Quantifying the Potential Impact of Leaky Boreholes

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Leaky boreholes can potentially impact on groundwater flow and water quality. Shales overlying Hawkesbury sandstones in the Sydney area containing saline water should be sealed off using pressure cementing techniques during drilling. However, due to various factors, current practice does not always comply with bore construction and abandonment guidelines. This poster presents an example of a poorly constructed bore, calculated mixing ratios of saline and fresh groundwater, and an example of numerical modelling to quantify bore leakage volume in a stressed aquitard-aquifer system.

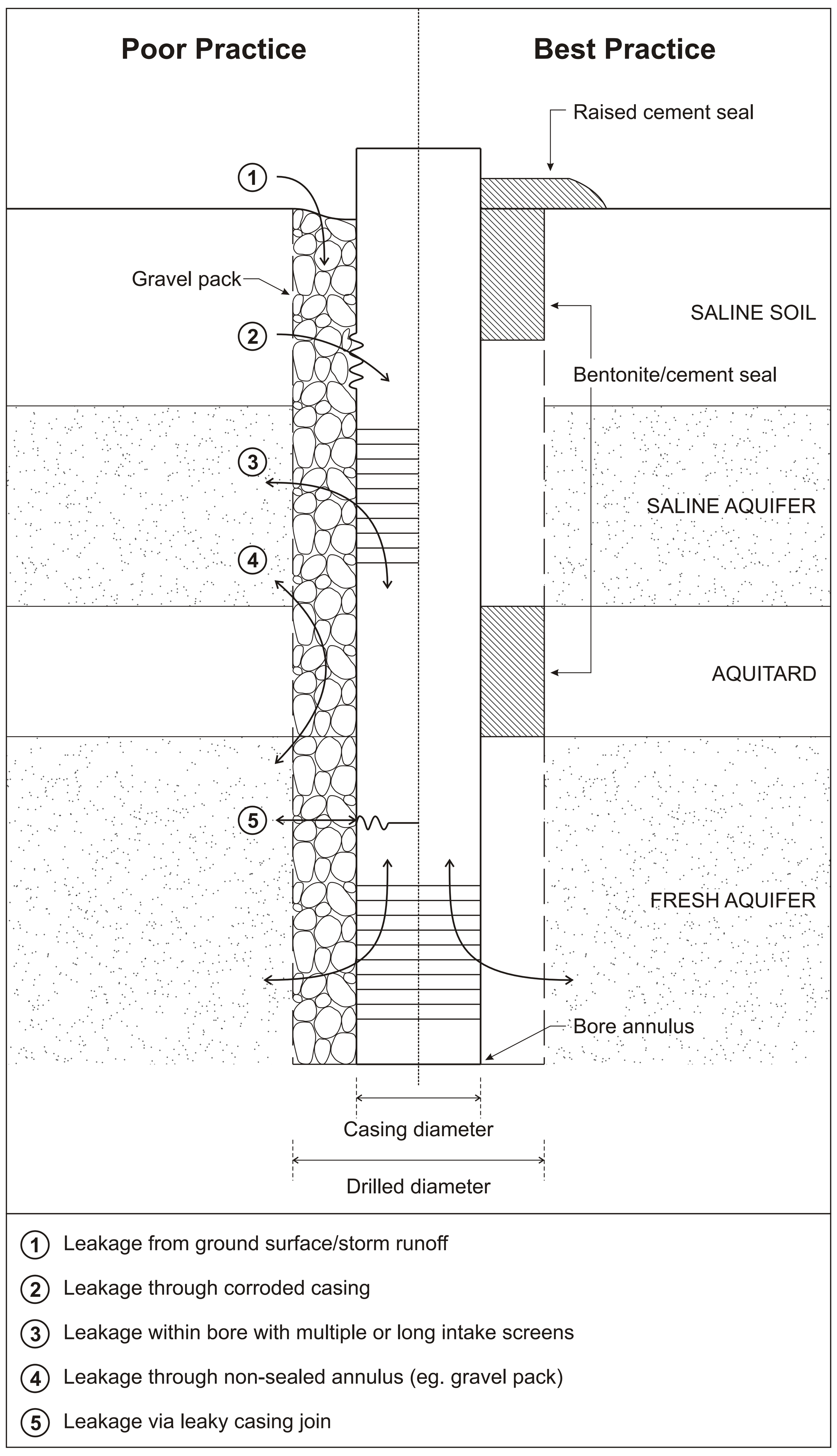


Figure 1. *Poor practice and best practice borehole condition.*

Thousands of bores have been drilled through sediments into underlying rock in NSW. Provided that sealing procedures in the Australian Standard and NSW DPI standards are adopted (ADIA, 2003; DPI 1997), drilling for water, testing or mineral resources is a negligible risk to groundwater quality. However, improperly constructed bores and failed aging bores may have impacted on groundwater quality in some locations.

Possible borehole leakage pathways are shown in Figure 1, compared with a borehole constructed and maintained according to best practice. Five possible leakage pathways are shown, including leakage through a poorly sealed annulus.

International studies on leaky bores have led to extension programs in areas to provide information and support for proper bore construction and abandonment. In one country, there is an estimated 30,000 leaky water supply bores that have passed their life expectancy of 30-50 years. Diagnosis of leakage pathways to support effective rehabilitation or abandonment should be based on a combination of evaluation tools (Santi et al, 2006). Testing of three leaky borehole sites found that calculation of flow rates for various leakage pathways was the most useful diagnostic method. Numerical modelling by Lacombe et al. (1995), found that an entire contaminant plume, or a significant portion of it, could be diverted to a lower aquifer via an open borehole subjected to high hydraulic gradient.

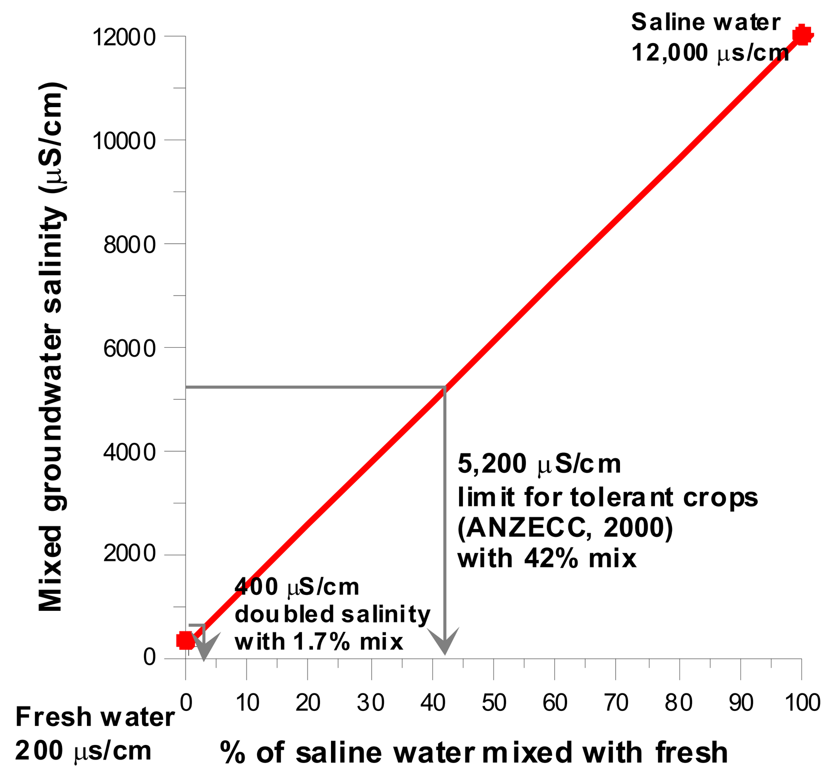
Drilling through saline shale

A bore recently installed in the Bankstown area yielded groundwater that was too saline (7,900 mg/L TDS, 12,520 S/cm) for irrigation. By comparison, water in the Hawkesbury sandstone is known to be saline with TDS values >3000 mg/L reported in this area by Russell (2007). The bore was drilled to 240 m using rotary air and mud techniques with no record of pressure cementing or attempts to seal between shale and an underlying sandstone groundwater source. The bore was completed with open-ended PVC casing through shale to 42 m depth and completed as an open-hole bore below that depth. Airlift yield estimates were 3 L/second with most of the inflow at about 200 m depth. It is possible, though unproven that saline leakage from the shale occurs in the borehole, given the relatively high groundwater salinity that was observed in the Hawkesbury sandstone.

Mixing ratios of salt and freshwater were calculated to assess possible solutions for bore remediation and irrigation usage. Figure 2 shows mixed salinities for non-reactive or conservative mixing at the Bankstown site (1), compared with a reactive mixing of a saline and fresh groundwater at an unidentified site (2). At the Bankstown site, a saline groundwater with 12,000 S/cm is mixed with fresh dam water of 200 S/cm. Alternatively, although there is no site specific data, the fresh water value could represent fresh groundwater. It is significant that a relatively small proportion of saline water (1.7%) would result in a doubling of salinity to 400 S/cm. For this borewater to comply with irrigation guidelines (5,200 S/cm for tolerant vegetation) a mix of 42% saline plus 58% fresh water would be required. Irrigation water drawn from this bore must therefore be mixed with a larger volume of fresh dam water.

Downhole geophysical logging and chemical tracing techniques were recommended as an independent check on borehole construction and the salinity profile in rock surrounding the casing to enable the bore to be modified and produce lower salinity water. However, the potential costs of diagnosis and rehabilitation of this bore meant that alternative water sources were pursued.

(1)



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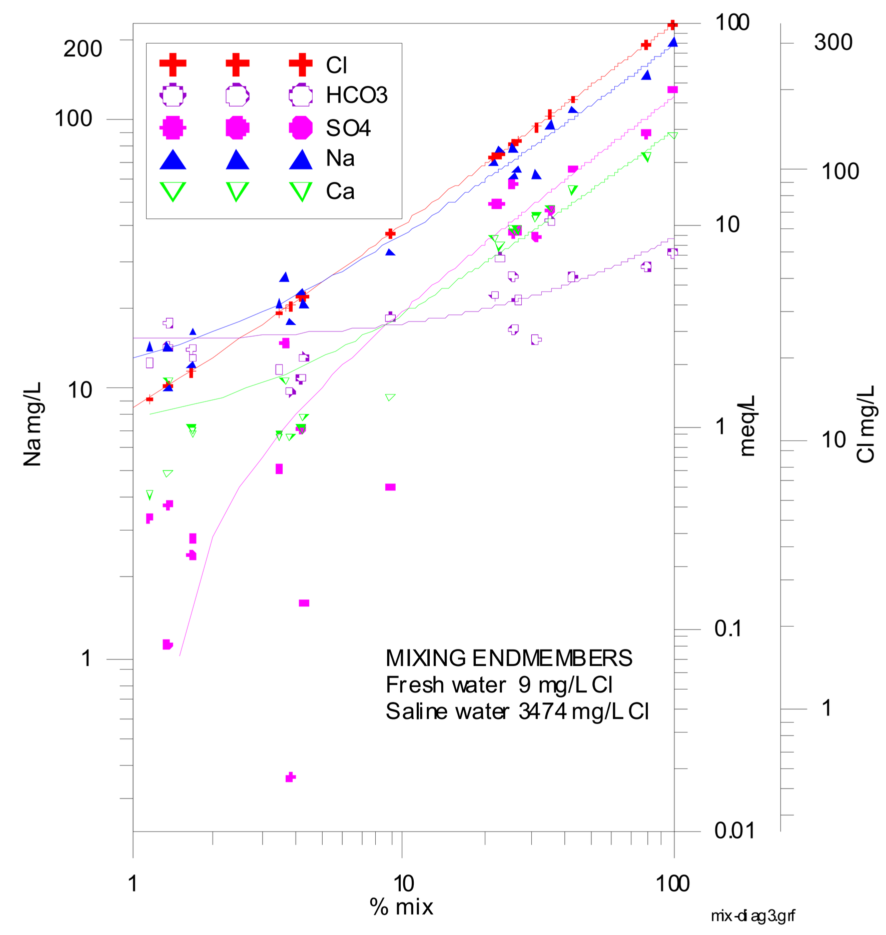

Figure 2. *Groundwater salinity mixing diagrams (1) Conservative mixing at Bankstown site and (2) Mixing diagram for a site with linear trend for chloride (conservative mixing) and non-linear trends for bicarbonate, sulphate, sodium and calcium (reactive mixing).*

Numerical modelling of leaky boreholes

Although leaky boreholes potentially impact on groundwater quality, numerical modelling indicates that the volume of leakage compared to aquifer flow may not be significant. A multi-layered axisymmetric FEFLOW model (Figure 3) was developed to quantify fluxes in an aquifer-aquitard system that was stressed by an irrigation bore (Timms, 2001). A rectangular mesh, with mesh enrichment around a single bore was developed including a leaky gravel pack in the annular space (0.2-0.4 m radius) with a vertical hydraulic conductivity of 40-100 m/day.

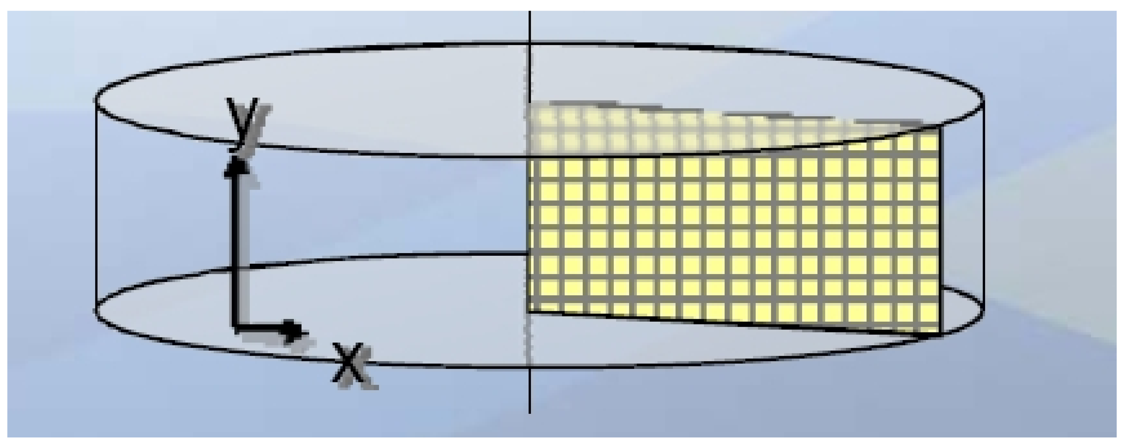

Figure 3. *Axisymmetric flow (DHI-WASY, 2009).*

Bore radius (m)	Annulus K* (m/day)	Flow pathway %		
		Bore annulus	Vertical aquitard	Horizontal aquifer
0	-	-	19.7	80.3
0.2	40	0.035	19.7	80.3
0.2	100	0.084	20.1	79.9
0.4	40	0.24	19.1	80.6
0.4	100	0.58	-	-
0.4	200	1.16	-	-

*K = hydraulic conductivity

Table 1. *Leakage via a borehole annulus compared to other flow pathways as a % of groundwater extracted.*

The leaky annulus accounted for 0.04-1.2% of total volume extracted from the irrigation bore, and was of minor importance relative to horizontal flow in the multiple layered aquifers. Total flow rate through the borehole was very sensitive to borehole radius similar to findings by Lacombe et al. (1995) who showed that bore flux Q was proportional to bore radius, r4. In this example, horizontal flow and vertical leakage through aquitards were of greater significance than a single leaky borehole for vertical flow (Figure 4), particularly where natural discontinuities occurred in the aquitard.

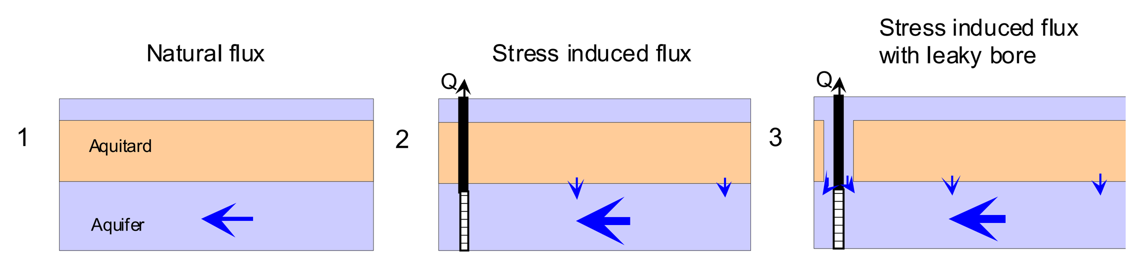

Figure 4. *Conceptual models of an aquifer-aquitard system with a continuous aquitard where flux is proportional to the number and size of arrows. Scenario 1 Natural flux. Scenario 2 Stress induced flux. Scenario 3 Leaky borehole flux.*

Conclusions

These examples indicate that depending on site conditions, bore leakage may account for a relatively small proportion of flow (0.04-1.2%), however a small proportion of leakage (1.7%) can result in a doubling of salinity if there is a source of highly saline groundwater. The potential impact of transient flow conditions, and more than one leaky borehole could be further assessed by numerical modelling. Geophysical and chemical tracing techniques are recommended for assessing aging bore infrastructure. The proper abandonment of unsatisfactory bores is considered to be both an opportunity for the drilling industry and essential for sustainable groundwater resources. Improved training, supervision and auditing of water bore drillers is recommended to ensure good environmental practice.

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