directly affected by these events. Health risks associated with exposure to polluted waters include gastrointestinal illnesses and infections (Ross et al., 2023).

Schoen, M.E. et al (2021) study on risk of acute gastrointestinal illness (AGI) found that recreating in waters within 24 hours after a CSO event increased the risk of AGI by 39–75%, compared to recreating more than 24 hours after such an event. The findings underscore the significant health risks posed by exposure to CSO event. Recreational users demand access to real time data and notifications about sewage discharges and improved water quality.

3.2.3 General Public and Communities:

Public sentiment reflects growing dissatisfaction with the management of sewage systems. Reports from CCW (2024) detail that in 2023-2024, complaints to water companies in England and Wales rose by 29%. With many of these complaints driven by customer concern over environmental issues, including the impact of spills from SO which increased by 217%.

The public expects proactive measures with investment in infrastructure to prevent sewage spills and for water utilities to protect communities. Transparency from water companies regarding sewage management practices and CSO and SO incidents. There is also a push for greater accountability of water companies for spills to prevent future occurrences

3.3 VoC Summary and Outlined Critical to Quality requirements (CTQs)

Implementing real-time monitoring systems. Install reliable sensors and telemetry technologies to provide immediate data on CSO and SO events to enhance transparency. Enhancing public communications with the development of platforms to share live CSO and SO status' and to share information about water quality to build public trust.

Focused investment by identifying high risk and problematic assets. Including modernising sewer networks, increasing storm storage capacity and resilience, identify/clear/reduce blockages, adopt nature-based solutions reducing the frequency of CSO and SO events.

Collaborate with regulatory bodies to ensure adherence to environmental standards and swiftly address violations to strengthening regulatory compliance:

By integrating these requirements within the project, Welsh Water can effectively respond to the Voice of the Customer, leading to improved environmental outcomes and improved public satisfaction.

CTQs translate customer needs into measurable parameters (Bicheno and Holweg, 2016).

Based on VoC, the following are CTQs:

- Provide visibility to Stakeholders with Real-time data and alerts with accuracy ($\geq 95\%$)
- CSO and SO event frequency reduction (30% Target)
- Compliance with regulatory discharge limits
- Identify high risk assets for investment

3.4 Current Initiatives and Actions by Welsh Water

Welsh Water is actively addressing the concerns highlighted in the Voice of the Customer (VoC) analysis. Near real-time monitoring and public communication has been implemented with an online access storm overflow map which provides public access CSO and SO events and bathing water quality. The map prioritises assets near bathing waters and popular recreational sites.

To modernise its wastewater infrastructure, Welsh Water has committed £420 million planned from 2025 to 2030. These investments aim to upgrade sewer networks, increase storm storage capacity, and adopt nature-based solutions to reduce the frequency and impact CSO and SO events.

3.5 Ongoing Challenges Welsh Water

The near real-time data provided is subject to delays and potential inaccuracies, as it is unvalidated and may be affected by technical issues such as sensor issues or connectivity problems. Currently not all storm overflow assets are represented on the map but there is work ongoing to include all 2,300 assets in the near future.

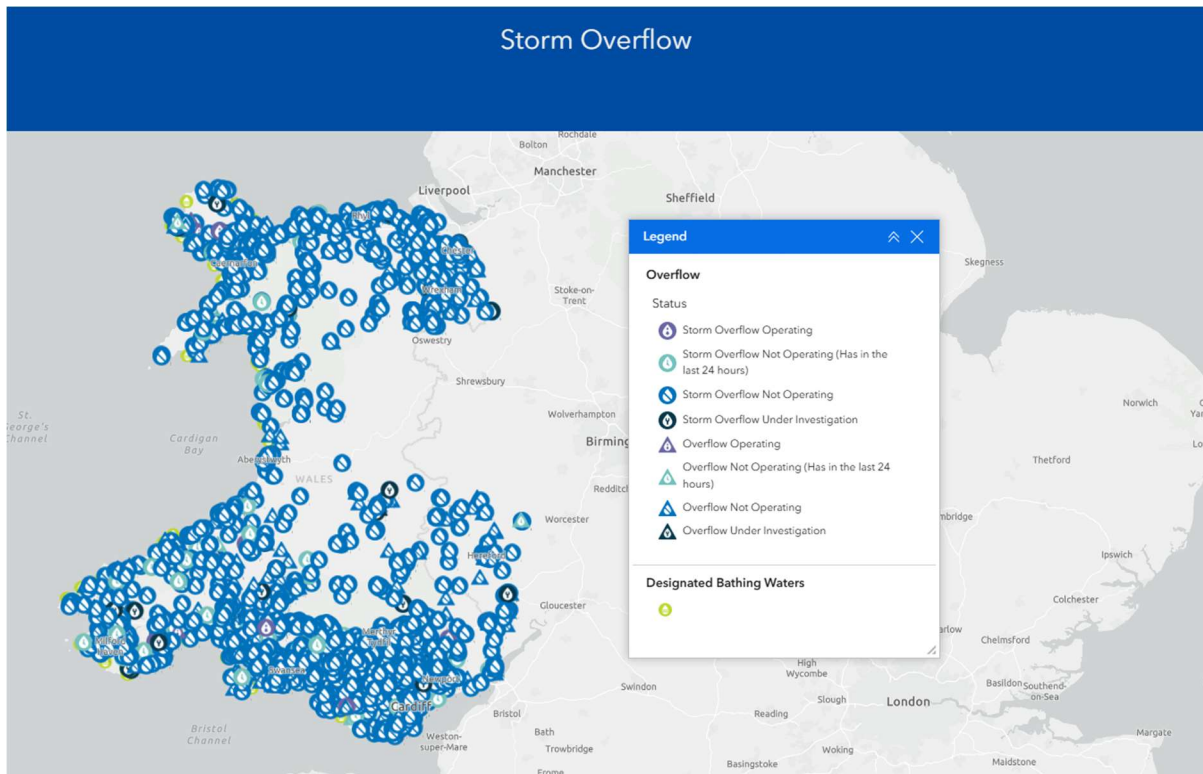


Figure 1 - DCWW Storm Overflow Map (Welsh Water, Dwr Cymru, no date)

Welsh Water is taking steps to address CSO and SO event concerns through transparency and infrastructure improvements. However, ongoing challenges such as resources, data accuracy and full asset coverage remain areas for development to fully meet stakeholder expectations.

3.6 Project Scope

In Scope:

- Analysis of historical CSO Spill data from the last year
- Evaluation of near real-time monitoring system's data and performance (accuracy, coverage, responsiveness).
- Identification of critical factors contributing to CSO and SO events
- Identification and prioritisation of investment locations based on spill frequency and severity.
- Development of recommendations for operational improvements.

Out of Scope:

- Spill data not recorded or validated
- Broader water quality concerns unrelated to CSO and SO events (e.g., agricultural runoff)

Proper scoping ensures the project remains manageable and focused (Munro, 2007).

3.7 Business Case & Benefits

Frequent CSO and SO events pose a serious environmental and reputational risk to Welsh Water. Public scrutiny is rising due to the near real-time visibility of these spills, supported by stakeholder activism and regulatory pressure. A systematic Six Sigma project focused on spill data can uncover trends, root causes, and operational inefficiencies to enable Welsh Water to take evidence-based actions that reduce events and enhance public trust and confidence.

This aligns with Welsh Water's broader goals of regulatory compliance, sustainability, and customer engagement, while avoiding potential fines and reputational damage.

- Avoid regulatory penalties
- Reduce reputational risk
- Improve environmental performance
- Enhance customer satisfaction

3.8 Project Charter

Element	Details
Project Title	CSO and SO Event Reduction and Monitoring Enhancements through Six Sigma
Project Lead	Andrew Madelin
Problem	Frequent CSO and SO events have led to environmental risks, regulatory scrutiny, and public dissatisfaction. Current monitoring systems lacks full coverage and accuracy, and root cause requires investigation.
Goal	Reduce the frequency of CSO spills by 30% in 12 months and improve the accuracy and transparency of monitoring systems to $\geq 95\%$.
Scope	Refer to Section 7.9
Timeline	12 months (April 2025 – April 2026)
Key Stakeholders	General Public, Recreational Water Users, Environmental groups, Asset Managers, Public Communications Team
Success Metrics	Identification of High Risk CSO and SO Targeted Assets for Investment Spill frequency reduction Public complaints decrease Monitoring data accuracy $\geq 95\%$ Completion of CTQs

A strong charter clarifies purpose and roles, providing a roadmap for the DMAIC journey (Pyzdek, 2018).

3.9 Risk and Assumptions

3.9.1 Risks

- Delays in funding for infrastructure upgrades.
- Resistance to change from operational staff.
- Technical challenges in integrating new EDM systems, especially with the geographical difficulties with Welsh Water assets

3.9.2 Assumptions

- Available budget and resources
- Regulatory bodies will support proposed improvements.
- Access to accurate and comprehensive data on CSO and SO events

4 Measure

The Measure phase is the second stage in the DMAIC framework and is important in establishing baseline performance and identifying variation (Pyzdek, 2018). For Welsh Water, this phase focuses on assessing the current frequency, duration, and monitoring effectiveness of CSO and SO events, with the aim of analysing to find data-driven improvements.

4.1 Purpose of the Measure Phase

According to Muroe (2007), the measure phase is about collecting reliable data to assess the current performance. It lays the foundation for analysis by defining what constitutes a defect, quantifying current performance metrics, and ensuring the data collected is valid, consistent, and relevant to customer-defined Critical to Quality (CTQ) outputs. Bicheno and Holweg (2016) emphasise that metrics must reflect what customers care about

For this project the CTQ from the Voice of the Customer review include:

- Provide visibility to Stakeholders with Real-time data and alerts with accuracy ($\geq 95\%$)
- CSO and SO event frequency reduction (30% Target)
- Compliance with regulatory discharge limits
- Identify high risk assets for investment

These targets require robust data and a clear understanding of how performance is currently measured and reported.

Bicheno and Holweg (2016) emphasise that metrics must reflect what customers care about

4.2 Data Sources and Methodology

Data for this stage was sourced from Welsh Water's 2024 Annual Unpermitted Storm Overflow (uSO) EDM Return, which was submitted to Natural Resources Wales (NRW). The dataset includes performance metrics for assets that are permitted as Emergency Overflows but were found to be operating under storm conditions. This means that these assets are only permitted to spill in case of an emergency, electrical mains failure or multiple pump failures. This information is supported by near real-time monitoring provided on the company's online portal (Dŵr Cymru, 2025).

Each storm overflow asset is fitted with level sensor connected to a telemetry outstation which is used as an Event Duration Monitoring (EDM) device, designed to log when an CSO or SO event occurs and for how long. The devices form part of a wider data-driven strategy to increase transparency and compliance with environmental obligations. These systems record:

- Total CSO and SO event durations (in hours)

- CSO and SO event frequency
- Telemetry EDM system uptime as a percentage of the year
- Free text comments on unusual performance or exceedances

This data is essential for understanding how different assets contribute to environmental risk, enabling targeted improvements. These metrics not only provide insight into current system performance but also reveal where urgent investment or reclassification is required (Bicheno and Holweg, 2016).

4.3 Understanding Measurement Variation

As highlighted by Pyzdek (2018), identifying and controlling measurement variation is essential for accurate decision making. Measurement variation for this project refers to inconsistencies in how CSO and SO events are recorded. Sources of variation identified in this project include:

4.3.1 Sensor calibration and accuracy

Level instruments are used to measure water levels. Errors with level instruments, calibration issues and sensor positional disruption can lead error in EDM by either under or over reporting.

4.3.2 Data availability

Not all CSO and SO asset are currently capable of recording and sending telemetry data. Welsh Water aims to achieve full coverage in 2025.

4.3.3 Telemetry Connectivity

Real time monitoring depends on stable telemetry. Downtime due to network issues can cause delayed or missing data. Welsh Water is undertaking a project to replace all telemetry outstation PSTN lines, in line with the government's transition from analogue to digital telecommunications. The PSTN lines are being replaced with M2M (Machine-to-Machine) connectivity. However, this change may leave systems more susceptible to issues within the mobile phone networks but hopefully the upgraded hardware will add resilience long term as data can be stored and retrieved on network recovery.

4.3.4 Free Text Comments

While free text entries provide additional information the input is not standardised and is often lacking the detail required.

To address these challenges, Russell (2009) recommends that organisations develop and enforce standard operating procedures for data capture and validation, ensuring consistency across assets and over time. The free text comments could be improved with standard drop downs or further columns to identify subcategories of perceived faults.

4.4 Baseline Performance Establishment

To establish a performance baseline key metrics were summarised from the 2024 dataset. For example, the asset "CREIGIAU PS" recorded 108.25 hours of overflow discharge with an EDM uptime of 99.8%. Similarly, "PENYBONT P.S." logged 205 hours, suggesting a cause for concern at these assets. These data points provide a clear "before" state from which future improvements can be benchmarked and any reduction in key metrics can be measured.

In accordance with Dale, Bamford and Van der Wiele (2016), baseline data also supports meaningful performance reviews, resource allocation, and root cause analysis in subsequent phases. It provides project teams with solid evidence to back their improvement initiatives

5 Analyse

The Analyse phase in the Six Sigma DMAIC methodology aims to identify root causes of defects or inefficiencies within the process (Pyzdek, 2018). By objectively analysing data gathered during the Measure phase, Welsh Water can focus improvement efforts on areas with the highest environmental and customer impact. According to Muroe (2007), structured data analysis combined with root cause techniques ensures that corrective actions are based on fact rather than assumption.

For this project, three Pareto analyses were conducted to prioritise CSO sites based on spill frequency, spill duration, and EDM system downtime. Root Cause Analysis was performed using a Fishbone Diagram to systematically categorise potential causes, followed by a Failure Modes and Effects Analysis (FMEA) to assess the relative risk and criticality of each failure mode. This structured approach allowed for the prioritisation of issues based on their impact and likelihood, ensuring that improvement efforts were directed towards the most significant areas of concern.

5.1 Pareto Analysis Findings

The Pareto principle, or 80/20 rule, suggests that a small number of causes typically account for many problems (Bicheno and Holweg, 2016). This principle was applied across three key performance indicators:

- Spill Frequency: 55 sites were responsible for 80% of all CSO spill events.
- Spill Duration: 32 sites accounted for 80% of the total hours of untreated discharge.
- EDM Downtime: Only 10 sites contributed to 80% of the monitoring system downtime.

As seen in Figure 2, Figure 3 & Figure 4.

These results indicate that focusing interventions on a relatively small subset of the total asset base could yield substantial improvements in environmental outcomes and customer satisfaction.

Analysis of spill frequency and spill duration highlighted that certain sites consistently perform poorly across both metrics, suggesting persistent issues such as sewage system overload, storm storage capacity constraints, or inflow and infiltration problems. Assets with high EDM downtime point toward EDM systematic process issues, indicating a risk of underreporting events and reducing public trust in data accuracy.

By isolating the worst performing assets, Welsh Water can allocate resources more strategically, prioritising sites that will deliver the greatest benefit per investment.

5.2 Root Cause Analysis – Fishbone Diagram

A Fishbone Diagram was used to categorise the potential causes of CSO and SO events and monitoring failures into six key areas. This structured approach ensures that all aspects of the system

are examined and that root causes are considered (Dale, et al. 2016). Brainstorming of root causes was undertaken via interviews with Smith, A (2025), Jones, B (2025) and Dodd, A (2025). See Figure 5.

5.2.1 Infrastructure

- Aging sewage networks and pumping stations
- Limited storm storage
- Limited sewage network flow capacity
- Historical combined sewer designs not suited to current urban loads
- Lack of sustained capital investment
- Illegal network connections (e.g. connections of stormwater systems into foul sewers)

5.2.2 Environmental

- Increased rainfall linked to climate change
- Urbanisation leading to higher impermeable surface coverage creating more run-off into sewage system

5.2.3 Equipment

- Aging pumps, valves, and mechanical equipment
- Degradation of sewer lining and structural materials
- Level sensor positioning errors
- Level sensor calibration errors
- Poorly designed or deteriorated overflow chambers

5.2.4 Blockages

- Fats, oils, and grease buildup
- Blockages caused by wipes, sanitary products, and non-flushable materials
- Illegal network connections (e.g. connections of stormwater systems into foul sewers)
- Sediment and debris accumulation

5.2.5 Maintenance

- Infrequent proactive inspections
- Predominantly reactive maintenance strategies
- Missed screen cleaning schedules
- Calibration and realignment issues with level sensors
- Resource and staffing affecting routine maintenance activities
- Difficulties in investigation and maintenance due to geographical spread

5.2.6 Data acquisition

- Telemetry communication failures leading to data gaps
- Hardware faults in EDM systems and remote monitoring equipment
- Incorrect or outdated Event Duration Monitoring (EDM) configurations
- Lack of redundancy in critical monitoring systems

5.3 Failure Modes and Effects Analysis (FMEA)

Failure Modes and Effects Analysis (FMEA) is a tool that helps identify and prioritise potential process failures. A Risk Priority Number (RPN) is calculated by assessing their severity, likelihood, and detectability (Pyzdek, 2018). It encourages cross functional collaboration (Russell, 2009) although scoring can be subjective and if not managed, poorly scored risks becoming distracting and time consuming (Pyzdek, 2018). Reliance on RPN values alone may mask critical risks with low occurrence but severe consequences, suggesting the need for a common sense review alongside RPN scoring (Barsalou, 2014).

The FMEA conducted, see Figure 7, took the items detailed in the root cause analysis and process failures of high risk. The high priority items which fall within the scope were identified as:

- Sensor calibration/positional errors – RPN 384
- Fat, oil and grease and debris accumulation – RPN 378
- Telemetry communication failure – RPN 252
- Sediment and grit buildup – RPN 288
- Missed screen cleaning schedules – RPN 210

5.4 Analysis Conclusion

The Analysis phase identified and prioritised the key causes of CSO and SO events through recognised six sigma techniques, including Pareto analysis, Root Cause Analysis, and Failure Modes and Effects Analysis (FMEA). The Pareto analysis revealed that a small number of assets are responsible for most CSO and SO events and monitoring failures This will allow the upcoming improvements to focus specifically on these assets

The analysis aligns closely with the project's Critical to Quality (CTQ) requirements, ensuring customer and regulatory priorities are addressed. Additionally, it has identified challenges such as aging infrastructure and climate-driven inflow which fall outside the project scope but are items which can be addressed under another project in the future.

From the data and resources available the analysis phase has provided a data-driven focus for the improvement stage of the project.

6 Improve

The Improve phase focuses on developing and implementing targeted solutions to address the key root causes identified during the Analyse phase. The Improve stage uses creative problem solving and collaboration to reduce high-priority failures identified in the Root Cause Analysis and FMEA (Pyzdek, 2018). The goal is to deliver measurable improvements aligned to the project's Critical to Quality (CTQ) requirements which are reducing CSO and SO event frequency by 30%, achieving 95% monitoring accuracy, and improving compliance with regulatory discharge limits.

6.1 Improvement Ideas

In relation to the items with the highest Risk Priority Number (RPN) and for the items that fall within scope. Brainstorming of improvement ideas was undertaken via interviews with Smith, A (2025), Jones, B (2025) and Dodd, A (2025).

6.1.1 Sensor calibration/positional errors

- Implementing a structured calibration and realignment programme
- Increase the calibration checks to quarterly for high risk assets
- The level monitor should be repositioned and adequately secured to ensure it remains in the correct position
- Prioritise high-risk first

6.1.2 Fat, oil and grease and debris accumulation

- Continue “Stop the Block” campaign (Dŵr Cymru Welsh Water, n.d.)
- Launch investigation and cleaning campaign to CSO and SO assets identified in Pareto Analysis
- Consider more localised awareness campaigns around key assets.

6.1.3 Telemetry communication failures

- Accelerate migration from PSTN to M2M connectivity
- Implement on site data logs for assets with poor network coverage
- Implement dual sim modems in high-risk assets

6.1.4 Sediment and grit buildup

- Increase the frequency of inspections at priority sites
- Investigate options for sediment traps where accumulation is recurrent.

6.1.5 Missed screen cleaning schedules

- Strengthen proactive maintenance scheduling with digital tracking of screen cleans
- Prioritising cleans before adverse weather

- Schedule Sensor Calibrations after screen cleaning schedules for verification of work complete.

6.2 Improve FMEA Phase

The updated Improve FMEA, see Figure 8, demonstrated that the proposed improvement actions have significantly reduced the Risk Priority Numbers (RPN) across all key failure modes that were initially prioritised during the Analyse phase.

Key improvements and RPN reductions include:

- Sensor calibration or positional errors reduced from RPN 384 to 96
- Fat, oil, grease (FOG) and debris accumulation reduced from 378 to 144
- Sediment and grit buildup reduced from 288 to 144
- Missed screen cleaning schedules reduced from 210 to 20
- Telemetry communication failures reduced from 252 to 72

The Improve FMEA confirms that the mitigation measures implemented are effective at addressing the root causes of high-risk failures, with no new significant risks being introduced. This ensures that corrective actions are robust, manageable, and aligned with Welsh Water's operational objectives and stakeholder expectations.

6.3 Perform Cost/Benefit Analysis

When comparing estimated cost and effort of the additional mitigations against expected benefits the costs are relatively low.

The sensor calibration and realignment programme is expected to involve moderately increased resource costs for increased scheduling. This should deliver significant benefits in monitoring accuracy and compliance reporting. Upgrading telemetry systems, including migration to M2M connectivity and the installation of dual SIM modems, represents a higher upfront investment and additional cost of dual sim contracts. Although the migration to M2M is necessary the updated hardware will provide benefits in terms of improved hardware reliability, standardisation, data reliability, enhanced real-time reporting, and regulatory compliance. Enhancing screen cleaning schedules will require moderate resource allocation but will significantly reduce the likelihood of blockages and emergency spill events. Follow up visits to ensure screens are cleaned after CSO and SO events is critical to minimise reoccurrence.

Similarly targeted campaigns to reduce fat, oil and grease and debris in the sewage networks are low-cost initiatives that are expected to yield high environmental returns by reducing sewer blockages and associated overflows. These public facing campaigns can also be used to promote CSO and SO event reduction off the back of public involvement.

Overall, the predicted environmental, regulatory, and reputational benefits outweigh the costs, making

the improvements proposed cost effective.

7 Control

The Control Phase ensures that the improvements introduced during the Improve Phase are sustained, monitored, and continuously reviewed to ensure the proposed benefits are met and continue to be met. Following Six Sigma best practices (Pyzdek, 2018), Welsh Water must implement systems to continuously monitor critical variables, control variation, and standardise improvements across all targeted CSO and SO assets.

7.1 Controlling Improvements

To ensure improvements are fully embedded, maintenance and calibration tasks should be formalised into standard operating procedures. These maintenance and calibration tasks should be signed off and stored digitally for validation. Data should also be analysed quarterly and not annually to ensure that these CTQ targets proposed are met and are continued to be met. Training sessions should be delivered to operational staff to reinforce new procedures, ensuring that process changes are consistently understood and applied. Without formal auditing and feedback systems, control measures may deteriorate over time allowing errors less effective operational process to resume (Slack, 2019).

Standardised work procedures, staff training, and strong governance arrangements ensure that improvements become embedded within Welsh Water's operational culture, supporting long-term environmental, regulatory, and customer satisfaction goals.

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9 Appendices

9.1 Appendix A – Pareto Analysis

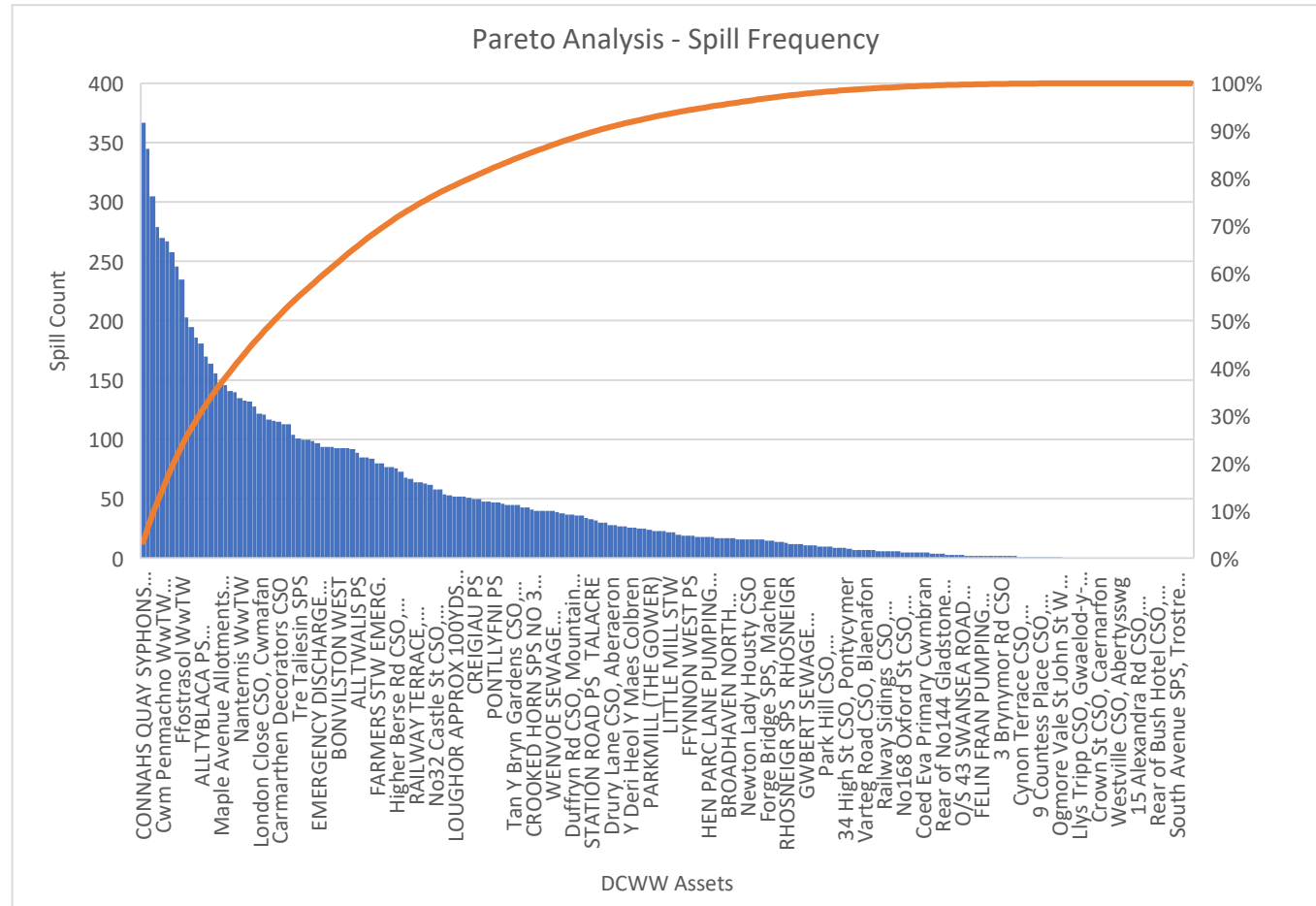


Figure 2 - Pareto Analysis - Spill Frequency

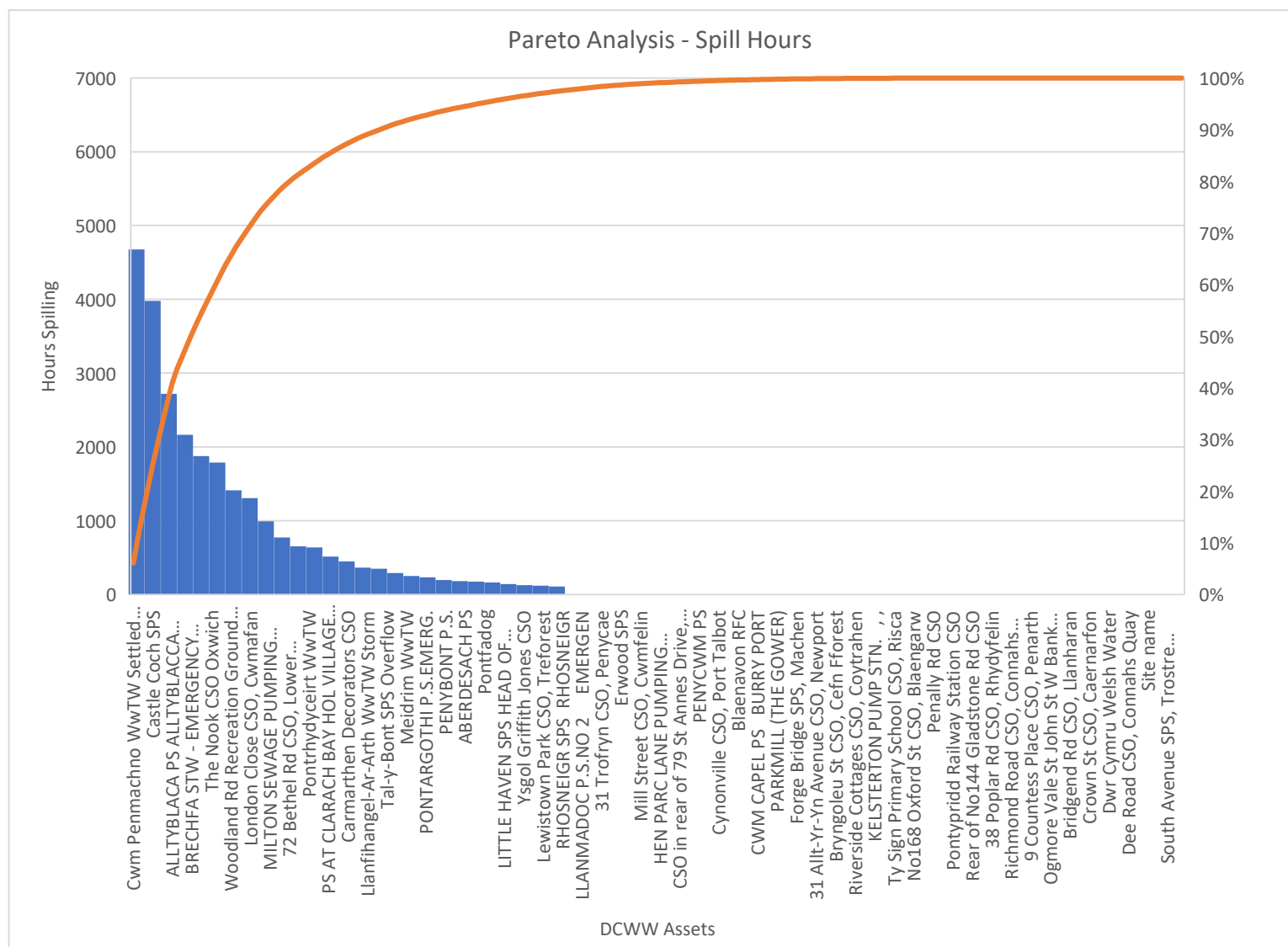


Figure 3 – Pareto Analysis – Spill Hours

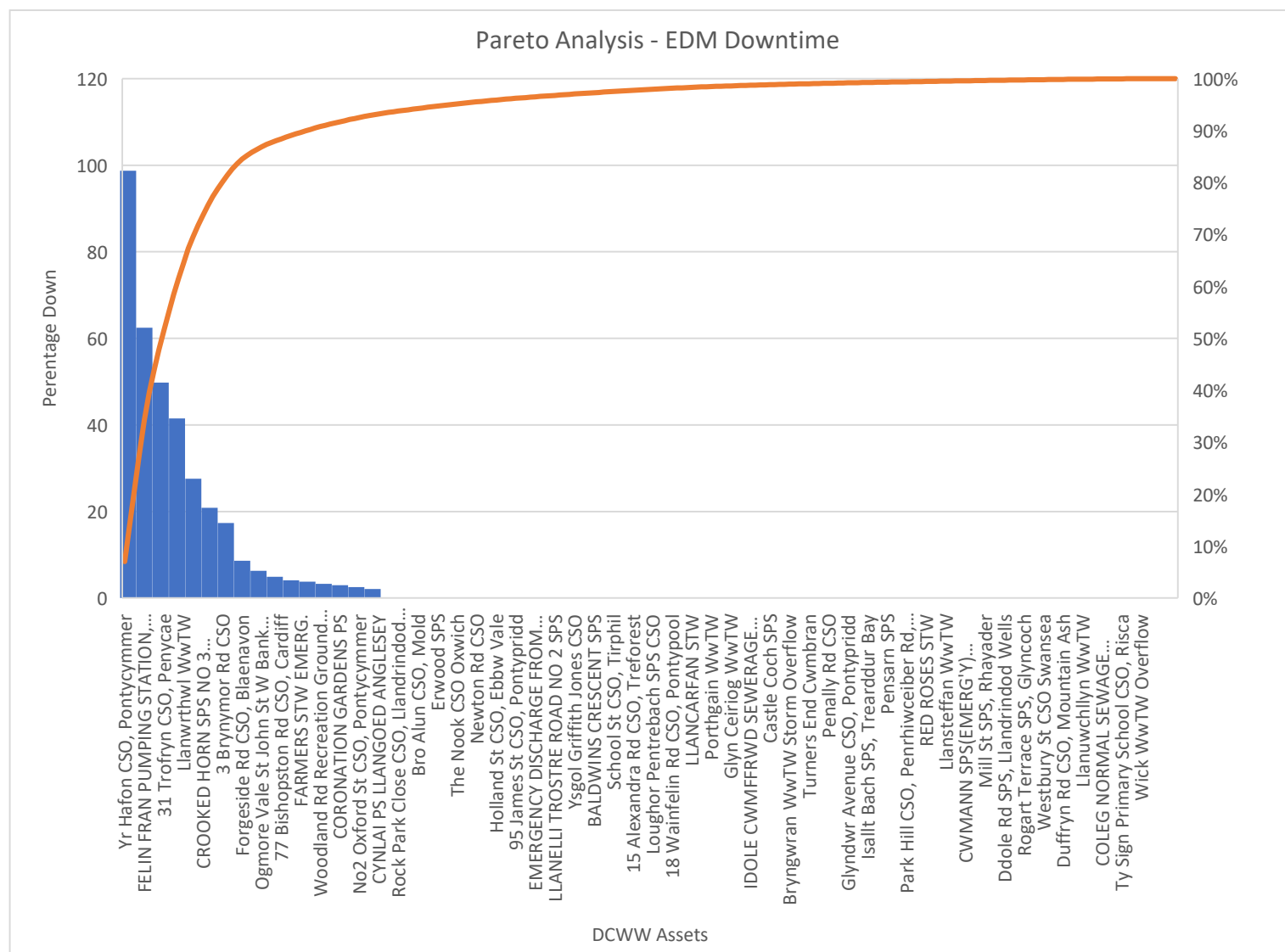


Figure 4 - Pareto Analysis - EDM Downtime

9.2 Appendix B – Root Cause - Fishbone Diagram

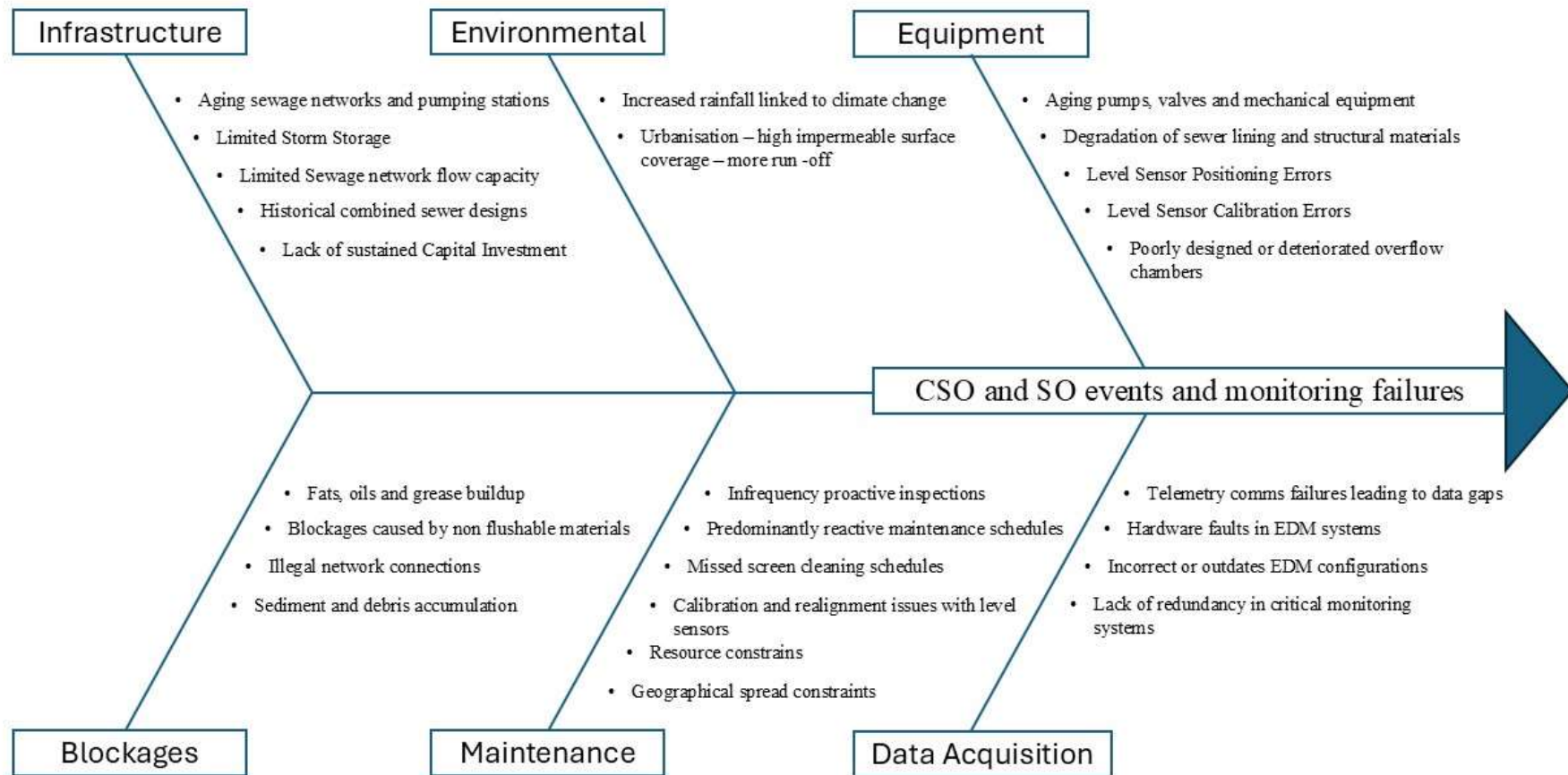


Figure 5 - Root Cause Analysis - Fishbone Diagram

9.3 Appendix C – Analysis – CSO and SO event FMEA

	Failure Mode & Effect Analysis (FMEA) - CSO and SO events							
Root Cause Area	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Likelihood of Occurrence	Current Controls	Likelihood of Detection	Risk Priority Number (RPN)
Infrastructure	Limited storm storage capacity	Heavy rainfall causing CSO and SO events	9	Aging infrastructure, historical designs not suited for current load	7	Emergency spill permits, limited storm storage	2	126
Infrastructure	Network hydraulic overload	High flows cause CSO and SO events	9	Urban expansion, climate change increasing rainfall intensity	7	Network modeling updates.	4	252
Environmental Factors	Increased impermeable area	Higher surface runoff into sewers causing CSO and SO events	7	Urban expansion, loss of natural drainage	5	Natural urban drainage encouraged in new builds	7	245
Equipment	Sensor calibration or Positional errors	Missed or false reporting of spill events. Inaccurate compliance reporting.	8	Sensor drift, lack of periodic calibration, sensor damage	6	Annual calibration	8	384
Equipment	Pump failure	Overflow event at pumping stations. Emergency discharges	8	Wear and tear, insufficient preventative maintenance	5	Routine maintenance, Telemetry failure alarms	4	160
Equipment	Overflow chamber deterioration	Reduced flow capacity, increased chance of blockages and overflow	6	Ageing chambers, poor maintenance access.	4	Visual inspections, Emergency repairs	8	192
Blockages	Fat, oil and grease and debris accumulation	Sewer blockages, emergency discharges, flood risk to public	6	Improper disposal of fats, oils, wipes, sanitary products, illegal connections	7	Public educational campaigns, reactive unblocking operations	9	378
Blockages	Sediment and grit buildup	Loss of sewer capacity, CSO and SO events	6	Age of infrastructure, build up not easy to access and clear.	6	Targeted jetting programs, CCTV surveys	8	288
Maintenance	Infrequent inspection and maintenance	Delayed fault detection, Worsening equipment performance, Higher risk of sudden failures	5	Reactive maintenance culture, Resource shortage	5	Annual asset inspections; telemetry alarms	7	175
Maintenance	Missed screen cleaning schedules	Screens blockages, CSO event	5	Resource limitations, manual error, Asset access difficulties, No review of work complete.	6	Planned maintenance schedules, Differential levels in some instances	7	210
Maintenance	Limited staff availability	Delay in responding to failures, longer event durations, Less frequent maintenance	6	Geographical spread, recruitment challenges	6	24/7 standby response teams	4	144
Data Acquisition	Telemetry communication failure	Data gaps, underreporting of events, No real time alerts, loss of public trust, potential regulatory action	6	Hardware faults, connectivity issues, Network issues, power failures	6	Backup power supplies, communication alarms	7	252
Data Acquisition	Incorrect or outdated EDM configuration	Incorrect CSO and SO event reporting, regulatory risk	6	Incorrect figures for commissioning, Failure to update settings after system changes	3	Asset commissioning	8	144
Data Acquisition	Lack of redundancy in monitoring	Instrument failures cause undetected events, compliance breaches	4	Cost, If 2x level sensors, unclear which is correct.	2	Dual network sim installation at key assets to maintain network.	6	48

Figure 6 - Analysis - CSO and SO Event FMEA

10 Appendix D – Improve – CSO and SO event FMEA Update

Failure Mode & Effect Analysis (FMEA) - CSO and SO events										
Root Cause Area	Potential Failure Mode	Potential Failure Effects	Severity	Potential Causes	Likelihood of Occurrence (Update)	Updated Controls	Likelihood of Detection (Update)	Risk Priority Number (RPN) (Update)	Risk Priority Number (RPN) (Previous)	Risk Priority Number (RPN) (Reduction)
Equipment	Sensor calibration or Positional errors	Missed or false reporting of spill events. Inaccurate compliance reporting.	8	Sensor drift. lack of periodic calibration. sensor damage	3	- Implementing a structured calibration and realignment programme - Increase the calibration checks to quarterly for high risk assets - The level monitor should be repositioned and adequately secured to ensure it remains in the correct position - Prioritise high-risk first	4	96	384	288
Blockages	Fat, oil and grease and debris accumulation	Sewer blockages. emergency discharges. flood risk to public	6	Improper disposal of fats, oils, wipes, sanitary products. illegal connections	4	- Continue "Stop the Block" campaign - Launch proactive investigation and cleaning campaign to CSO and SO assets identified in Pareto Analysis - Consider more localised awareness campaigns around key assets.	6	144	378	234
Blockages	Sediment and grit buildup	Loss of sewer capacity. CSO and SO events	6	Age of infrastructure, build up not easy to access and clear.	6	- Targeted jetting programs - Increase the frequency of inspections at priority sites - CCTV Surveys - Investigate options for sediment traps where accumulation is recurrent.	4	144	288	144
Maintenance	Missed screen cleaning schedules	Screens blockages. CSO event	5	Resource limitations. manual error. Asset access difficulties. No review of work complete.	2	- Strengthen proactive maintenance scheduling with digital tracking of screen cleans - Prioritising cleans before adverse weather - Schedule Sensor Calibrations after screen cleaning schedules for verification of work complete.	2	20	210	190
Data Acquisition	Telemetry communication failure	Data gaps. underreporting of events. No real time alerts. loss of public trust. potential regulatory action	6	Hardware faults. connectivity issues. Network issues. power failures	3	- Backup Power Supplies - Accelerate migration from PSTN to M2M connectivity - Implement on site data logs for assets with poor network coverage - Implement dual sim modems in high-risk assets	4	72	252	180

Figure 7 - Improve - CSO and SO Event FMEA