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Section 2 Test Methodology and Assessment

A Method for Studying Boron Redistribution and Leaching in Timber Framing

J A Drysdale[1], N Marston[2], M E Hedley[3]

[1]Consultant, PO Box 72 275, Papakura, Auckland 2244, New Zealand

[2]Materials Team Leader, BRANZ, Private Bag 50908,
Porirua City 5240, New Zealand

[3]Project Leader – Wood Preservation, Scion, Private Bag 3020,
Rotorua 3046, New Zealand

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IRG SECRETARIAT
Box 5609
SE-114 86 Stockholm
Sweden
www.irg-wp.com

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Rotorua 3046, New Zealand

ABSTRACT

In typical New Zealand timber framed house construction, the timber framing has a vapour permeable building wrap applied to the exterior and a cladding applied over 20 mm battens. An interior lining usually of gypsum plasterboard is then fixed once the timber framing has a moisture content of < 20%. Timber framing within the building envelope is not expected to be wet in-service or exposed to a leaching risk if the building is compliant with the NZ Building Code. However, there remains a potential risk that timber framing may still be exposed to inadvertent wetting during the lifetime of the building due to construction errors, lack of maintenance or extreme weather events. In New Zealand, it is usual to preservative treat timber framing to prevent or contain any fungal decay that might develop under these conditions until the moisture source can be identified and rectified.

This paper describes a method developed by BRANZ for a study to gain a better understanding of the redistribution and possible leaching of boron, an approved preservative for timber framing that might occur over time in wall framing being wetted regularly and in a non-drying environment. The water dosage rate of 100g per linear metre that was chosen exceeds natural drying rates in a wall cavity in summer and winter, and has been shown to increase the timber moisture content above the fibre saturation value. Additional studies of the distribution of the boron preservative concentration along radiata pine boards showed variation and this is a challenge when trying to determine a benchmark reference value to measure redistribution effects or possible losses against over time.

The boron concentrations (expressed as Boric Acid Equivalent) in timber samples were determined at intervals over a 18 month period. At the time of treatment some boards showed an uneven boron distribution in the cross-section. Over time the boron redistributed within the cross-section. Some boards also showed a downward trend in boron concentration and with depletion from the timber edge where water was being directly applied over the surface every 4 days. The overall trend was for a reduction in average % m/m BAE of approximately 30% over the first 6-8 months of the testing then the BAE levels levelled off (or increased).

Keywords: boron, timber, redistribution, leaching, framing, New Zealand

1. INTRODUCTION

Timber is a versatile and durable building material and the application of an appropriate preservative treatment will enhance the durability for specific end-uses. More than 90% of all new houses and buildings in New Zealand are constructed with timber framing. However, there have been systemic building weathertightness problems that have resulted in decay of timber framing. This situation primarily arose from 1998 changes to the Building Code Durability Acceptable solution B2/AS1 to allow some building methods and materials including use of untreated timber framing in most residential buildings.

In 2003, the relevant New Zealand Standards for timber uses in structures and for timber treatment (NZS 3602 and NZS 3640) and the Building Code Acceptable Solutions were amended to redefine timber framing preservative treatment requirements. The continued use of untreated timber framing was still allowed in some low-risk uses (e.g. roof framing, internal walls), a H1.2 treatment for timber framing was introduced for external wall framing , and a H3.1 level of treatment was specified for some higher risk uses (e.g. joists under enclosed decks, framing in parapet walls, bottom plates for some wall framing).

More recently, a review has been underway in New Zealand to rationalize and simplify the preservative treatment options with the objective of a having the option for a single specified hazard class for all timber framing within the building envelope (DBH, 2010). Timber in these situations should not be exposed to a leaching risk if the building is compliant with the Building Code. However it is also generally recognised, there remains a potential risk that timber framing may still be exposed to inadvertent wetting during the lifetime of the building. The purpose of the preservative treatment for this timber framing is therefore to prevent or contain any fungal decay until that leak can be identified and rectified. As part of the review, a lack of information on the potential leaching of boron treated framing within a wall environment was identified.

Normal standard leaching tests are on small test samples typically submerged in water as a pre-conditioning step before exposing to test fungi to determine a toxic threshold for a particular preservative system or active ingredient. This type of leaching regime is accepted for timber that will be exposed outdoors (above or in-ground) and in wet environments where the end-use service conditions will result in leaching. However for timber framing within the building envelope, i.e. behind cladding and a building wrap, this leaching test methodology is not appropriate. This paper describes the methodology developed for a study to gain a better understanding of the redistribution and leaching of boron that might occur over time where a leak might occur and timber framing does not dry even when the wall is constructed with a wall cavity to facilitate drainage and ventilation.

The leaching regime chosen represented a water leak through the cladding and building wrap to the framing that no wall design (either with a drained vented cavity or with direct fixed cladding) could effectively manage (Bassett, 2007). Water was applied at 4 day intervals at a rate equivalent to 100g per linear metre as might occur from a leak through the building envelope from a significant rain event. Moisture accumulation also needed to exceed the natural drying rates in either summer or winter environments so that over time the timber moisture content would increase to above fibre saturation and therefore become suitable for the development of decay. The water application rate was also designed to result in some run-off from timber surfaces so any leaching effects could be identified. The study achieved the objectives (Marston, 2011) and this paper is a summary of the method used and the resulting effects on boron distribution.

2. MATERIALS AND METHODS

2.1 Timber selection

The timber framing was cut from 28 year old radiata pine trees grown in the Central North Island. In total, 270 x 2.330 m lengths of kiln dried machined 90 x 45 mm MPG 8 radiata pine framing was selected from a large commercial sawmill located in Rotorua. The boards were selected for uniform grain, minimising whenever possible, the presence of large knots, and for a high proportion of sapwood either visually from the grain orientation and/or using the PCV heart/sap indicator reagents (Fig. 1). Boards with greater than 20% heartwood on the end cross-section were rejected. The boards were stacked into packets (Fig. 2) and after strapping the packets were transported to the *Scion* campus also located in Rotorua, and stored under cover until treated.

Figure 1. PVC heart/sapwood test; top board is sapwood and red colour on second board identifies presence of heartwood

Figure 2. Packet of selected framing timber

2.2 Preservative treatment

The preservative treatment solution was prepared from disodium octaborate tetrahydrate dissolved in water. Thirty of the boards were initially treated for a scoping study. This assisted in selecting the most appropriate treatment process parameters to achieve complete penetration of the sapwood yet to allow for wood and treatment variability while targeting a treatment charge uptake that would be similar to a conservative commercial treatment situation.

Two boron timber treatment target retentions were included. The lower 0.40% m/m Boric Acid Equivalent (BAE) retention was as currently approved for hazard class H1.2 (timber framing). The higher retention of 0.08% m/m was as used for hazard class H3.1 (for products used above ground and painted in-service, e.g. cladding, fascia, joinery).

Each board was uniquely numbered and treated with an identical Lowry process (Fig.3) to a target nett uptake of 70 L/m^3 with either a 3.08% w/v or 6.01% w/v BAE solution.

Ten sample boards representative of the range of treatment uptakes for each boron concentration set were selected for analysis at 250 mm from the board end and then from the midpoints of 5 x 375 mm long sub-samples cut from the remaining length of the board. The boron concentration was analysed by extraction of the boron under reflux then titrimetrically using mannitol to a bromothymol blue endpoint (Vogel, 1956).

Boards from each boron set were then selected for the leaching trials to be undertaken at the BRANZ site in Wellington. These boards were selected for; an expected boron retention of no more than a third higher than the target, having minimum defects (knots, heartwood variation), grain uniformity (along the board) and straightness. A % m/m BAE analysis was undertaken on a sample cut from 250 mm in from one end of the board as a reference BAE concentration.

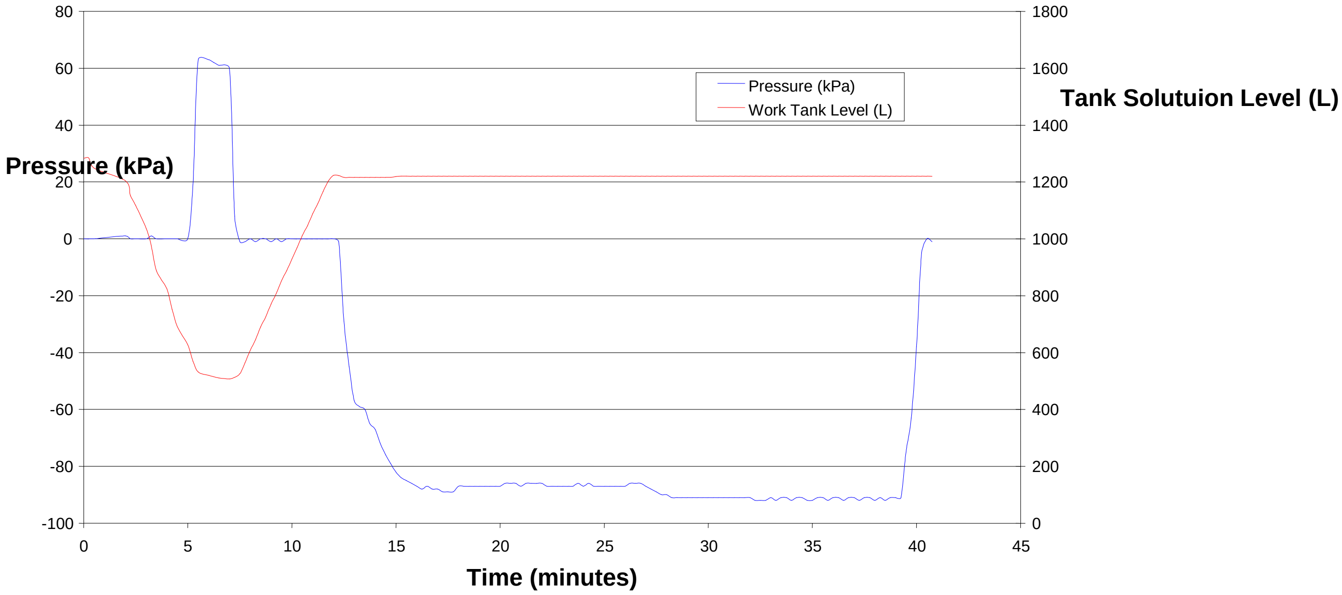

Figure 3. Treatment process schedule

2.4 Wetting and leaching

Before exposure, each end of every board was end-sealed with an epoxy-based paint. Each specimen board was laid flat on a PVC plate and as if configured as a bottom plate in the timber wall frame and in contact with building underlay on two sides held in place with two other PVC plates (Fig. 4). The PVC was laid over black plastic polythene sheeting but not so the timber boards were in direct contact or would be sitting in any run-off water ponding under the test rig.

Every 4 days a moving syringe apparatus travelled on a trolley along the board length (Fig. 5) to dose a uniform amount of water onto the exposed top timber surface and along one edge that was in contact with building underlay. As the trolley moved, a converging bar above the syringe pushed down the syringe plunger. The water was directed onto the surfaces through two irrigation heads (Fig. 6). The water application rate was set at 100 g per metre of timber.

Between water applications the boards were covered with black polyethylene sheet.
The temperature and humidly in the laboratory and the outside conditions were monitored and recorded for the duration of the wetting experiment.

Figure 4. Set up on specimen boards on PVC plates. (View is of final sub-sample of each board before trial was terminated)

Figure 5. View of syringe apparatus on trolley

Figure 6. Spray nozzles directing water onto timber surface and timber edge in contact with building underlay material

2.5 Sampling

Each of the twenty boards was sampled at approximately 1, 2, 3, 6, 9, 12 and 18 months. A 250 mm long piece was cut from one end of each board at each time interval. The fresh cut exposed board end was then immediately end-sealed to prevent any end-drying and possible boron redistribution effects that might affect the next sub-sample cut from that board. The sub-sample was cut from the same end of the board at each sampling time.

The samples for analysis were wrapped individually in plastic film to avoid drying and possible re-distribution effects before being subsequently re-cut for the analytical and moisture determination samples. Arrangements were made so there was minimal delay between the cutting of the sub-samples and the cutting of the analytical samples.

The samples for analysis were cut and prepared by the analytical laboratory. Cross-sections were cut for a sapwood/heartwood assessment, boron penetration, moisture content determinations, and boron analyses. The analytical zones for the boron concentrations selected were the sapwood cross-section, the central ninth portion of the cross-section and the outer 10 mm zone of the timber edge that was irrigated and in contact with the building underlay (Fig 7). Care was taken to avoid potential cross-contamination during preparation and between samples given the timber was damp/wet.

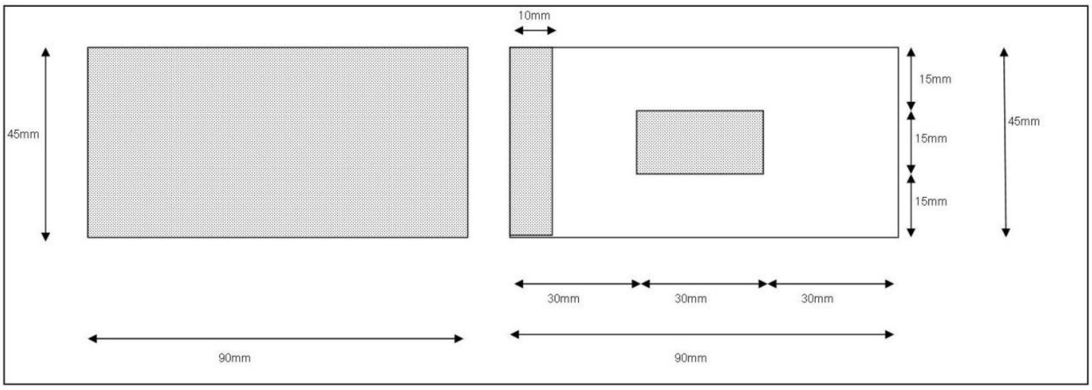

Figure 7. Analytical zones for BAE analysis; a cross-section, an edge, and a central ninth core section

3. RESULTS AND DISCUSSION

3.1 Temperature/humidity measurements

The exposure trial commenced in March 2009 and was terminated in September 2010. The comparisons of temperature and humidity for the laboratory and ambient outdoor environment are shown in Figs 8 and 9. Generally the laboratory was 5.5^{0}C warmer and had a lower humidity (~ 20% less) and therefore represented a better drying environment than a shaded outdoor environment. However these conditions did not adversely affect the timber moisture contents in the test samples as these were in excess of fibre saturation and also suitable for decay to develop.

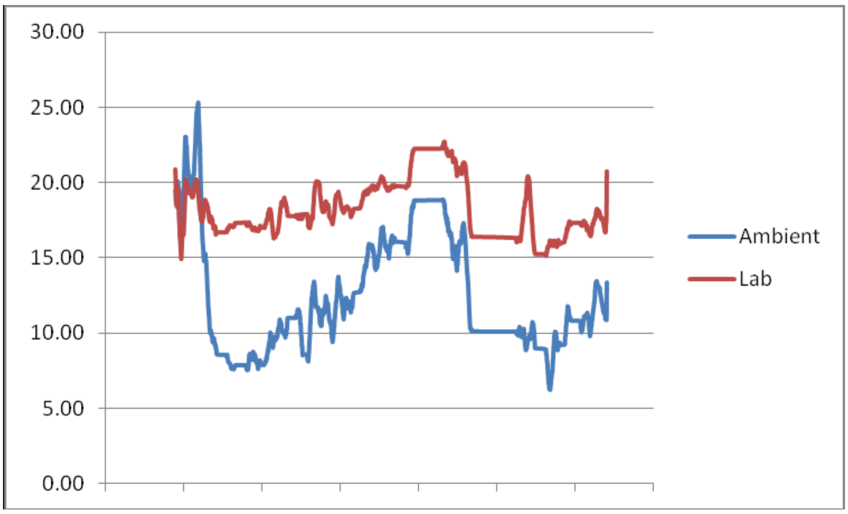

Figure 8. Comparison of outdoor ambient temperatures (^{0}C) and laboratory temperatures for the duration of the 18 month trial

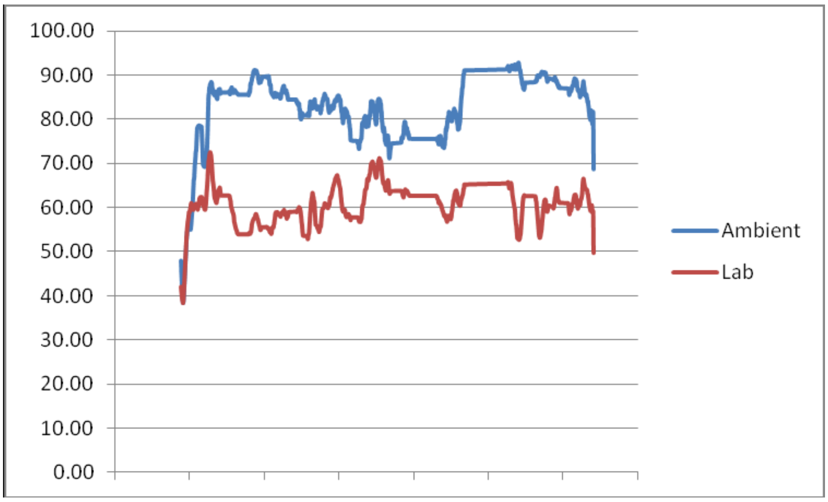

Figure 9. Comparison of outdoor relative humidity (% R.H.) and the laboratory for the duration of the 18 month trial

3.2 Analysis of unexposed treated control samples

Ten samples representing the range of treatment results were analysed for boric acid in cross-sections and the cores (central one-ninth). Sample position 1 was from approximately 250 mm from one end of the board and the subsequent sampling positions were at approximately 375 mm intervals from that end. The exact sampling position was influenced by the need to avoid any natural defects, e.g. knots. The cross-section analysis results are listed in order of the ascending calculated retention and are summarised in Table 1. The samples were chosen to span concentrations from below the H1.2 approved 0.40% m/m concentration, through to the 0.80 % m/m BAE concentrations and higher. The results in Table 1 illustrate that natural variability in boron concentrations can occur along the board following the preservative treatment and prior to any exposure to moisture.

Table 1. Cross-section retentions (as % m/m Boric Acid Equivalent) in unexposed boards

Sample No	*BAE % m/m*		*Sample position along board*						
	*Calculated**	*Analysis***	*1*	*2*	*3*	*4*	*5*	*Std dev*	*CV %*
6	0.31	0.27	0.32	0.25	0.23	0.29	0.28	*0.03*	*11.46*
75	0.32	0.39	0.46	0.35	0.31	0.32	0.51	*0.09*	*23.02*
13	0.34	0.37	0.35	0.37	0.42	0.35	0.36	*0.03*	*7.36*
12	0.36	0.33	0.34	0.31	0.35	0.30	0.34	*0.02*	*6.54*
69	0.39	0.41	0.37	0.36	0.46	0.45	0.43	*0.05*	*11.60*
21	0.41	0.38	0.34	0.39	0.38	0.39	0.41	*0.03*	*6.80*
11	0.42	0.44	0.44	0.43	0.54	0.38	0.41	*0.06*	*13.43*
4	0.48	0.42	0.50	0.48	0.42	0.26	0.46	*0.09*	*22.10*
24	0.49	0.50	0.59	0.43	0.50	0.53	0.44	*0.07*	*13.39*
66	0.53	0.49	0.59	0.45	0.48	0.51	0.42	*0.06*	*12.86*
72	0.56	0.51	0.50	0.56	0.58	0.45	0.48	*0.06*	*11.14*
75	0.65	0.69	0.67	0.73	0.70	0.67	0.65	*0.03*	*4.53*
117	0.78	0.89	0.95	1.02	0.97	0.75	0.74	*0.13*	*14.77*
19	0.80	0.79	0.80	0.80	0.84	0.74	0.76	*0.04*	*5.38*
23	0.83	0.79	0.74	0.84	0.85	0.79	0.73	*0.05*	*6.95*

Sample No	BAE % m/m Calculated*	Analysis**	Sample position along board 1	2	3	4	5	Std dev	CV %
31	0.88	0.78	0.78	0.84	0.80	0.67	0.70	*0.07*	*8.37*
32	0.89	0.80	0.70	0.78	0.89	0.79	0.83	*0.07*	*8.44*
53	0.97	1.10	1.19	1.22	1.08	1.07	0.94	*0.11*	*10.12*
20	0.99	0.97	0.96	0.93	1.01	0.95	1.01	*0.04*	*3.96*
93	1.07	1.06	1.00	1.04	1.06	1.11	1.10	*0.04*	*4.09*

* Based on solution concentration, uptake and wood basic density

** Mean value of 5 analysis results along the board

The central ninth core results are summarised in Table 2 with the samples listed in ascending order of the average analysed cross-section BAE % m/m concentration. The variability in the BAE concentrations in the core analytical zone was even more pronounced than in the cross-section results. These analyses again highlight the potential difficulties with studies of this type when potential losses ideally need to be benchmarked to an unexposed reference value. The coefficients of variability for each set of treatments were typical for the low pressure, low uptake process schedule even though samples were selected to minimise heartwood content.

Analytical cross-section results were generally in agreement with the calculated BAE retentions. Difference can probably be attributed to the variability in retention along each board that are possibly influenced by variations in wood basic density, varying proportion of heartwood and differences in wood moisture content.

Table 2. Central ninth retentions (as % w/w Boric Acid Equivalent) in unexposed boards

Sample No	BAE % m/m* by analysis C /S**	1/9th core	Sample position along board 1	2	3	4	5	Std dev	CV %
6	0.27	n.d	0.10	<0.01	<0.01	<0.01	<0.01	*n.d*	*n.d*
12	0.33	n.d	0.01	<0.01	<0.01	<0.01	<0.01	*n.d*	*n.d*
13	0.37	0.03	0.02	<0.01	0.03	0.03	0.04	*0.01*	*25.93*
21	0.38	0.05	0.06	0.02	0.03	0.07	0.05	*0.02*	*45.10*
75	0.39	0.09	0.05	0.07	0.06	0.02	0.26	*0.10*	*107.02*
69	0.41	0.17	0.21	0.38	0.07	0.16	0.04	*0.13*	*79.04*
4	0.42	0.06	0.16	0.04	0.06	0.02	0.03	*0.05*	*87.25*
11	0.44	0.18	0.22	0.15	0.17	0.26	0.10	*0.06*	*34.09*
66	0.49	0.16	0.14	0.22	0.20	0.16	0.10	*0.05*	*28.26*
24	0.50	0.14	0.18	0.08	0.16	0.13	0.15	*0.04*	*29.12*
72	0.51	0.10	0.13	0.27	0.03	0.05	0.03	*0.10*	*102.62*
75	0.69	0.16	0.05	0.19	0.34	0.13	0.07	*0.12*	*74.48*
31	0.78	0.56	0.56	0.55	0.61	0.63	0.44	*0.07*	*13.08*
19	0.79	0.34	0.33	0.16	0.88	0.07	0.26	*0.32*	*92.79*
23	0.79	0.12	0.04	0.24	0.23	0.03	0.03	*0.11*	*95.62*
32	0.80	0.08	0.06	0.09	0.10	0.08	0.05	*0.02*	*27.85*
117	0.89	0.16	0.29	0.16	0.15	0.11	0.06	*0.09*	*54.48*
20	0.97	0.35	0.39	0.22	0.41	0.25	0.48	*0.11*	*31.43*
93	1.06	1.02	0.90	1.01	1.03	1.11	1.06	*0.08*	*7.62*
53	1.10	0.24	0.56	0.27	0.29	0.06	0.03	*0.21*	*88.36*

n.d = not determined

* Mean value of 5 analytical results taken along the board

** Timber cross-section (from Table 1)

3.3 Results for water irrigated samples

3.3.1 Moisture content

The application of 100 g water/linear metre timber equivalent was sufficient to gradually increase the mean timber moisture content and to overcome any external drying effects of the laboratory environment (Table 3). The moisture content of the cross-section and surface edge zone were at fibre saturation or higher at 56 days (~ 2 months). The moisture contents of the central ninth core had a wider range of values for the duration of this study.

Table 3: Overall average % moisture content (and %moisture content range) for all boron-treated samples as determined by oven-drying method

Days exposed	Cross-section	Central 1/9th core	Surface (edge)
0	9.9 [9.2 – 10.7]	8.9 [7.8 – 9.3]	8.8 [8.1 – 9.1]
23	23.1 [15.1 – 29.6]	14.7 [12.6 – 19.8]	21.3 [15.0 – 26.6]
56	38.4 [29.5 – 45.7]	22.0 [17.0 – 36.6]	39.4 [25.7 – 50.7]
84	46.7 [37.3 – 53.4]	26.8 [14.3 – 38.9]	45.4 [40.9 – 55.0]
182	50.9 [44.2 – 55.8]	38.6 [24.4 – 47.2]	54.7 [51.3 – 61.3]
261	48.5 [38.8 – 57.0]	34.6 [21.5 – 56.4]	55.4 [47.1 – 63.3]
365	52.4 [42.9 – 60.7]	39.2 [21.5 – 56.4]	58.3 [54.1 – 62.7]
548	55.0 [43.4 – 67.5]	40.7 [22.3 – 66.4]	59.6 [55.4 – 67.1]

3.3.2 Boron concentrations in timber

The results for each of the 20 sample boards are provided in Appendix A. The target BAE retentions were 0.40% m/m BAE and 0.80% m/m BAE for the B and C series respectively and were chosen to correspond to the approved boron retentions for hazard classes H1.2 and H3.1 in the New Zealand Timber Treatment Standard NZS 3640 (2003). These boards were treated with the 3.08% w/v and 6.01% w/v BAE solutions respectively.

The BAE ratio for the cross-section: core: surface zone analysed, was also calculated (Appendix A). Over time there was trend for the cross-section: core ratio to improve. Examples were samples B2, B8, B41, B82, B105, C10, C24, C52, C87, C92, C109, C110 and C112.
This indicates that as the timber wetted up there was diffusion and redistribution of the boron within the cross-section.

Some sample results indicated there was depletion of boron from the surface zone. This was either by diffusion deeper into the cross-section or as a loss from the cross-section. Examples were B2, B8, B34, B35, B68, B105, C10, C52, C54 and C110.

The average BAE concentration in the timber cross-section for the H1.2 and H3.1 series and the range of values for each series and at each sampling time (days of leaching) is shown in Figure 8. This graph shows a drop off in boron concentration in the 0.8% m/m treatment series in the first ~200 days period and then an evening out of remaining BAE concentrations out to 548 days and final sampling. The 0.4% m/m treatment series also had a drop off in boron concentration but the loss appeared to be less than the higher treatment series. However when the boron concentrations results were graphed on a log scale (Fig. 11) both boron series were more similar.

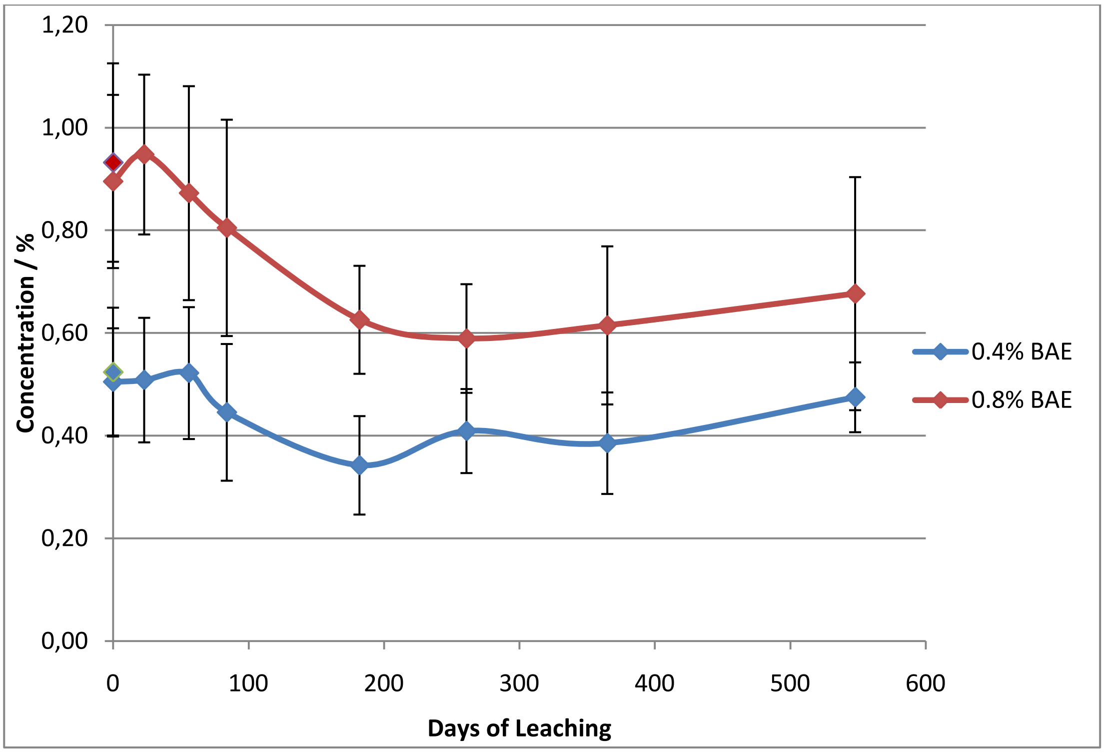

Figure 10. Comparison of 0.40% m/m BAE (H1.2) and 0.80% m/m BAE (H3.1) results over 548 days exposure to wetting and non-drying conditions

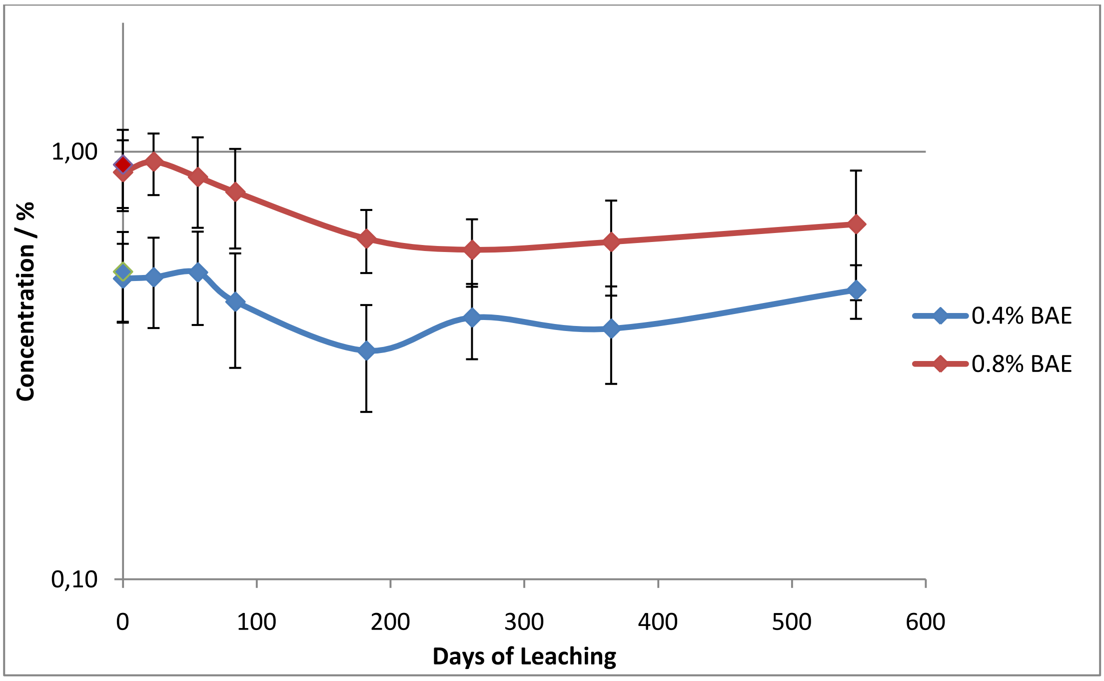

Figure 11. Comparison of 0.40% m/m BAE (H1.2) and 0.80% m/m BAE (H3.1) results over 548 days exposure to wetting and non-drying conditions using a log scale (for BAE concentration)

5. CONCLUSIONS

The methodology developed was successful in reproducing a scenario where a leak event through the cladding system occurs and the bottom plate of timber framing develops and maintains a moisture content above fibre saturation at levels suitable for fungal decay to develop.

The application of 100 g water per linear metre of timber every four days was sufficient to achieve these moisture levels.

The study also showed the initial boron distribution after treatment varied along boards and with cross-section gradient, and from piece to piece. Over time the boron redistributed within the cross-section. The application of water over a surface also caused some redistribution or depletion of the boron concentration from this zone.

The overall trend was for a reduction in average % m/m BAE of approximately 30% over the first 6-8 months of the testing then the BAE levels levelled off (or increased).

6. ACKNOWLEDGEMENTS

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APPENDIX A

Summary of boric acid equivalent concentrations (expressed as BAE %w/w) for 20 sample boards analysed at 3 sampling positions at each exposure period.

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X- section	Core	Surface	X-section : Core: Surface
B/2	0	0.42	0.15	0.48	1 : 0.36 : 1.14
B/2/C	23	0.45	0.13	0.44	1 : 0.28 : 0.98
B/2/D	56	0.52	0.31	0.51	1 : 0.60 : 0.98
B/2/E	84	0.30	0.16	0.28	1 : 0.53 : 0.95
B/2/F	182	0.49	0.48	0.39	1 : 0.98 : 0.80
B/2/G	261	0.45	0.37	0.42	1 : 0.82 : 0.93
B/2/H	365	0.41	0.41	0.41	1 : 1 : 1
B/2/I	548	0.52	0.37	0.33	1 : 0.71 : 0.63

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X-section	Core	Surface	X-section : Core: Surface
B/8	0	0.53	0.18	0.60	1 : 0.34 : 1.13
B/8/C	23	0.57	0.15	0.48	1 : 0.26 : 0.84
B/8/D	56	0.67	0.43	0.34	1 : 0.64 : 0.50
B/8/E	84	0.43	0.39	0.31	1 : 0.90 : 0.72
B/8/F	182	0.35	0.32	0.32	1 : 0.91 : 0.91
B/8/G	261	0.35	0.32	0.31	1 : 0.91 : 0.88
B/8/H	365	0.25	0.25	0.25	1 : 1 : 1
B/8/I	548	0.30	0.27	0.25	1 : 0.90 : 0.83

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X- section	Core	Surface	X-section : Core: Surface
B/34	0	0.51	0.50	0.42	1 : 0.98 : 0.82
B/34/C	23	0.50	0.33	0.34	1 : 0.66 : 0.68
B/34/D	56	0.50	0.26	0.29	1 : 0.52 : 0.58
B/34/E	84	0.36	0.35	0.24	1 : 0.97 : 0.67
B/34/F	182	0.19	0.20	0.19	1 : 1.05 : 1
B/34/G	261	0.34	0.29	0.25	1 : 0.85 : 0.74
B/34/H	365	0.33	0.33	0.33	1 : 1 ; 1
B/34/I	548	0.31	0.25	0.21	1 : 0.81 : 0.68

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/35	0	0.75	0.77	0.78	1 : 1.03 : 1.04
B/35/C	23	0.76	0.62	0.56	1 : 0.82 : 0.74
B/35/D	56	0.77	0.81	0.61	1 : 1.05 : 0.79
B/35/E	84	0.68	0.58	0.59	1 : 0.85 : 0.87
B/35/F	182	0.42	0.43	0.34	1 : 1.02 : 0.81
B/35/G	261	0.50	0.52	0.32	1 : 1.04 : 0.64
B/35/H	365	0.41	0.41	0.41	1 : 1 : 1
B/35/I	548	0.39	0.31	0.31	1 : 0.79 : 0.79

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/41	0	0.36	<0.01	0.45	1 : 0 : 1.25
B/41/C	23	0.33	0.03	0.38	1 : 0.09 : 1.15
B/41/D	56	0.36	0.12	0.49	1 : 0.33 : 1.36
B/41/E	84	0.32	0.20	0.36	1 : 0.63 : 1.13
B/41/F	182	0.21	0.21	0.21	1 : 1 : 1
B/41/G	261	0.32	0.30	0.31	1 : 0.94 : 0.97
B/41/H	365	0.28	0.28	0.28	1 : 1 : 1
B/41/I	548	0.29	0.25	0.32	1 : 0.86 : 1.10

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/68	0	0.48	0.06	0.59	1 : 0.13 : 1.23
B/68/C	23	0.47	0.16	0.53	1 : 0.34 : 1.13
B/68/D	56	0.42	0.33	0.35	1 : 0.79 : 0.83
B/68/E	84	0.48	0.45	0.33	1 : 0.94 : 0.69
B/68/F	182	0.33	0.32	0.27	1 : 0.97 : 0.82
B/68/G	261	0.36	0.32	0.30	1 : 0.89 : 0.83
B/68/H	365	0.46	0.46	0.46	1 : 1 : 1
B/68/I	548	0.73	0.61	0.43	1 : 0.84 : 0.59

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/82	0	0.51	0.21	0.63	1 : 0.41 : 1.24
B/82/C	23	0.57	0.37	0.49	1 : 0.65 : 0.86
B/82/D	56	0.49	0.35	0.44	1 : 0.71 : 0.90
B/82/E	84	0.60	0.52	0.51	1 : 0.87 : 0.85
B/82/F	182	0.38	0.35	0.34	1 : 0.92 : 0.89
B/82/G	261	0.42	0.36	0.33	1 : 0.86 : 0.79
B/82/H	365	0.46	0.46	0.46	1 : 1 : 1
B/82/I	548	0.75	0.43	0.42	1 : 0.57 : 0.56

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/97	0	0.56	0.45	0.65	1 : 0.80 : 1.16
B/97/C	23	0.52	0.40	0.50	1 : 0.77 : 0.96
B/97/D	56	0.62	0.48	0.57	1 : 0.77 : 0.92
B/97/E	84	0.58	0.51	0.55	1 : 0.88 : 0.95
B/97/F	182	0.35	0.38	0.50	1 : 1.09 : 1.43
B/97/G	261	0.47	0.37	0.68	1 : 0.79 : 1.45
B/97/H	365	0.42	0.42	0.42	1 : 1 : 1
B/97/I	548	0.43	0.57	0.34	1 : 1.33 : 0.79

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/105	0	0.44	0.24	0.58	1 : 0.55 : 1.32
B/105/C	23	0.36	0.18	0.37	1 : 0.50 : 1.03
B/105/D	56	0.40	0.30	0.32	1 : 0.75 : 0.80
B/105/E	84	0.34	0.35	0.23	1 : 1.03 : 0.68

B/105/F	182	0.43	0.44	0.30	1 : 1.02 : 0.70
B/105/G	261	0.56	0.47	0.49	1 : 0.84 : 0.88
B/105/H	365	0.48	0.48	0.48	1 : 1 : 1
B/105/I	548	0.72	0.61	0.37	1 : 0.85 : 0.51

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
B/114	0	0.50	0.49	0.40	1 : 0.98 : 0.80
B/114/C	23	0.54	0.13	0.41	1 : 0.24 : 0.76
B/114/D	56	0.47	0.11	0.33	1 : 0.23 : 0.70
B/114/E	84	0.37	0.28	0.30	1 : 0.76 : 0.81
B/114/F	182	0.27	0.18	0.19	1 : 0.67 : 0.70
B/114/G	261	0.32	0.31	0.25	1 : 0.97 : 0.78
B/114/H	365	0.36	0.36	0.36	1 : 1 : 1
B/114/I	548	0.31	0.37	0.29	1 ; 1.19 : 0.94

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/10	0	0.84	0.18	1.10	1 :1.21 : 131
C/10/C	23	0.97	0.41	1.01	1 : 0.42 : 1.04
C/10/D	56	0.79	0.46	0.84	1 : 0.58 : 1.06
C/10/E	84	0.64	0.50	0.58	1 : 0.78 : 0.91
C/10/F	182	0.52	0.42	0.37	1 : 0.81 : 0.71
C/10/G	261	0.52	0.41	0.51	1 : 0.79 : 0.98
C/10/H	365	0.38	0.33	0.27	1 : 0.87 : 0.71
C/10/I	548	0.45	0.44	0.31	1 : 0.98 : 0.69

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/21	0	1.15	0.84	1.11	1 : 0.73 : 0.97
C/21/C	23	1.28	0.96	1.32	1 : 0.75 : 1.03
C/21/D	56	1.27	0.81	1.01	1 ; 0.64 : 0.80
C/21/E	84	1.26	1.20	0.96	1 : 0.95 : 0.76
C/21/F	182	0.71	0.66	0.51	1 : 0.93 : 0.72
C/21/G	261	0.64	0.65	0.62	1 ; 1.01 : 0.97
C/21/H	365	0.67	0.49	0.52	1: 0.73 : 0.78
C/21/I	548	0.61	0.57	0.56	1 : 0.93 : 0.92

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/24	0	0.92	0.42	0.85	1 : 0.46 : 0.92
C/24/C	23	1.01	0.30	0.82	1 : 0.30 : 0.81
C/24/D	56	1.05	0.39	0.95	1 : 0.37 : 0.90
C/24/E	84	0.94	0.50	0.78	1 : 0.53 : 0.83
C/24/F	182	0.76	0.59	0.88	1 : 0.78 : 1.16
C/24/G	261	0.71	0.60	0.91	1 : 0.85 : 1.28
C/24/H	365	0.90	0.58	0.79	1 : 0.64 : 0.88
C/24/I	548	0.81	0.85	0.89	1 : 1.05 : 1.10

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/52	0	0.68	0.23	0.95	1 : 0.34 : 1.40
C/52/C	23	0.87	0.40	1.03	1 : 0.46 : 1.18
C/52/D	56	0.64	0.58	0.57	1 ; 0.91 : 0.89
C/52/E	84	0.78	0.69	0.63	1 : 0.88 : 0.81
C/52/F	182	0.79	0.64	0.53	1 : 0.81 : 0.67
C/52/G	261	0.76	0.77	0.67	1 : 1.01 : 0.88
C/52/H	365	0.75	0.61	0.54	1 : 0.81 : 0.72
C/52/I	548	1.18	0.84	0.75	1 : 0.71 : 0.63

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/54	0	0.81	0.61	0.95	1 : 0.75 : 1.17
C/54/C	23	0.84	0.53	1.08	1 : 0.63 : 1.29
C/54/D	56	0.68	0.76	0.69	1 : 1.12 : 1.01
C/54/E	84	0.51	0.28	0.54	1 : 0.55 : 1.06
C/54/F	182	0.54	0.43	0.44	1 : 0.80 : 0.81
C/54/G	261	0.46	0.46	0.52	1 : 1 : 1.13
C/54/H	365	0.52	0.47	0.44	1 : 0.90 : 0.85
C/54/I	548	0.71	0.52	0.52	1 : 0.73 : 0.73

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/87	0	0.92	0.13	1.29	1 : 0.14 : 1.40
C/87/C	23	0.93	0.10	1.17	1 : 0.11 : 1.26
C/87/D	56	1.03	0.65	0.69	1 : 0.63 : 0.67
C/87/E	84	0.76	0.67	0.71	1 : 0.88 : 0.93
C/87/F	182	0.62	0.58	0.52	1 : 0.94 : 0.84
C/87/G	261	0.63	0.60	0.56	1 : 0.95 : 0.89
C/87/H	365	0.62	0.44	0.48	1 : 0.71 : 0.77
C/87/I	548	0.64	0.49	0.59	1 : 0.77 : 0.92

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/92	0	1.04	0.31	1.14	1 : 0.30 : 1.10
C/92/C	23	1.06	0.70	1.22	1 : 0.66 : 1.15
C/92/D	56	0.97	0.82	0.83	1 : 0.85 : 0.86
C/92/E	84	0.93	0.95	0.72	1 : 1.02 : 0.77
C/92/F	182	0.66	0.69	0.60	1 : 1.05 : 0.91
C/92/G	261	0.56	0.56	0.65	1 ; 1 : 1.16
C/92/H	365	0.52	0.41	0.35	1 : 0.79 : 0.67
C/92/I	548	0.69	0.64	0.60	1 : 0.93 : 0.87

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/109	0	0.61	0.01	0.92	1 : 0.01 : 1.51
C/109/C	23	0.68	0.16	0.81	1 : 0.24 : 1.19
C/109/D	56	0.68	0.47	0.67	1 : 0.69 : 0.99
C/109/E	84	0.62	0.29	0.56	1 : 0.47 : 0.90

C/109/F	182	0.49	0.46	0.39	1 ; 0.94 : 0.80
C/109/G	261	0.44	0.36	0.34	1 : 0.82 : 0.77
C/109/H	365	0.44	0.34	0.32	1 : 0.77 : 0.73
C/109/I	548	0.46	0.38	0.40	1 : 0.83 : 0.87

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/110	0	1.07	0.58	1.01	1 ; 0.54 : 0.94
C/110/C	23	0.97	0.45	0.97	1 : 0.46 : 1
C/110/D	56	0.92	0.74	0.75	1 : 0.80 : 0.82
C/110/E	84	0.87	0.66	0.61	1 : 0.76 : 0.70
C/110/F	182	0.64	0.60	0.46	1 : 0.94 : 0.72
C/110/G	261	0.66	0.60	0.47	1 : 0.91 : 0.71
C/110/H	365	0.69	0.68	0.47	1 : 0.99 : 0.68
C/110/I	548	0.42	0.45	0.36	1 : 1.07 : 0.86

Sample	Exposure (days)	BAE % (w/w)			BAE Ratio
		X Section	Core	Surface	X-section : Core: Surface
C/112	0	0.91	0.62	0.91	1 : 0.68 : 1
C/112/C	23	0.88	0.03	0.93	1 : 0.03 : 1.06
C/112/D	56	0.70	0.53	0.54	1 : 0.76 : 0.77
C/112/E	84	0.74	0.66	0.64	1 : 0.89 : 0.86
C/112/F	182	0.53	0.48	0.64	1 : 0.91 : 1.21
C/112/G	261	0.52	0.49	0.51	1 : 0.94 : 0.98
C/112/H	365	0.67	0.54	0.51	1 : 0.81 : 0.76
C/112/I	548	0.82	0.76	0.77	1 : 0.93 : 0.94