Bow tie analysis in the water industry

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Abstract: This paper discusses using bow-tie analysis for drinking and recycled water quality risk assessments. Bow-tie diagrams are a highly visual communication tool resulting in increased analysis and communication of risk estimation information; well suited to documenting how a scheme is achieving a multiple barrier approach to water quality.

Keywords: Bow-tie, risk assessments, risk analysis

Introduction

Water quality risk assessments are an essential component of the Australian Drinking Water Guidelines (NHMRC and NRMMC 2011), the Australian Guidelines for Water Recycling (NHMRC and NRMMC 2006) and the World Health Organisation Water Safety Plan Manual (WHO 2009).

Bow-tie diagrams describe the pathways of a risk from its cause to its consequence and illustrate the barriers in place to reduce the risk (AS/NZS ISO 2009). The strength of bow-tie diagrams are that they go beyond the usual risk assessment 'snapshot' and highlight the links between the threat, its consequences, the barriers preventing the consequence from occurring and the strengths of these barriers. In its full application it can be used to demonstrate linkages between barriers and an underlying management system. The highly visual nature of the diagrams is well-suited to communicating risk issues to non-specialists.

Bow-ties originated as a method for assessing hazard and operational risks. The Royal Dutch/Shell Group was the first major company to integrate the total bow-tie method into its business practices and is credited with developing the technique which is widely used today. Use of bow-ties has subsequently spread between companies, industries, countries and from industry to regulator. Their application has extended across all risks, including financial, strategic, security, quality, business interruption, political, human resources, public health, environmental, design and project risk. Through the Engineered Safety Group, Engineers Australia promotes the use of bow tie analysis as a tool that promote safety in design across the engineering disciplines (Engineers Australia, 2016).

Typically water quality risk assessments are recorded in a tabular format, with hazards and hazardous events considered and assessed at each process step. Analysis and manipulation is required to help understand the risks, hazards, hazardous events and controls. In a catchment-to-consumer risk assessment, the process can feel tedious to participants as they get 'lost' in the detail of the system and may feel that risks are being assessed repeatedly.

Material and Methods

The authors facilitated drinking and recycled water quality risk assessments using the bow-tie analysis methodology for multiple water utilities across New South Wales, Australia. This involved live recording using a specialist bow-tie software package as part of a facilitated risk assessment workshop.

Thirty-nine facilitated risk assessments were carried out using bow-tie methodology from 2011 to 2016, of these, eight were undertaken on recycled water systems and thirty-one on drinking water supply systems.

One to three days were spent on each risk assessment workshop, dependent on the number of systems that were being assessed and the complexity of the systems. The workshops teams consisted of participants from management, operations and regulatory agencies.

The method for building a bow-tie diagram is well documented and involves asking a structured set of questions in a logical sequence to build up the diagram step by step. It starts with the hazardous event or initial loss of control, identifying the threats and consequences and the barriers to these (Engineers Australia, 2014). A basic bow-tie diagram is illustrated in Figure 1, showing the hazardous event at the centre of the diagram.

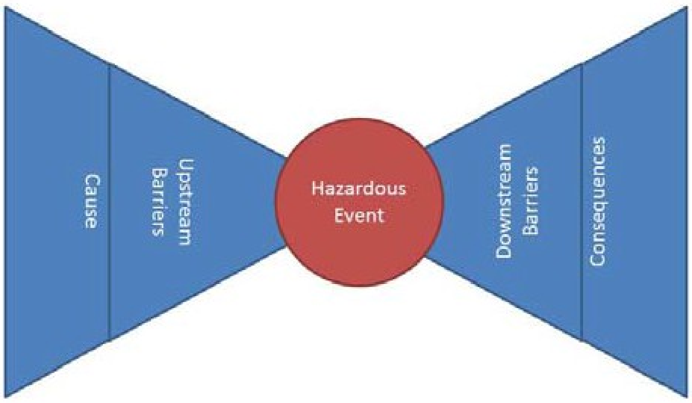


Figure 1 Basic Bowtie

Bow-tie diagrams are able to capture a broad range of information, as shown in Figure 2. The items that can be captured as part of the analysis are listed in Table 1.

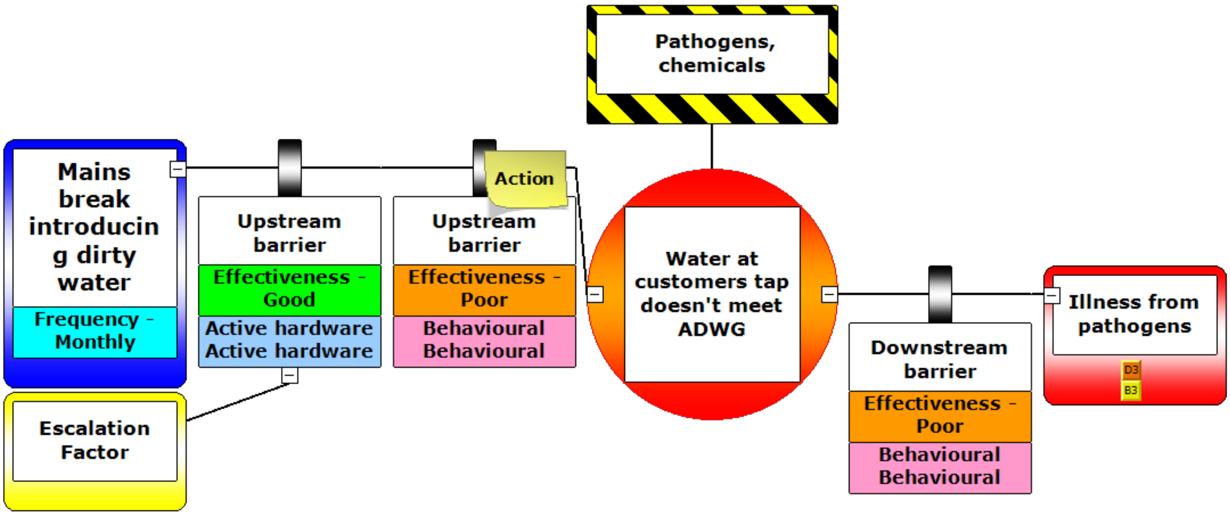


Figure 2 Conceptual simplified bow-tie diagram

Table 1 Information that can be captured using the bow tie method

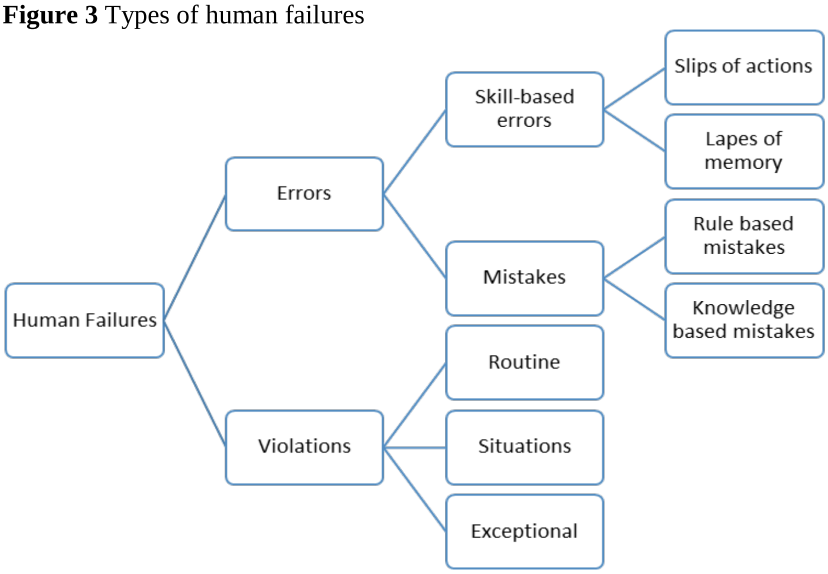
Component	Items	Example
Threat	Frequency	Continuous, daily, weekly, monthly, yearly
	Contribution (category)	High, medium and low contribution
Barriers	Barrier type	Active hardware, passive hardware, behaviour
	Effectiveness	Very good, good, poor, very poor
	Accountability	Operator / manager
	Criticality	Critical control points
	Activities	Routine checklists
Consequence	Category	Minor concern, medium concern, major concern
	Risk assessment	Considerations of operational, public health, environmental and reputational risks
Action	Action party	Works manager, operator, engineer
	Priority	High, medium, low

Consideration of upstream and downstream barriers was undertaken separately, with the hierarchy of risk controls (UK Health and Safety Executive, 2014) being used to assess the effectiveness of each barrier. Controls managed by procedures received an effectiveness rating equivalent to poor. This ranking acknowledged that procedures are an administrative control, ranked fifth out of six steps in the hierarchy of control measured to eliminate or control a risk under the Work Health and Safety Regulation 2011 (NSW):

1. Eliminate
2. Substitute
3. Isolate
4. Engineer
5. Administration
6. PPE

The risk assessments considered human factors as possible causes to hazardous event and in relation to the effectiveness of barrier implementation. The UK Health and Safety Executive (1999) breaks human failures into errors and violations as shown in Figure 3. The bow-tie diagram allows documentation of these through barrier type (e.g. behavioural, active hardware etc.) and through threats (e.g. chemical unavailability through delivery failure).

Figure 3 Types of human failures



Risk levels were ranked for health, aesthetic, environmental, operations, for both inherent (without barriers) and residual risks (with barriers). The risk matrices as documented in the ADWG (NHMRC and NRMMC (2011) and AGWR (NHMRC and NRMMC 2006) risk matrices were used to rank risks. Actions to mitigate the risks were applied to any part of the bow-tie diagram as appropriate.

Results and Discussion

Separate bow-tie diagrams were created during each workshop for different system processes from catchment to customer. Example hazardous events (bow-tie centre) for a de-identified drinking water supply system included:

- Raw water is outside water treatment plant design envelope
- Failure of filtration
- Disinfection is not effective
- Underdoing and overdosing of fluoride
- Water quality at customer's tap does not meet Australian Drinking Water Guidelines limits

Example/tool 4.10 and 6.4 taken from the World Health Organisation Water Safety Plan Manual (WHO 2009) has been used as a basis to compare bow-tie and traditional spreadsheet matrix risk assessment methodology, as shown in Figure 4 and Table 2.

Figure 4 Comparison of bow-tie vs spreadsheet matrix methodology outputs

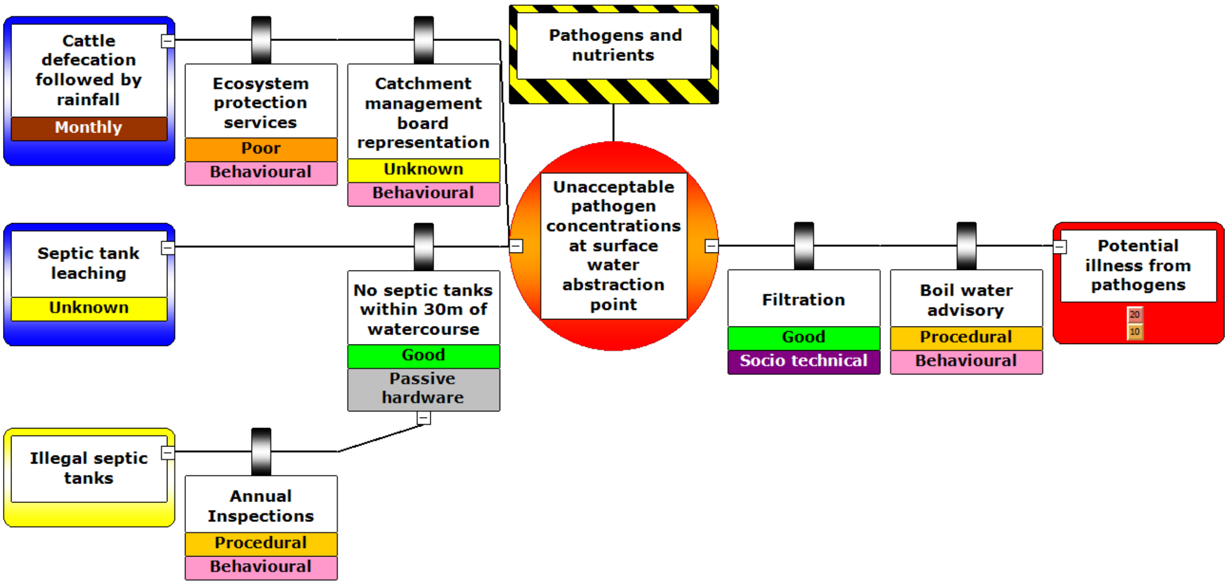


Table 2 Traditional spreadsheet matrix

Process	Hazardous event	Hazard Type	Like-lihood	Severity	Risk	Control Measure
Catchment	Cattle defecation followed by rainfall, transporting pathogens to reach unacceptable concentrations at the surface water abstraction point, leading to potential illness from pathogens	Pathogens & nutrients	3 Moderate	5 Catastro-phic	15 Severe	• Implementation of Ecosystem Services Practices • Filtration of water • Boil water advisory

Process	Hazardous event	Hazard Type	Like-lihood	Severity	Risk	Control Measure
Catchment	Septic tank leaching in catchment area, with unacceptable pathogen concentrations at the surface water abstraction point, leading to potential illness from pathogens	Pathogens & nutrients	3 Moderate	5 Catastro-phic	15 Severe	• No septic tanks within 30m of watercourse • Filtration of water • Boil water advisory

As demonstrated above the diagrammatic methodology of bow-tie provides a clear visualisation of the risk pathway from the hazardous event through to the consequence, and the barrier upstream and downstream of the initial loss of control. During the risk assessment workshop process, bow-tie methodology was found to encourage participant thinking and learnings around the effectiveness of individual barriers in the management of water quality risks. This was most apparent once distribution system risks were considered, with the most barriers for distribution systems being on the preventative side and participants were able to realise this distinction when the results were presented visually.

While the bow-tie methodology output is a structured diagram, the process is inherently more flexible than the spreadsheet matrix methodology. The authors found that in the development of a bow-tie, the facilitator was able to record the experience drawn from a range of participants rather than the discussion being constrained to the tabular format. It was observed by the authors that workshop participants had a greater level of engagement and that workshop fatigue was significantly reduced, with greater participation, 'story-telling' and capturing of real experiences.

The bow-tie methodology allows discussion of barrier effectiveness and failure. Studies show the importance of having effective multiple barriers in place and the conditions in which barriers fail (Wu et al. 2009; Tang et al. 2013). Evaluation of barriers effectiveness helps to inform and direct actions, to either improve existing barriers or by adding new barriers. In the authors experience, while assessment of overall barrier effectiveness may occur it is very unusual to consider individual barrier effectiveness using the spreadsheet matrix methodology.

The bow-tie methodology allows an enormous amount of information to be collected and disseminated in an easy to understand manner and it was found that the use of bow-tie diagrams:

- Provided a visual illustration of hazards, causes, consequences, controls and control failures
- Increased operator knowledge transfer within the workshops, resulting in better analysis of barrier effectiveness
- Provided a flexible methodology in documenting hazards and hazardous events
- Visually demonstrates the routes to incidents and the presence (or lack) of multiple barriers, including assessment of barrier effectiveness
- Allowed consideration of additional aspects of risk management
- Could link to existing documentation and practices

- Outputs can be used to communicate risk to a diverse audience.
- Provided differentiation between upstream and downstream barriers
- Allowed more information to be able to be captured within the workshop timeframe.

Both traditional and bow-tie risk assessments rely on effective facilitation and the expertise of the people involved in a workshop. The primary disadvantage of the bow-tie methodology is that it requires specialist software for efficient risk capture and analysis. While it is possible to develop bow-tie diagrams in community settings or using standard desktop software, recording and analysing information cannot be easily done without the use of a specialised software package.

By providing a visual representation of the risk pathways, bow-tie diagrams provide better overall risk analysis compared to the traditional risk assessment methodology for the water industry. When bow-tie analysis was used as part of a risk assessment the focus shifted from the outcome of the hazardous event to the effectiveness of barriers – an approach well suited to documenting how a scheme is achieving a multiple barrier approach to water quality.

Conclusions

Bowtie analysis is an effective methodology used in a number of industries including oil and gas, and aviation and mining for conducting risk assessments. Bow-tie diagrams can incorporate and display a wealth of information relating to the risk assessment in an effective and easy to use manner. This method is particularly effective when applied to water quality and operational risk assessment. This methodology can help to ensure that risks are managed, rather than just analysed; it is also an excellent means of communicating risk issues to non-specialists.

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