Competence under constraint: Maintenance work and the governance of stability in regulated water infrastructure

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Abstract

Regulated infrastructure systems increasingly operate beyond their original design horizons, relying on sustained technical work to maintain compliance, reliability, and service continuity. In sectors such as water, governance frameworks emphasise measurable outcomes and performance indicators, yet offer limited visibility into the sustaining practices that underpin stability. This paper examines how maintenance work and expertise are represented within the governance documentation of regulated water infrastructure in Australia and the United States. Drawing on qualitative documentary analysis of regulatory, audit, and performance reports, the study identifies four consistent patterns: system stability is presented as an achieved state rather than an ongoing accomplishment; maintenance work becomes textually visible primarily during escalation rather than routine operations; outcome-oriented reporting compresses sustaining labour into aggregate indicators; and documentary representation privileges managerial and professional expertise over experiential, trade-based knowledge.

The paper introduces the concept of competence under constraint to characterise the structural conditions under which maintenance professionals exercise skilled, continuous, and adaptive work within governance regimes that both depend upon and limit the articulation of their expertise. Unlike accounts of invisible work or articulation work, this concept foregrounds the coupling of operational dependence and representational restriction within accountability systems: governance formats themselves narrow what counts as valid evidence of competence. The contribution lies in identifying outcome-oriented regulatory governance as a mechanism through which sustaining competence is not merely overlooked but rendered weakly visible. By situating maintenance expertise within metricised accountability systems, the analysis clarifies how infrastructure can appear stable while increasingly reliant on intensifying but weakly documented forms of operational competence. The findings have implications for governance design, workforce sustainability, and infrastructure resilience.

Keywords: maintenance work; infrastructure governance; regulated water systems; invisible labour; competence under constraint; asset ageing; skills and expertise; stability; documentary analysis

1. Introduction

Large-scale infrastructure systems increasingly operate beyond their original design horizons (Furlong, 2019; Graham and Thrift, 2007). In regulated sectors such as water, infrastructure continuity depends not only on formal governance arrangements but also on sustained technical work that compensates for asset ageing, regulatory tightening, and operational constraints (Infrastructure Australia, 2023). While regulatory frameworks are effective at defining performance expectations and compliance outcomes, they provide limited insight into the forms of work through which system stability is achieved in practice.

Recent scholarship has highlighted the centrality of maintenance and repair in sustaining long-lived systems (Bowker and Star, 2008; Graham and Thrift, 2007; Orr, 2016). Rather than treating maintenance as a residual activity that follows construction or innovation, this work frames sustaining labour as constitutive of infrastructure itself (Denis and Pontille, 2014; Jackson, 2014; Russell and Vinsel, 2018). From this perspective, infrastructure persists not through static robustness but through continuous intervention, adjustment, and care.

At the same time, research on contemporary governance has shown that regulated systems increasingly rely on indicators, metrics, and outcome-based frameworks to render complex operations visible and accountable (Mennicken and Espeland, 2019; Porter, 1995; Rottenburg and Merry, 2015). These instruments privilege forms of knowledge that are comparable, auditable, and abstractable, while obscuring work that is situational, preventive, or context-specific. As a result, governance systems may systematically under-represent sustaining labour even as they depend upon it.

Water infrastructure exemplifies this tension, operating as critical yet largely invisible systems that combine technical complexity with public health imperatives (Larkin, 2013). This paper examines how maintenance work and expertise are represented—or rendered invisible—within publicly available regulatory, oversight, and utility documents.

This paper contributes to scholarship on infrastructure governance, maintenance studies, and vocational learning by showing how sustaining work is structurally underrepresented within outcome-oriented regulatory regimes. It advances existing research by identifying the governance conditions that make maintenance competence both indispensable and difficult to articulate, and by demonstrating how tacit, experiential, and situated forms of expertise underpin system stability. In doing so, the paper positions maintenance work as a form of vocational practice shaped by regulatory constraint rather than organisational discretion.

Using documentary analysis, the paper does not evaluate regulatory intent, corporate responsibility, or organisational performance. Instead, it analyses how governance arrangements represent system functioning, and what forms of competence are foregrounded or obscured in the process. In doing so, it reframes maintenance professionals not as marginal actors, but as system stabilisers exercising competence under structural constraint.

2. Theoretical framing: maintenance, governance, and competence under constraint

2.1 Maintenance as constitutive infrastructure work

Contemporary studies of maintenance and repair challenge the assumption that infrastructure stability derives primarily from design, construction, or innovation. Instead, maintenance is increasingly understood as the ongoing work through which infrastructure becomes durable over time (Denis and Pontille, 2014). This work encompasses inspection, adjustment, substitution, and care, and is central to system persistence under conditions of wear and constraint.

Infrastructure is never fully stable but requires continuous work to manage degradation, obsolescence, and breakdown (Bowker and Star, 2008; Jackson, 2014). Similarly, Russell and Vinsel (2018) argue that modern societies systematically undervalue maintenance labour despite its centrality to system reliability. These accounts highlight a structural paradox: sustaining work is most successful when it remains unnoticed.

In regulated infrastructure systems operating beyond original design assumptions, maintenance competence is not reactive or episodic, but continuous and anticipatory (Hommels, 2005). Its contribution is expressed through avoided failures rather than visible interventions, making it difficult to represent within outcome-oriented governance frameworks.

2.2 Governance by metrics and the production of visibility

The turn to outcome-based governance reflects broader shifts in how organisations demonstrate accountability and legitimacy. Porter (1995) traces the historical rise of quantification as a form of mechanical objectivity, showing how numbers acquire authority by seeming to remove human judgment. Power (1997) similarly documents the expansion of audit culture, in which verification rituals come to substitute for trust in professional expertise. These developments produce what Espeland and Stevens (1998) term ‘commensuration’—the transformation of qualitative differences into quantitative measures that enable comparison and control.

A parallel body of work examines how contemporary governance relies on metrics, indicators, and performance frameworks to render organisations accountable (Rottenburg and Merry, 2015). These tools do not merely describe performance; they actively shape what is recognised as legitimate knowledge within governance systems.

Mennicken and Espeland (2019) show that indicator-based governance privileges forms of expertise that can be stabilised, compared, and audited, while marginalising work that is context-dependent or resistant to standardisation. Beer (2016) similarly demonstrates how metric power redistributes authority by privileging measurable outputs over experiential knowledge.

Within infrastructure governance specifically, metrics privilege forms of knowledge that are standardised and remotely auditable (Furlong, 2019; Larkin, 2013). Work that is preventive, context-specific, or expressed through continuous adjustment resists such abstraction, creating systematic blind spots in governance visibility (Bowker and Star, 2008). This dynamic produces a systematic emphasis on outcomes—compliance status, risk ratings, performance scores—at the expense of process visibility. Work that prevents incidents rather than responding to them is particularly vulnerable to disappearance within such frameworks.

2.3 Skills hierarchies and epistemic inequality

Governance by metrics also interacts with organisational skill hierarchies. Professional and managerial expertise, grounded in formal credentials and aligned with documentation practices, gains authority within indicator-based accountability structures (Abbott, 1988). Trade-based and maintenance expertise, by contrast, is typically experiential, site-specific, and accumulated through prolonged engagement with particular assets (Espeland and Stevens, 1998; Harper, 1987; Sennett, 2009).

Such expertise is often tacit rather than codified, exercised through embodied practice rather than explicit procedure. Recent scholarship on expertise and valuation highlights how these differences produce epistemic inequality within organisations (Mennicken and Espeland, 2019). Knowledge that cannot be readily documented or abstracted may be treated as routine or interchangeable, even when it is operationally indispensable.

In regulated infrastructure systems, this creates a structural misalignment between where expertise resides and how it is recognised within governance frameworks.

2.4 Competence under constraint

Taken together, these strands suggest that maintenance work in regulated infrastructure systems can be understood as competence exercised under constraint. Star and Strauss (1999) identify ‘invisible work’ as labour that is essential to organisational functioning yet systematically unrecognised within formal structures. Strauss et al. (1985) developed the concept of ‘articulation work’—the ongoing effort required to coordinate activities and manage contingencies in complex systems. Building on these foundations, this paper proposes the framework of competence under constraint to understand maintenance work in regulated infrastructure.

Maintenance professionals operate within ageing asset environments, intensified oversight, and outcome-driven governance regimes that limit the visibility of sustaining work (Strauss et al., 1985). Their expertise is expressed through continuous adaptation rather than formal authority or recognition. This framing shifts attention away from narratives of neglect or failure, and toward the conditions under which system stability is actively achieved.

Figure 1: The Visibility Paradox of Maintenance Competence

Figure 1: The Visibility Paradox of Maintenance Competence. During routine operations (left), maintenance work is continuous but remains invisible within governance documentation. During an escalation or failure (right), the same work suddenly becomes visible through regulatory intervention. This temporal asymmetry means competence is most recognised when insufficient, rather than when it successfully prevents disruption.

While this analysis builds on established STS concepts such as invisible work and articulation work, the notion of competence under constraint offers distinct analytical leverage. Invisible work highlights how essential labour remains unrecognised within formal organisational structures, and articulation work draws attention to the coordination required to hold complex systems together. Competence under constraint extends these accounts by foregrounding the specific governance conditions under which skilled maintenance work is exercised, yet is structurally difficult to articulate. The distinctive analytical move is not simply that maintenance work is hidden, but that governance formats themselves through their reliance on metrics, indicators, and outcome-based accountability narrow what counts as valid evidence of competence, coupling operational dependence on skilled labour with representational restriction of that labour.

In regulated infrastructure systems, maintenance competence is not merely overlooked; it is exercised within accountability frameworks that privilege outcomes, metrics, and abstraction over the maintenance of processes. The constraint is therefore not only material or organisational, but representational: governance systems appear to depend on maintenance expertise while simultaneously limiting the means through which that expertise can be rendered visible, valued, or justified. Framing maintenance as competence under constraint shifts analysis from questions of recognition or neglect to

the structural conditions that shape how skilled work is expressed, evaluated, and absorbed within regulated systems. This lens enables closer examination of how stability is actively produced under conditions that tend to obscure the work required to sustain it.

3. Method: documentary analysis of regulated infrastructure systems

3.1 Research design

This study employs qualitative documentary analysis to examine how sustaining work and technical expertise are made visible or obscured within the governance of regulated water infrastructure (Bowen, 2009; Prior, 2003). Documentary analysis is particularly appropriate for research concerned with institutional representation, visibility, and accountability, as governance is enacted primarily through formal texts (Bowen, 2009; Rapley, 2007).

Documents are treated as empirical material rather than contextual background (Prior, 2003). The analysis focuses on how system functioning is rendered legible within regulatory, oversight, and corporate publications, rather than on organisational behaviour or intent.

3.2 Documentary corpus

The study examines water infrastructure governance in Australia and the United States. These cases were selected for theoretical variation within structural similarity (Tilly, 1985). Both countries operate federal systems with state-level regulatory diversity and ageing infrastructure. Both maintain outcome-focused accountability regimes while facing similar challenges posed by assets operating beyond their original design life. However, they differ in regulatory philosophy: Australia emphasises economic regulation through independent regulators (e.g., IPART in New South Wales and the Essential Services Commission in Victoria), while the United States emphasises environmental and public health regulation through the Environmental Protection Agency (EPA) and state environmental agencies. This structural difference enables analysis of whether maintenance invisibility patterns are specific to regulatory architectures or reflect broader governance dynamics.

Documents were selected because they are authoritative, externally published, and intended to shape or demonstrate governance. The corpus is bounded rather than exhaustive, enabling analysis of representational patterns across documents that are repeatedly mobilised within governance processes. The corpus is intentionally heterogeneous, combining policy assessments, audit reports, regulatory documents, and compliance reports, because governance visibility is distributed across multiple document types rather than concentrated in a single genre. The analytical goal is pattern detection across governing texts, not comparison of equivalent document classes.

Table 1. Summary of core document corpus

Document	Jurisdiction	Year	Type	Focus
Infrastructure Market Capacity Report (Infrastructure Australia, 2023)	Australia (Federal)	2023	Policy assessment	Workforce capacity and infrastructure delivery constraints
Australian Infrastructure Audit (Infrastructure Australia, 2019)	Australia (Federal)	2019	Performance assessment	National asset condition and maintenance requirements
Water Performance Report 2022–23 (ESC, 2023)	Victoria	2023	Regulatory report	Victorian water utility service delivery and performance
IPART Water Utility Performance Reporting (Licence Data)(IPART, 2025)	New South Wales	2025	Regulatory report	NSW water utility performance, compliance, and escalation requirements
EPA Victoria Compliance & Enforcement Summary 2018–19 (EPA Victoria, 2019a)	Victoria	2019	Compliance report	Environmental compliance actions and statutory notices
ANAO Major Projects Report 2019–20 and 2020–21(ANAO, 2022)	Australia (Federal)	2021	Audit report	Commonwealth infrastructure program delivery and oversight
U.S. EPA Drinking Water Infrastructure Enforcement FY2018(US EPA, 2018)	United States	2018	Compliance report	Federal drinking water compliance and enforcement actions
Victorian Auditor-General Annual Report 2019–20(VAGO, 2020)	Victoria	2020	Audit report	Victorian water infrastructure investment and maintenance oversight

3.3 Analytic approach and treatment of repetition

Analysis proceeded through iterative close reading and thematic interpretation of the documentary corpus. Documents were read multiple times to identify how maintenance work, expertise, and system stability are represented within governance texts. Analytical attention focused on four dimensions: (1) how system stability is linguistically constructed—whether framed as an achieved property or as requiring continuous sustaining work; (2) the conditions under which maintenance work becomes textually

visible or remains implicit; (3) how different forms of expertise (managerial, professional, trade-based) are represented and valued; and (4) moments where acknowledgments of asset constraints, aging infrastructure, or workforce risks create tensions with outcome-oriented reporting.

The analytical process involved systematic comparison across document types and jurisdictions. Regulatory frameworks, audit reports, and performance disclosures were examined for patterns in what generates documentary traces: which actors are named, which forms of work are foregrounded, and which practices remain backgrounded despite being operationally necessary. Attention was paid to moments of escalation—statutory notices, enforcement actions, audit interventions—where routine invisibilities become temporarily legible through intensified textual representation.

Comparative analysis of Australian and US documents identified patterns that transcend specific regulatory architectures. While the two jurisdictions differ in regulatory philosophy (economic regulation versus environmental/public health regulation), convergent patterns in how maintenance work is represented suggest structural features of outcome-oriented governance rather than jurisdiction-specific arrangements.

This approach aligns with critical documentary analysis traditions that treat texts as constitutive of organisational realities rather than neutral descriptions (Bowen, 2009; Prior, 2003). Documents do not merely describe infrastructure systems; they actively shape what is recognised, valued, and rendered visible within governance arrangements. The analysis, therefore, focuses on representational logics—how governance frameworks construct and delimit organisational visibility.

The author's position as a consulting engineer with 25 years of experience in regulated water systems across multiple jurisdictions informed document selection and provided sensitising concepts for the analysis, particularly awareness of which operational practices generate documentary traces and which do not. Field experience shaped the analytical questions brought to the corpus, not the evidentiary claims drawn from it. All findings are grounded in the documentary record rather than practitioner inference. This positioning reflects the value of combining insider familiarity with analytical distance by focusing on publicly available documents (cf. Star and Strauss 1999, on infrastructure studies that require both insider and outsider perspectives).

Repeated reference to a limited set of core documents (Table 1) is treated as an analytic feature rather than a limitation. These documents function as organising texts within governance systems—they are repeatedly mobilised in regulatory processes, performance assessments, and accountability mechanisms. Their recurrence signals which forms of knowledge are stabilised, privileged, and treated as authoritative within infrastructure governance. Documents are therefore introduced once in the corpus table, with

subsequent analysis focusing on cross-document patterns and representational convergences rather than restatement of individual sources.

3.4 Scope and limitations

Documentary analysis is sufficient for this study because the object of analysis is not maintenance practice itself, but how system stability, competence, and responsibility are represented within governance arrangements. As established in Section 3.3, governance texts are constitutive rather than merely descriptive; they define what becomes visible and what remains obscured (Bowen, 2009; Coffey, 2004; Prior, 2003). Analysing such texts provides direct access to the representational logics through which maintenance work is foregrounded or obscured.

While interviews or ethnographic methods could illuminate lived experience, this study deliberately confines itself to governance texts to examine how accountability systems construct visibility, competence, and responsibility within regulated infrastructure.

4. Findings: maintenance competence and visibility in governance documentation

4.1 Maintenance as an implicit condition of system stability

Across the documentary corpus, system stability is consistently portrayed as an achieved and reportable state, typically measured by compliance status, service continuity, and asset performance indicators. These outcomes are treated as properties of the system rather than as the result of continuous intervention. Stability appears as something that exists, not something that must be actively sustained. This pattern exemplifies what Star and Strauss (1999) term the ‘ecology of visible and invisible work’: maintenance competence is essential but structurally backgrounded within governance documentation. The abstraction of outcomes obscures the labour required to produce them (Bowker and Star, 2008).

At the same time, regulatory and audit documents repeatedly acknowledge that much of the sector operates beyond original design life. National audit reports in both the USA and Australia note that significant proportions of water and wastewater assets remain in service well past their intended lifespan, often under increasing regulatory scrutiny and heightened expectations for reliability and environmental performance (ANAO, 2022; Infrastructure Australia, 2023). Environmental guidance similarly references ageing treatment works, legacy sewer networks, and constrained assets as persistent sector features rather than exceptional cases (EPA Victoria, 2019b).

These acknowledgements implicitly signal a reliance on maintenance competence. Operating assets beyond their design horizon requires intensified inspection, condition monitoring, and intervention to manage degradation and uncertainty. However, the labour needed to achieve this is rarely articulated directly. Enhanced monitoring and

surveillance are framed as neutral compliance requirements rather than as increases in maintenance effort involving additional site access, manual inspection, interpretive judgement, and responsive intervention.

Maintenance competence, therefore, appears in governance documentation as an assumed background capacity. For instance, Victorian water performance reporting describes outcomes in terms of achievement: “water and sewer network reliability improved in 2022–23, indicating continued good levels of service overall” (ESC, 2023). This linguistic framing treats stability as a reportable state rather than as work that must be continuously performed—maintenance competence remains implicit rather than documented. This example illustrates a broader pattern observed across the corpus: governance documents in both jurisdictions consistently frame system performance in terms of achieved outcomes without articulating the sustaining work required to produce those outcomes.

It is necessary for system stability but not represented as work in its own right. Where stability is achieved, sustaining labour remains invisible; where stability is threatened, its absence becomes more legible.

4.2 Visibility through escalation rather than routine practice

Maintenance work becomes most visible in governance documentation during escalations. Statutory notices, enforcement actions, and audit interventions contain markedly more operational detail than routine reporting mechanisms (IPART, 2025; US EPA, 2018). These documents specify inspection frequencies, sampling locations, corrective actions, and site-specific requirements with a level of granularity not found in standard compliance reporting.

For example, regulatory intervention documents commonly outline detailed operational expectations following identified risks or non-compliance, including enhanced monitoring regimes and remedial works (IPART, 2025; US EPA, 2018). Even in crisis contexts, maintenance work is described in general terms. Victorian regulators noted that water utilities “maintained a strong focus on supporting their customers and community” (ESC, 2023) during flood responses. The verb “maintained” refers to continuity rather than to the technical interventions, operational adjustments, or expert judgment required during system stress.

Such requirements imply a substantial increase in maintenance activity and technical oversight. Yet outside these escalation contexts, routine documentation provides little insight into the sustaining practices that prevent such interventions from being triggered in the first place.

This pattern produces a structural asymmetry in visibility. Routine maintenance work that sustains compliance generates few documentary signals, while deviations from expected performance prompt intensive textual representation. Maintenance competence is therefore rendered legible primarily by its failure to prevent escalation, rather than by its continuous role in avoiding it. This temporal asymmetry in visibility reflects broader dynamics identified in studies of infrastructure breakdown. As Graham and Thrift (2007) observe, sustaining practices become most visible at moments of crisis or failure, while successful prevention generates few signals. Larkin (2013) similarly notes that infrastructure occupies a 'peculiar ontological state between visibility and invisibility,' becoming apparent primarily through disruption.

The findings suggest that governance systems are better equipped to describe breakdown and remediation than continuity and care. Maintenance expertise occupies a paradoxical position: essential to system functioning, yet most visible when it is insufficient or overwhelmed.

4.3 Outcome-oriented governance and abstraction of sustaining work

A further consistent pattern across the corpus is the prioritisation of outcome-based representations of performance. Governance documents foreground compliance status, risk ratings, and performance indicators, while descriptions of how these outcomes are achieved remain limited (ESC, 2023; Infrastructure Australia, 2019; US EPA, 2018). Performance outcomes are reported as binary states: "customers continue to receive good service from their water businesses" (ESC, 2023). This compressed indicator provides no visibility into the inspection effort, interpretive judgment, or preventive interventions required to generate such service outcomes. This abstraction supports comparability and accountability, but it also compresses diverse forms of work into standardised categories. This pattern is consistent across the corpus: regulatory, audit, and performance documents in both jurisdictions foreground compliance status and risk ratings while providing limited articulation of the operational practices that produce those outcomes.

Maintenance work resists such abstraction. It involves context-specific judgement, local knowledge of assets, and continuous adjustment to material conditions. These features make it difficult to represent within indicator-driven frameworks. As a result, maintenance effort is subsumed under aggregate outcomes—such as asset condition scores or compliance ratings—rather than articulated as an active, skilled practice.

For instance, asset health reporting aggregates conditions across large portfolios, masking site-level variability and obscuring the role of ongoing maintenance in sustaining acceptable performance (Infrastructure Australia, 2023). The labour required to stabilise individual assets under constrained conditions is obscured by summary indicators that privilege outcomes over processes.

This abstraction does not imply that maintenance work is marginal. Instead, it reflects the limits of governance frameworks designed to prioritise measurable outputs over sustaining practices (Mennicken and Espeland, 2019; Merry, 2016). This compression of process into outcome reflects what Power (1997) identifies as the 'audit explosion': governance systems designed to make organisations accountable may inadvertently obscure the very practices that enable compliance.

This abstraction produces a particular paradox around ageing infrastructure. National audit findings note that significant proportions of water assets "remain in service well past their intended lifespan" (Infrastructure Australia, 2023), yet performance reporting records improving or stable outcomes across the same period. Improving metrics and ageing assets coexist without contradiction in governance documentation precisely because the intensified inspection, condition monitoring, and adaptive intervention required to sustain performance as assets deteriorate generate no documentary signal of their own. The work that bridges the gap between a deteriorating asset base and a satisfactory performance record is the work that governance frameworks are least equipped to see.

A related pattern concerns how compliance itself is represented. Victorian regulatory frameworks require utilities to demonstrate compliance against an expanding set of water industry standards, with performance assessed annually against service benchmarks (ESC, 2023). Compliance is reported as an administrative achievement—a binary outcome—rather than as the result of continuous technical work. The sustained monitoring, sampling, and corrective intervention required to remain within regulatory thresholds are subsumed under the compliance status they produce, rendering the sustaining labour invisible within the very documentation designed to assure it.

4.4 Differential visibility of expertise and skills

The documentary corpus also reveals a persistent hierarchy in the visibility of expertise. Managerial and professional roles are prominently represented through plans, submissions, and reporting structures, reflecting their alignment with governance and accountability mechanisms (ESC, 2023). These forms of expertise translate readily into documents, metrics, and formal assurances.

By contrast, trade-based and maintenance expertise are primarily reflected in indirect references to workforce risk. National audit and workforce reports identify skills shortages, ageing workforces, and recruitment challenges across the water sector, often warning of future capability gaps (ANAO, 2022; GAO, 2021; Infrastructure Australia, 2019; Paxton et al., 2022). This hierarchy reflects what Abbott (1988) terms the 'jurisdictional' claims of different forms of expertise. Professional knowledge, as documented and formalised, gains recognition, while embodied, experiential knowledge remains tacit and undervalued (Sennett, 2009).

What is largely absent from these discussions is a detailed articulation of the expertise at stake. While documents acknowledge that expertise is being lost, they rarely explain how this expertise sustains system stability or what operational risks may arise from its erosion. Maintenance competence is treated as an interchangeable capacity rather than as specialised, asset-specific knowledge developed over time.

This appears to produce a structural hierarchy of skill visibility. Expertise that aligns with documentation and abstraction is foregrounded, while experiential and situational knowledge remains backgrounded. The findings indicate that this hierarchy reflects representational compatibility with governance systems rather than relative importance to operational outcomes.

As national infrastructure assessments observe, workforce challenges cut across "infrastructure delivery" and "productivity priorities" (Infrastructure Australia, 2023). This framing flags the issue at a policy level without specifying the operational expertise at stake—the inspectors, operators, and maintenance technicians whose site-specific knowledge sustains system performance. Workforce risk is acknowledged in aggregate terms, while the competence being lost remains unnamed within governance documentation. This pattern is observed across both Australian and US documents, suggesting it reflects structural features of outcome-oriented governance rather than jurisdiction-specific arrangements.

5. Discussion: competence under constraint in regulated infrastructure systems

5.1 Maintenance competence as a condition of regulatory success

The findings indicate that maintenance work is not peripheral to regulated water systems, but constitutive of their continued functioning. Across governance documentation, compliance and service continuity are presented as achieved outcomes, yet these outcomes rely on sustained technical work to compensate for asset ageing, intensified oversight, and organisational constraints (ANAO, 2022; GAO, 2021; Infrastructure Australia, 2023, 2019). Maintenance competence emerges as a condition of possibility for regulatory success rather than as a discrete organisational function. This reframing parallels Mol's (2008) analysis of care work in medical settings, which shows that care is not a discrete intervention but an ongoing practice of adjustment and attention. Similarly, maintenance competence is not episodic repair but continuous monitoring, interpretation, and intervention (Denis and Pontille, 2014).

Despite the constraints documented in Section 4, the governance record indicates that system stability is routinely achieved. Compliance is maintained, services continue, and major failures remain relatively infrequent (ANAO, 2022; GAO, 2021; Infrastructure Australia, 2023, 2019). The absence of disruption functions as indirect evidence of effective maintenance competence, even as governance documentation provides little

space to acknowledge it directly. This reframing is significant: it shifts attention away from episodic narratives of failure and toward the continuous stabilisation required to keep systems operating within acceptable bounds.

The gap between acknowledged constraint and reported outcome is illustrated by the juxtaposition of two documentary registers. Infrastructure assessments identify workforce capacity as cutting across “infrastructure delivery” and “productivity priorities” (Infrastructure Australia, 2023), while regulatory performance reports simultaneously confirm that “customers continue to receive good service” (ESC, 2023). Neither document accounts for how this gap is bridged. That bridging is the work of maintenance competence—continuous, adaptive, and structurally invisible within the documentation that depends upon it.

5.2 Latent capacity, buffering, and the management of uncertainty

The documentary patterns identified in Section 4 suggest that maintenance competence functions as a latent system capacity: a resource that is continuously drawn upon but rarely explicitly named. Regulatory and audit documents routinely assume that assets operating beyond original design life will continue to meet performance and compliance thresholds, provided that appropriate monitoring and controls are in place (ANAO, 2022; GAO, 2021; Infrastructure Australia, 2023, 2019). These assumptions implicitly rely on the availability of skilled maintenance personnel who can assess asset condition, respond to early signs of degradation, and intervene before failure. This reliance is rarely articulated as such. Instead, governance documentation frames continuity as a characteristic of the system, supported by frameworks, plans, and controls. As long as assets continue to perform within acceptable bounds, the sustaining work that enables this performance remains backgrounded.

Maintenance work also functions as an organisational buffer, absorbing multiple forms of constraint. Regulatory tightening, environmental standards, and public health expectations have increased over time, often without corresponding reductions in asset age or complexity (Beecher, 2013; Infrastructure Australia, 2023). Where regulatory requirements intensify, maintenance regimes are adjusted by increasing inspection frequency, enhancing monitoring, and setting more conservative intervention thresholds. Where assets deteriorate, maintenance effort is offset by repair, substitution, and adaptive operation. These adjustments are rarely described as increases in labour or expertise demand; instead, they are presented as neutral compliance responses. This buffering role allows governance frameworks to evolve without disrupting service continuity, but it also masks the cumulative burden placed on maintenance capacity.

At the operational level, ageing infrastructure introduces variability in asset behaviour, increasing reliance on judgement-based decision-making rather than standardised procedure. Maintenance professionals manage this uncertainty through continuous engagement with assets, drawing on experience to interpret ambiguous signals and prioritise interventions. This form of expertise is inherently challenging to codify, as it relies on familiarity with specific systems and contexts rather than universal rules. The absence of explicit representation does not imply the absence of activity; it reflects the mismatch between the nature of maintenance competence and the representational tools available within governance systems. This condition parallels what Strauss et al. (1985) identify as 'articulation work' in medical settings: the ongoing, largely invisible work of coordinating activities and managing contingencies that keeps complex systems functioning.

5.3 Temporal asymmetry and the invisibility of sustained success

A central feature of maintenance competence is its temporal orientation. Maintenance work unfolds over long time horizons, involving continuous monitoring, incremental adjustment, and anticipatory intervention. Governance recognition, by contrast, is largely episodic. Documentation expands sharply around incidents, breaches, or escalations, while remaining sparse during extended periods of stable operation (IPART, 2025; US EPA, 2018).

This temporal asymmetry reflects deeper challenges in governing activities that unfold over extended time horizons (Adam, 2006). Long stretches of sustained success generate few documentary signals, while short periods of disruption attract intensive scrutiny. As a result, recognition is concentrated on moments of failure, even though most competence is exercised during periods of apparent normality. This creates a structural bias in which sustained success is normalised and taken for granted, while deviations become the primary objects of governance attention.

5.4 Skills hierarchy and epistemic inequality

The documentary patterns described in Section 4.4 reveal a persistent hierarchy of expertise that extends beyond mere oversight. Managerial and professional skills are prominently represented through planning frameworks, regulatory submissions, and performance reports, reflecting their compatibility with outcome-based governance systems (ESC, 2023). Maintenance expertise, by contrast, is experiential, situational, and asset-specific. It is developed through prolonged engagement with systems and environments and is often exercised through judgment rather than procedure. Studies of workplace learning demonstrate that expertise is often 'learned in practice' rather than acquired through formal training (Darrah, 2013), yet governance systems privilege credentialed knowledge over situated competence.

This asymmetry produces a form of epistemic inequality. Knowledge that can be readily documented is treated as authoritative, while knowledge that is embedded in practice remains backgrounded (Mennicken and Espeland, 2019; Beer, 2016). This is not a reflection of relative importance but of representational compatibility with governance frameworks reliant on metrics and indicators.

5.5 Competence exercised without authority or visibility

Maintenance competence within regulated infrastructure systems is exercised under conditions of limited formal authority. While governance frameworks specify outcomes and compliance thresholds, they provide limited mechanisms for recognising or representing the sustaining work required to achieve them. Maintenance professionals operate within tight regulatory constraints, constrained budgets, and ageing asset bases, yet are expected to deliver stability without explicit acknowledgement of their contribution.

This creates a distinctive professional condition. Maintenance competence is exercised continuously, but its effects are primarily evident when failures do not occur. Credit for compliance accrues to the organisation or the system, while accountability for failure is often localised and immediate. The position of maintenance professionals parallels what Lipsky (1980) identifies as ‘street-level bureaucracy’: front-line workers who exercise substantial discretion in implementing policy but operate within severe resource constraints and limited formal authority.

5.6 System dependence on invisible competence

Taken together, the findings and analysis indicate that regulated water systems are deeply dependent on forms of competence that are poorly represented in their own governance documentation. Maintenance professionals stabilise systems that operate beyond original design assumptions, absorb variability introduced by regulatory change, and translate abstract requirements into workable practice.

This dependence is not incidental. As infrastructure ages and regulatory expectations intensify, the gap between formal governance representations and operational reality is likely to widen. When maintenance competence is eroded by workforce attrition, skill loss, or under-recognition, system vulnerability may increase without triggering early warning signals within governance frameworks.

By reframing maintenance work as competence under constraint, this analysis contributes to scholarship in infrastructure studies in three ways. First, it extends work on invisible labour (Denis and Pontille, 2014; Star and Strauss, 1999) by showing how sustaining practices remain hidden within, specifically, outcome-focused governance. Second, it shows empirically how metric-based accountability (Mennicken and Espeland, 2019; Power, 1997) tends to obscure certain forms of expertise. Third, it offers a framework—

competence under constraint—for analysing skilled work exercised under structural conditions that limit its recognition and articulation.

The contribution of this paper lies not in demonstrating that maintenance work is invisible—a well-established insight within science and technology studies—but in specifying the governance conditions under which that invisibility is structurally produced within systems of accountability. The concept of competence under constraint identifies outcome-oriented regulatory governance as the mechanism through which operational dependence on skilled labour is coupled with representational restriction of that labour.

6. Implications for governance, workforce, and system stewardship

6.1 Implications for governance and regulation

The findings suggest that current governance arrangements systematically under-represent the sustaining work on which regulated infrastructure systems depend. Outcome-based frameworks successfully demonstrate compliance and accountability, but they provide limited visibility into the operational practices that enable these outcomes. From a governance perspective, this matters because it obscures emerging risk. Where maintenance competence compensates for ageing assets and tightening regulatory requirements, the system may appear stable even as underlying capacity becomes increasingly fragile.

Regulatory documentation demonstrates that oversight bodies already have mechanisms to mandate detailed operational activities when risks are formally identified. Regulatory notices explicitly specify inspection frequencies, sampling regimes, and site-visit requirements (IPART, 2025; US EPA, 2018). Yet outside of escalation contexts, regulatory frameworks largely rely on outcome-based reporting. This structure suggests that regulatory assurance may underestimate the extent to which compliance depends on continuous, labour-intensive maintenance. Recognising maintenance as a stabilising function does not require fundamental reform of regulatory regimes. Instead, it suggests scope for complementary mechanisms that explicitly acknowledge the sustaining work—for example, by enhancing attention to asset stewardship, maintenance capacity, and long-term workforce resilience within governance discourse.

6.2 Implications for workforce sustainability and planning

The analysis highlights a growing disconnect between the importance of maintenance competence and its representation within governance documentation. Workforce documentation from oversight bodies and sector organisations identifies skills shortages and ageing workforces as material risks to infrastructure delivery. Yet these risks are

typically framed in generic terms—such as skills shortages or recruitment difficulty—without articulating the specific expertise involved.

The findings suggest that workforce capability is not only a future concern but a present operational dependency. Where ageing assets remain in service under intensified oversight regimes, system reliability depends on experienced maintenance personnel who can interpret asset behaviour and respond to deviations in real time. The loss of experienced staff may represent a non-linear risk: because sustaining work is weakly represented in governance documentation, the erosion of tacit knowledge may not trigger early warning signals until compliance margins are compromised. Training, succession planning, and knowledge transfer require long time horizons, particularly in sectors characterised by complex legacy infrastructure. Explicit recognition of maintenance expertise as a form of professional competence may support more realistic assessments of system vulnerability and long-term capability.

6.3 Implications for risk, resilience, and recognition

The dependence of regulated infrastructure systems on weakly visible maintenance competence raises essential questions about resilience. Resilience is typically understood in terms of system properties—redundancy, modularity, adaptive capacity (Walker et al., 2012). This analysis suggests that workforce competence constitutes a form of latent resilience, essential yet largely unrecognised. Where such competence is eroded, system vulnerability may increase without being immediately reflected in conventional performance indicators. When maintenance work absorbs asset degradation and operational variability without generating formal signals, risk assessments based solely on asset condition metrics or performance outcomes may underestimate system vulnerability.

Finally, the relative invisibility of sustaining work can foster the perception that maintenance is routine, interchangeable, or secondary to planning and management functions. This misalignment may affect professional identity, recruitment, and retention. Reframing maintenance work as competence under constraint highlights the professionalism required to sustain regulated systems. Importantly, such recognition need not be framed in oppositional terms. Acknowledging maintenance competence does not diminish the role of governance or management; rather, it clarifies how abstract requirements are translated into reliable service through skilled operational practice.

7. Conclusion

This paper examines how maintenance work and expertise are represented in the governance documentation of regulated water infrastructure systems. Drawing on documentary analysis of regulatory, oversight, and utility texts, it has shown that maintenance competence is fundamental to system stability, even as it remains weakly

articulated within the formal narratives through which infrastructure is governed, assessed, and made accountable.

By making these dynamics visible, the paper contributes to scholarship on infrastructure, governance, and work. Empirically, it demonstrates how regulated systems rely on sustaining practices that are only weakly represented in their own documentary record. Conceptually, it extends contemporary work on maintenance and repair by situating sustaining labour within the specific context of outcome-oriented governance regimes. Analytically, it shows how a system's dependence on maintenance competence can persist without being articulated, masking emerging vulnerabilities until performance thresholds are breached.

This analysis does not advance a critique of regulation or management per se. Instead, it clarifies how abstract governance requirements are translated into reliable service through skilled operational practice. As infrastructure systems continue to age and regulatory expectations intensify, reliance on weakly visible maintenance competence is likely to increase. Understanding this dependence is essential for realistic assessments of system resilience, workforce sustainability, and long-term stewardship.

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