HUMAN FACTORS AND PREVENTIVE RISK MANAGEMENT IN THE WATER INDUSTRY

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ABSTRACT

The need to consider and manage human factors is widely recognised across industries as diverse as aviation, medicine and chemical processing. Human factors are well recognised and managed through a safety culture in industries where process failure can have catastrophic human health and environmental impacts. However, the consideration of human factors as a component of water safety management is not standard practice throughout the industry. The breadth of human factors within other industries are reviewed and summarised. The Frameworks in the ADWG and AGWR provide opportunities for the consideration of human factors and these are mapped at the action level to identified human factors.

The development of a safety culture comprising worker safety and product safety may be more difficult than worker safety and process safety.

INTRODUCTION

Consultation on the preventive risk management approach in the Australian Drinking Water Guidelines (ADWG) commenced in 2001 and the Framework for Management of Drinking Water Quality, including the 12 elements, was published in the 2004 review. This approach was adopted in the Australian Guidelines for Water Recycling (AGWR) with the Framework for Management of Recycled Water Quality and Use. These frameworks shift focus from end point testing to developing and understanding how and where to best manage each water quality hazard.

Human factors have been identified as contributing to many incidents in the water industry. However, it is the authors' observation that human factors are rarely formally recognised in approaches to water quality risk management. This paper considers the contribution of human factors to water quality incidents, reviews how other industries incorporate human factors within their organisational cultures and proposes the frameworks within the ADWG and AGWR are used for consideration of human factors.

PROCESS

To investigate previous work in this area a literature review of peer reviewed papers considering the assessment of human factors within the water industry was undertaken. The areas considered as human factors were also researched through a survey of publicly available industry guidance. The ADWG and AGWR were reviewed for human factor references. The outcomes of these studies are discussed below.

FINDINGS

Human Factors and Drinking Water Incidents

Limited peer-reviewed consideration of human factors has been published in the urban water field. A review undertaken by Wu *et al.* (2009) was the most comprehensive paper the authors found in this area. Wu *et al.* (2009) categorised 62 drinking water incidents occurring in affluent countries from 1974 to 2001 as active errors, latent errors, customer and regulator errors and physical errors. Active errors were those errors that typically became apparent to an operator in a short period of time and were the result of an omission or using the wrong rule or procedure. Latent errors were those that were only apparent after a period of time, or when combined with other errors, or particular operational conditions. Of these four error categories only physical errors, including equipment failure and extreme weather did not contain a human factor component. Wu *et al*. found that only 22% of all incidents did not include a human component (Figure 1). They further considered the nature of active error (Figure 2). This study demonstrates the contribution and importance of human factors in managing water supply risks. The recent book *Ensuring Safe Drinking Water* (Hrudey

and Hrudey 2014) also highlights operators' actions in managing drinking water incidents.

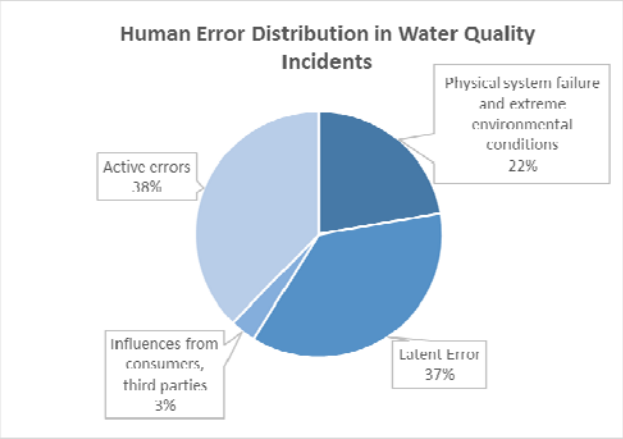

Figure 1: Human Error Distribution in Water Quality Incidents (Wu et al. 2009)

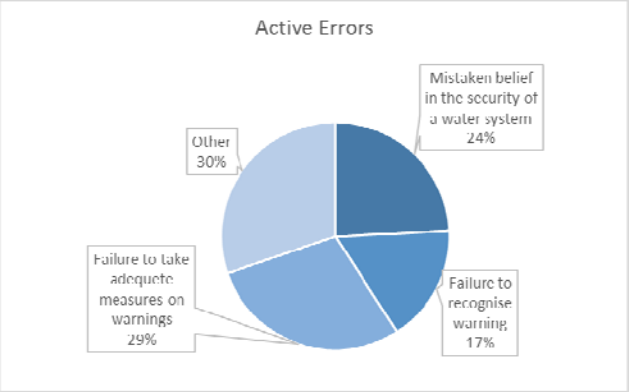

Figure 2: Breakdown of Active Errors

Incorporation of Human Factors in Other Industries

Human factors are recognised, articulated and managed in industries where breaches of safety lead can lead to catastrophic impacts for people and the environment including the chemical, oil and gas and nuclear industries. Human factors identified by leading regulators and associations in these areas are summarised in Table 1. In these industries there is a close link between the safety of personnel and processes safety; if control of processes is lost, the safety of personnel may be threatened. As a result, these industries acknowledge human failures (Figure 3) and actively manage human factors through their safety culture.

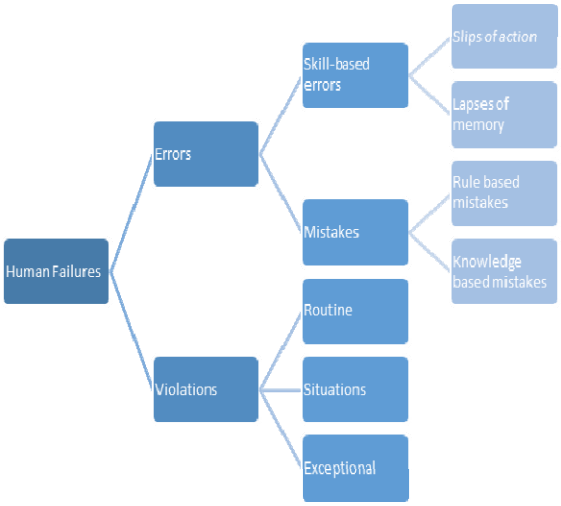

Figure 3: Conceptual Model of Human Failures

The concept of safety culture model maturity then follows, as organisations work to continually improve this aspect of their culture.

For the urban water industry, product safety, or lack thereof, will have a larger impact than process safety. Water, once distributed, cannot be recalled. The link between worker safety and product safety is much weaker than the abovementioned industries making it harder to transfer organisational awareness of human factors from personal safety to product safety.

DISCUSSION

Mapping Human Factors to Existing Water Industry Frameworks

Safety culture as it applies to product safety may not transfer well in the water industry from the organisational culture surrounding personal safety.

Table 1. Consideration of human reliability factors

Human reliability factors	UKHSE	US NRC	NEA	NOPSA	QME	CASA
Alarm handling & emergency response	✓	✓	✓		✓	✓
Competence	✓	✓	✓	✓	✓	✓
Fatigue	✓	✓		✓		✓
Maintenance error	✓	✓	✓			✓
Organisation change	✓		✓	✓		✓
Procedures	✓	✓	✓	✓	✓	✓
Safety culture	✓			✓		✓
Safety-critical communications	✓	✓		✓		✓
Staffing & training (or resources)	✓	✓	✓	✓	✓	✓
Thinking errors	✓		✓	✓	✓	✓

UKSHE - United Kingdom Health & Safety Executive
USNRC - United States Nuclear Regulatory Commission
NOPSA - National Offshore Petroleum Safety Authority (Australia)
QME - Queensland Mines & Energy (Australia)
CASA - Civil Aviation Safety Authority (Australia)
NEA – OECD Nuclear Energy Agency

However, the frameworks in the ADWG and the AGWR are generally well established in water utilities. These frameworks allow organisations to identify and manage human factors through consideration of the elements, components and actions comprising in the frameworks.

The ADWG are prefaced by 6 guiding principles for drinking water quality. These fundamental principles are vital to ensuring safe drinking water quality. The importance of active human involvement is implicit through phrases including 'arouse suspicion', 'respond quickly', 'personal sense of responsibility' and 'never ignore' in these principles.

Table 2 shows a mapping of human factors against the 12 elements of the ADWG and AGWR at the element level, showing the top-level linkages. Table 3 (located at the end of the paper) extends this to the action level for the Framework of Management of Drinking Water Quality. This extension allows a more detailed consideration of each human factor. Thus there is not a 1:1 correlation between Table 2. and Table 3. For example at the element level we propose the mapping of competence, safety culture and organisation change human factors to element 11 (Evaluation & audit) however at the action level, an audit could consider all of the human factors as part of the audit process. Incidents bring focus to failures by individual operators, usually without consideration of management and organisation defects which make such incidents inevitable.

Reason (1990) noted "Rather than being the main instigators of an accident, operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking"

Available tools

There are many opporunities to transfer already developed tools for considering and managing human factors into the water industry. The UK Health and Safety executive provides extensive resources including breifing notes on the human factors described above. They have also produced a human factors inspectors tool kit for inspections of major hazard facilities which contains points to examine, guidance on good practice, and a question set for each topic that could be easily adapted for the Australian water industry.

CONCULSION

Human factors have been shown to be a contributor to 78% of water quality incidents. The consideration of human factors should be a priority for water utilities. While the safety culture model used in other industries may not be suitable for the water industry, the 12 elements in the ADWG and AGWR can be used as a roadmap to consider human factors.

REFERENCES

AGWR. 2006. Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 1). Natural Resource Management Ministerial Council, Environment Protection and Heritage Council, Australian Health Ministers Conference. Web Copy: ISBN 1 921173 06 8

ADWG. 2011. Australian Drinking Water Guidelines National Health and Medical Research Council ISBN Online: 1864965118

Hrudy, S.E., Hrudy, E.J. 2014. Ensuring Safe Drinking Water: Learning from Frontline Experience with Contamination. American Water Works Association, ISBN: 9781583219249

Table 2. Linkages between Human Factors and the 12 Framework Elements.

	ADWG/AGWR Element											
Human Factor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Alarm handling & emergency response		✓	✓	✓	✓	✓						
Competence	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fatigue	✓			✓		✓	✓					
Maintenance error		✓	✓	✓	✓							
Organisation change	✓						✓				✓	✓
Procedures		✓		✓		✓						
Resources	✓	✓	✓	✓			✓					
Safety culture	✓	✓	✓	✓		✓	✓			✓	✓	✓
Safety-critical communications	✓			✓		✓		✓				✓
Staffing & training		✓	✓				✓	✓		✓		✓
Thinking error – slips, lapse, mistakes & violations		✓	✓	✓			✓			✓		

Reason J. 1990. Human Error ISBN 978-0-521-30669-0

UK Health and Safety Executive. 2005. Inspectors Toolkit Human factors in the management of major accident hazards

Wu S., Hrudey S., French S., Bedford T., Soane E., Pollard S. 2009. A role for human reliability analysis (HRA) in preventing drinking water incidents and securing safe drinking water, Water Research, vol 43, 13, p 3227–3238

Table 3. Linkages between Human Factors and the ADWG Framework Actions.

Framework for Management of Drinking Water Quality			**Alarm handling and Emergency response**	**Competence**	**Fatigue**	**Thinking error**	**Maintenance error**	**Organisational change**	**Procedures**	**Resources**	**Safety culture**	**Safety critical communication**	**Staffing & training**
1: Commitment to drinking water quality management	Drinking Water Quality Policy	Formulate a drinking water quality policy, endorsed by senior executive, to be implemented throughout the organisation.									✓		
		Ensure that the policy is visible and is communicated, understood and implemented by staff.									✓		✓
	Regulatory & formal requirements	Identify and document all relevant regulatory and formal requirements.							✓	✓			
		Ensure responsibilities are understood and communicated to staff.		✓									✓
		Review requirements periodically to reflect any changes.								✓			✓
	Engaging stakeholders	Identify all stakeholders who could affect, or be affected by, decisions or activities of the drinking water supplier.									✓		
		Develop appropriate mechanisms and documentation for stakeholder commitment and involvement.								✓	✓		
		Regularly update the list of relevant agencies.							✓		✓		
2 Assessment of the drinking water supply system	Water supply system analysis	Assemble a team with appropriate knowledge and expertise.		✓						✓			✓
		Construct a flow diagram of the water supply system from catchment to customer.		✓									✓
		Assemble pertinent information and document key characteristics of the water supply system to be considered.								✓	✓		✓
		Periodically review the water supply system analysis.								✓			✓
	Assessment of water quality	Assemble historical data from source waters, treatment plants and finished water supplied to consumer (over time and following specific events).							✓	✓			
		List and examine exceedances.							✓				
		Assess data using tools such as control charts and trends analysis to identify trends and potential problems.		✓		✓			✓		✓		✓
	Hazard identification & risk assessment	Define the approach and methodology to be used for hazard identification and risk assessment.								✓	✓		✓
		Identify and document hazards, sources and hazardous events for each component of the water supply system.	✓	✓	✓	✓	✓	✓	✓		✓		✓
		Estimate the level of risk for each identified hazard or hazardous event.	✓	✓	✓	✓	✓				✓		✓
		Evaluate the major sources of uncertainty associated with each hazard and hazardous event and consider actions to reduce uncertainty.	✓	✓	✓	✓	✓				✓		✓

Framework for Management of Drinking Water Quality			Alarm handling and Emergency response	Competence	Fatigue	Thinking error	Maintenance error	Organisational change	Procedures	Resources	Safety culture	Safety critical communication	Staffing & training
		Determine significant risks and document priorities for risk management.			✓	✓	✓			✓	✓		✓
		Periodically review and update the hazard identification and risk assessment to incorporate any changes.						✓					
3 Preventative measures for drinking water quality	Preventative measures & multiple barriers	Identify existing preventive measures from catchment to consumer for each significant hazard or hazardous event and estimate the residual risk.	✓	✓					✓		✓	✓	✓
		Evaluate alternative or additional preventive measures where improvement is required.	✓	✓					✓		✓	✓	✓
		Document the preventive measures and strategies into a plan addressing each significant risk.								✓	✓		✓
	Critical control points	Assess preventive measures from catchment to consumer to identify critical control points.									✓		✓
		Establish mechanisms for operational control.		✓		✓			✓				
		Document the critical control points, critical limits and target criteria.							✓	✓		✓	
4 Operation procedures & process control	Operational procedures	Identify procedures required for processes and activities from catchment to consumer.							✓				
		Document all procedures and compile into an operations manual.								✓			
	Operational monitoring	Develop monitoring protocols for operational performance of the water supply system, including the selection of operational parameters and criteria, and the routine analysis of results.		✓					✓				
		Document monitoring protocols into an operational monitoring plan.								✓			
	Corrective action	Establish and document procedures for corrective action to control excursions in operational parameters.	✓						✓	✓			
		Establish rapid communication systems to deal with unexpected events.										✓	
	Equipment capability & maintenance	Ensure that equipment performs adequately and provides sufficient flexibility and process control.					✓						
		Establish a program for regular inspection and maintenance of all equipment, including monitoring equipment.					✓		✓				
	Materials & chemicals	Ensure that only approved materials and chemicals are used.							✓		✓		
		Establish documented procedures for evaluating chemicals, materials and suppliers.							✓				

Framework for Management of Drinking Water Quality			Alarm handling and Emergency response	Competence	Fatigue	Thinking error	Maintenance error	Organisational change	Procedures	Resources	Safety culture	Safety critical communication	Staffing & training
5 Verification of drinking water quality	Drinking water quality monitoring	Determine the characteristics to be monitored in the distribution system and in water as supplied to the consumer.							✓				
		Establish and document a sampling plan for each characteristic, including the location and frequency of sampling.							✓	✓			
		Ensure monitoring data is representative and reliable.										✓	
	Customer satisfaction	Establish a consumer complaint and response program, including appropriate staff training.	✓										✓
	Short term evaluation of results	Establish procedures for the daily review of drinking water quality monitoring data and consumer satisfaction.							✓				
		Develop reporting mechanisms internally, and externally, where required.								✓			
	Corrective action	Establish and document procedures for corrective action in response to non-conformance or consumer feedback.	✓						✓	✓			
		Establish rapid communication systems to deal with unexpected events.	✓						✓			✓	
6 Management of incidents and	Communication	Define communication protocols with the involvement of relevant agencies and prepare contact list of key people, agencies and businesses.							✓		✓	✓	
		Develop a public and media communications strategy.	✓						✓			✓	
	Incident & emergency response protocols	Define potential incidents and emergencies and document procedures and response plans with the involvement of relevant agencies.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Train staff and regularly test emergency response plans.	✓	✓									✓
		Investigate any incidents or emergencies and revise protocols as necessary.	✓						✓		✓	✓	
7 Employee awareness & involvement	Staff awareness & involvement	Develop mechanisms and communication procedures to increase staff awareness of and participation in drinking water quality management.		✓								✓	✓
	Staff training	Ensure that staff, including contractors, maintain the appropriate experience and qualifications.	✓	✓				✓					✓
		Identify training needs and ensure recourses are available to support training programs.	✓					✓		✓			✓
		Document training and maintain records of all staff training.								✓			
8 Community	Community consultation	Assess requirements for effective community involvement.									✓		
		Develop a comprehensive strategy for community consultation.							✓		✓		
	Communication	Develop an active two-way communication program to inform consumers and promote awareness of drinking water quality issues.									✓		

Framework for Management of Drinking Water Quality			Alarm handling and Emergency response	Competence	Fatigue	Thinking error	Maintenance error	Organisational change	Procedures	Resources	Safety culture	Safety critical communication	Staffing & training
9 Research & development	Investigate studies & research monitoring	Establish programs to increase understanding of the water supply system.								✓			
		Use information to improve management of the water supply system.								✓			
	Validation of processes	Validate processes and procedures to ensure that they are effective at controlling hazards.					✓		✓				
		Revalidate processes periodically or when variations in conditions occur.											
	Design of equipment	Validate the selection and design of new equipment and infrastructure to ensure continuing reliability.					✓		✓				
10: Documentation & reporting	Management of documentation & reports	Document information pertinent to all aspects of drinking water quality management.							✓	✓			
		Develop a document control system to ensure current versions are in use.							✓				
		Establish a records management system and ensure that staff are trained to fill out records.							✓				✓
		Periodically review documentation and revise as necessary.						✓	✓				
	Reporting	Establish procedures for effective internal and external reporting.							✓				
		Produce an annual report to be made available to consumers, regulatory authorities and stakeholders.									✓		
11 Evaluation & audit	Long-term evaluation of results	Collect and evaluate long-term data to assess performance and identify problems.								✓	✓		
		Document and report results.								✓	✓		
	Audit of drinking water quality management	Establish processes for internal and external audits.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Document and communicate audit results.										✓	✓
12 Review & continual improveme	Review by senior executive	Senior executive review of the effectiveness of the management system.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Evaluate the need for change.						✓					
	Drinking Water Quality management improvement plan	Develop a drinking water quality management improvement plan.							✓	✓	✓		
		Ensure that the plan is communicated and implemented, and that improvements are monitored for effectiveness.		✓						✓	✓		