Rowe [1] defines risk as *"the potential for the realisation of unwanted consequences from impending events"*.

Waterhammer in sewage and wastewater pipelines is certainly an unwanted - but often unavoidable event. Sometimes it's simply ignored and consequently the effects are unexpected because the events causing it have not been considered. Waterhammer is a prime case for risk assessment.

Professor AR Thorley in his book Fluid Transients in Pipeline Systems [2] provides useful guidance on such a risk assessment, which includes …

- Understanding the nature and extent of the risks.
- The likelihood of the risks materialising.
- The options available to reduce the incidence and impact of risks.

Even if a waterhammer risk assessment has been performed during the design phase of a project for normal operational conditions, Professor Thorley cautions that the risk of waterhammer from the 'unexpected' still exists. Examples of the unexpected are …

1. Last minute changes during construction.
2. Commissioning and start-up tests under non-standard conditions such as part-load or with areas of the system shut off.
3. An upgrade to the system at a later time.

Transient pressure waves or waterhammer are caused by a change in flow conditions. The pressure waves may harmlessly attenuate due to friction in the pipeline. Alternatively they may superimpose on each other resulting in very high pressures or cause zero absolute pressure resulting in column separation and a whole new set of pressure transients when the columns rejoin. Waterhammer is as likely to be destructive in a short low-pressure pipeline as it is in a long high-pressure pipeline. A simple "rigid column" analysis using the Joukowski equation is just not adequate and cannot predict the effect of the full range of events that might occur.

The actual or *impending* events likely to generate pressure transients are numerous and varied. Many can be easily predicated, for example pump trip or start-up, valve closure, check valve slam. The unexpected by their very nature are harder to determine – operator error, equipment failure, unforeseen demands on the system. To winkle out the unforeseen, a structured approach to waterhammer risk assessment needs to be followed. Professor Thorley provides both the structure and number of examples taken from real situations.

Once potential operational/failure scenarios have been defined (Rowe's "impending events"), then the consequences need to be calculated and, if necessary, ameliorated. The *"options available to reduce the incidence and impact of risks"* need to be considered - the pressure transients need to be calculated. And here lies the rub. Hand calculation is out of the question for most engineers so a computer-based analysis is required. Yet even a computer-based study has its problems, one of the main ones being the shear volume of data produced as a result of the method of characteristics calculation. A stream of digital data may well warn of unacceptable peak pressures, but the warning may be hidden in the numbers.

Real-time graphical presentation of results is a must for any waterhammer software and there are many programs available which do just this. Graphical presentation of results provides not just a summary of the calculation; it assists in a greater understanding of the phenomenon and also with communication between colleagues and clients. It's easy to appreciate the effect of a reflected wave from a sea wall because the wave pattern can be directly observed; a graphical presentation of pipeline transients provides a similar understanding.

The two screen shots below are taken from the Hytran computer program. The simulation is a 3km wastewater pipeline with a single pump discharging 174 l/s to a reservoir with a static rise of 41m. There are two high points in the system prior to the reservoir. The simulation is of pump trip. Local pressure transients are displayed at the pump (the blue line on the inset graph) and at the first high point (the red line on the inset graph).

In screen-shot No.1, the blue line shows steady-state conditions for 5 seconds prior to pump trip, after which the pump head falls rapidly to zero. Shortly afterwards, the pressure at the first high point falls to *absolute* zero as a result of the elevation of the pipe in respect of the hydraulic grade line. A vapour cavity occurs at this point. Approximately 25 seconds later the vapour cavity collapses as the columns rejoin causing a peak transient pressure or head at the pump of more than twice the pump shut-off head. The cycle repeats itself every 20 seconds thereafter, with the second peak significantly attenuated due to friction in the system. But by this time the damage may be done!

What options are available to reduce the peak pressures? There are many commercially available equipment items such as air chambers – bladder or Charlatte for example; pressure relief valves, surge tanks etc.

A solution to the problem shown in screen shot No.1 could be as simple as a discharge tank located at the high point, its purpose being the prevention of the formation of the vapour cavity and therefore its subsequent collapse. Screen-shot No.2 shows just this. The discharge tank measures approximately 1.5m diameter with the head in the tank 1.2m above the pipe center-line. The tank is connected to the pipeline via a 100mm pipe fitted with a non-return valve. As the negative pressure wave caused by the pump trip passes the high point, water is drawn into the pipeline from the discharge tank filling the cavity that would otherwise be formed. Consequently the high pressure caused by the collapsing cavity cannot occur. In fact, as the blue line on the inset graph shows, the peak head at the pump after trip is not just lower that the shut-off head of the pump but lower than the duty head.

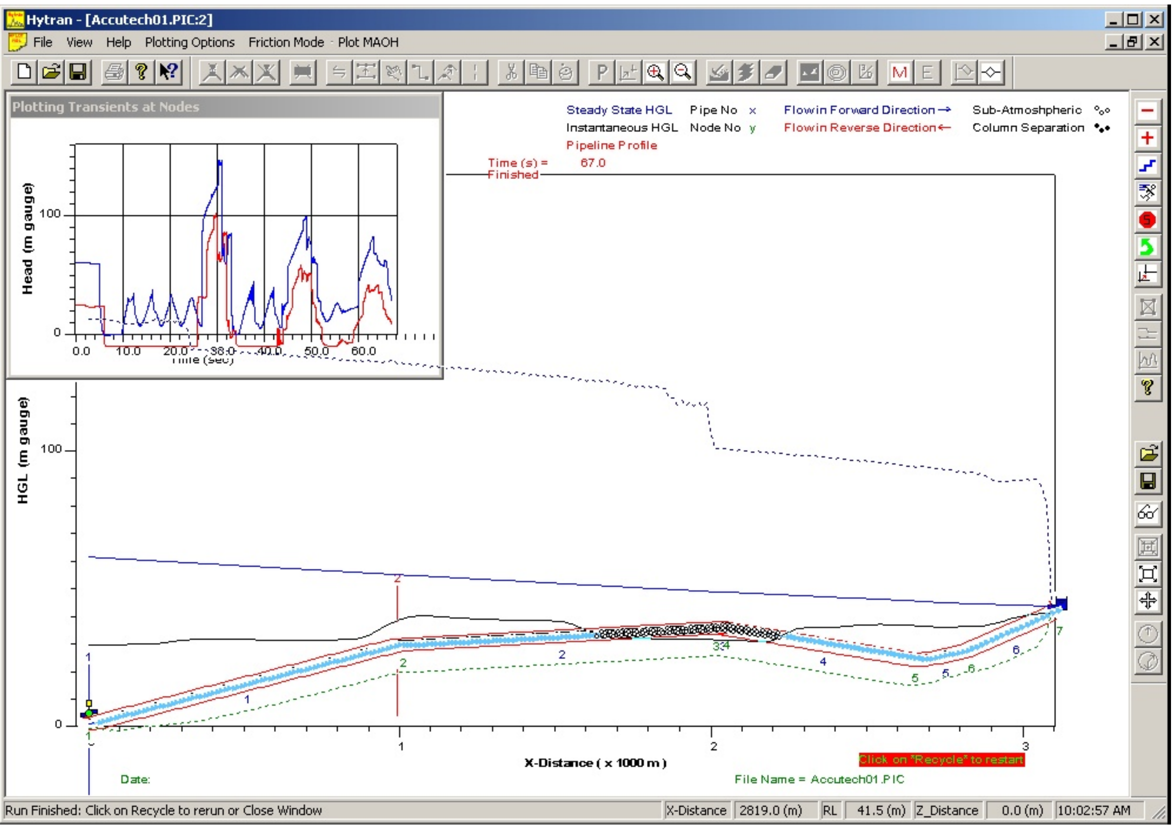
Waterhammer risk analysis should be performed on all pipelines. A risk analysis cannot be complete without a calculation of the magnitude of the peak pressures and, where appropriate, the effect of protection equipment. A visual presentation of the transients from a software program such as Hytran, graphically presenting the various case studies, will assist in both the risk assessment and the prevention of *"unwanted consequences from impending events"*.

References:

Rowe, WD (1979) Introduction to risk assessment , in *Energy Risk Management*, Eds GT Goodman and WD Rowe, Academic Press, pp. 7-19

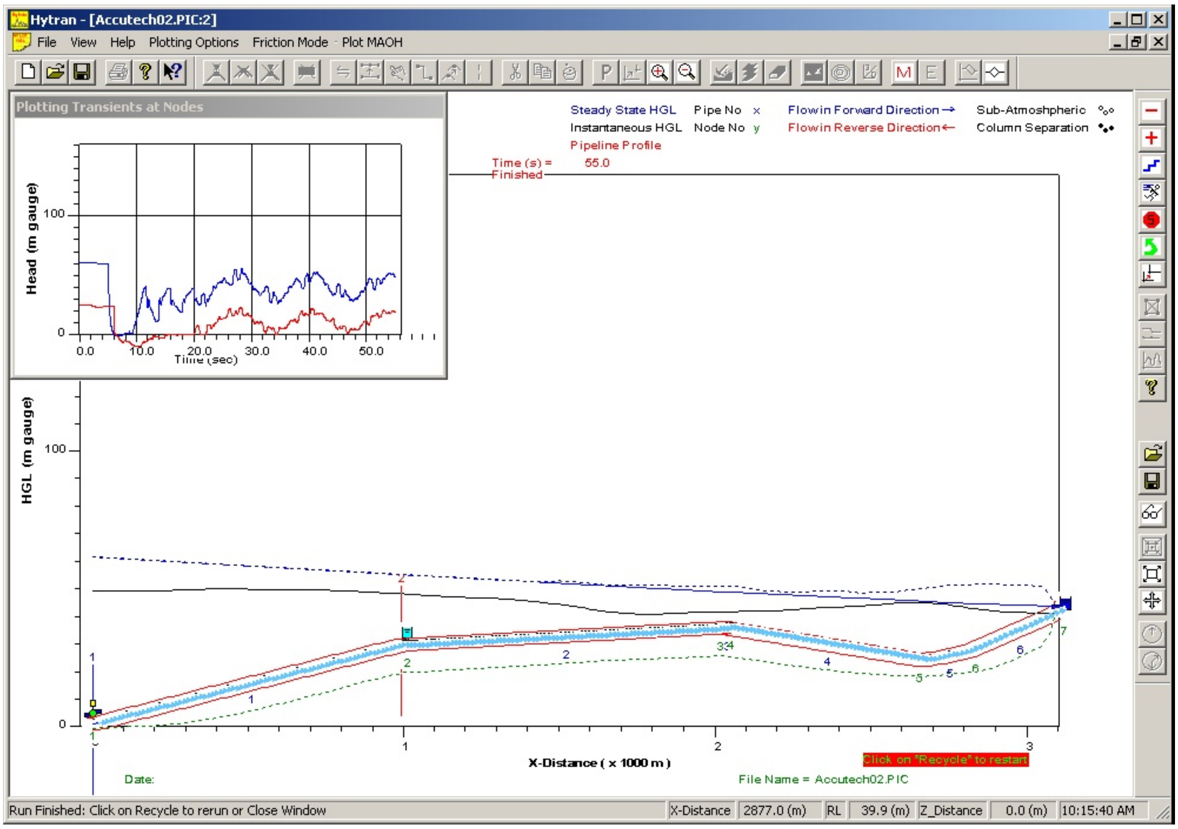
Thorley ARD (2004) Fluid Transients in Pipeline Systems, 2nd Edition, Professional Engineering Publishing Ltd.

Graeme Ashford, through his company Accutech, specialises in the supply, support and training in a range of fluid flow simulation programs. Information about the programs supplied by Accutech can be obtained from www.accutech2000.com.au



Screen Image No.1.

The 3km pipeline runs from the pump station at 0.0m elevation to the reservoir at 41m elevation. The dotted lines above and below the pipeline show the "pressure envelope" developed during the simulation period. The dark "bubbles" in the pipeline indicated pressures below atmospheric. The inset graph shows the head at the pump station (blue line) and at the first high point (red line).



Screen Image No.2.

The effect of the discharge tank is obvious. Head at the pump station does not exceed the duty head of the pump prior to trip and the pressure envelope is much reduced.