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Leaching from Instream Structures

THIS DOCUMENT PRESENTS THE FINDINGS OF RESEARCH REGARDING THE TREATMENT OF MATERIALS USED IN WATERWAYS, AND THE USERS AWARENESS OF THEIR ENVIRONMENTAL EFFECTS.

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Abstract

There is concern regarding the state of freshwater in Aotearoa, which is thought to be at risk. There are a number of stressors that impact freshwater quality and quantity, and subsequently endanger the habitats and wellbeing of aquatic species. This research sought to investigate one such stressor; leachates that are potentially released from materials used in instream structures. The materials investigated in this research were chromated copper arsenate (CCA) treated timber, galvanised steel, and concrete. Using qualitative interviews of suppliers and contractors for Christchurch City Council works, this research aimed to understand, firstly, the user's awareness of the potential adverse effects from leaching on aquatic biota; secondly, what methods are used by industry to prevent leaching; and finally, whether the recommendations regarding the use of the materials were achievable to implement. Overall, there was general understanding in the industry about the potential environmental leaching effects of the materials. It was also found that several recommended precautions, are currently already in practice to prevent leaching. However, is it concluded that timber fixation should be incorporated into New Zealand standards, and that further awareness of proper timber fixation should be raised, if leaching is to be prevented from CCA treated timber. Further precautions to prevent leaching do not appear to be necessary for the use of galvanised steel. The use of concrete by large companies follows strict industry protocol that is considered to be standard practice, which would help limit leaching from this material. The soaking of timber and concrete, which was recommended in the literature, would be the most difficult for industry to achieve. Based on the procedures already in place to reduce leaching, as described by participants, more information is required as to whether soaking is required for these two materials. Finally, the research highlighted the importance of considering the impacts of the entire life-cycle of each material, and how critical it is to use materials in the correct application.

1.0 Introduction

It is well known in Aotearoa that fresh and saltwater environments face various stressors and are arguably, in a poor condition. Water characteristics and quality vary considerably across the country. They change as a response to the landscape, climate, population, and catchment use (Environment Foundation, 2018; Ministry for the Environment, 1997). Whilst the quality and quantity of freshwater has continued to decline (Freshwater Independent Advisory Panel, 2020; Ministry for the Environment, 2020); the quality of saltwater environments overall has improved (Ministry for the Environment, 2019).

Key stressors on Aotearoa's waterways include nutrients, pathogens, sediment, organic matter, other pollutants and saltwater intrusion (Environment Foundation, 2018). Due to the variables that influence water quality, such as catchment use, there is subsequent variability between pollutants concentrations across most sites. And so, for example in coastal and estuarine environments, whilst some stressors are generally improving in most locations (e.g. 'Total phosphorus' layer), some stressors are certainly worsening (e.g. 'Dissolved oxygen' layer) (Ministry for the Environment, n.d.).

Research and projects are undertaken countrywide to better understand the extent of various stressors and pollutants, and to reduce their impacts. But few projects focus on the effects of leaching from instream structures. Instream structures include, but are not limited to, waterway linings, retaining walls, utility holes, gates, bridges, and culverts. They are more commonly used in urban environments to manage water movement around civilisation.

Lowland and subsequent urban environments already act as a sink point for many stressors on waterways (Environment Foundation, 2018; Larned, Scarsbrook, Snelder, Norton, & Biggs, 2004). Considering that instream structures are more commonly found in the urban and lowland environments, it is important to consider what impact the use of the materials for these structures have on waterways in these areas. The main concerns regarding leaching from instream structures are heavy metals and an increase in pH to an alkaline state, which can have toxic effects on aquatic life (Marshall & Margetts, 2020).

Many sites within Christchurch urban waterways do not meet the relevant guideline levels for metals that may leach from instream structures. For example, 23 out of 42 sites did not meet the guideline level for copper during 2019 (Margetts & Marshall, 2020). For zinc, 18 out of 42 sites in Christchurch urban waterways did not meet the relevant guidelines in 2019 (Margetts & Marshall, 2020). Although arsenic and chromium, which are of particular relevance to chromated copper arsenate (CCA), are generally not recorded in Christchurch waterways, there are potentially localised discharges of these contaminants in the proximity of structures (Dr Belinda Margetts, Christchurch City Council, *personal communication*, January 2021). Although these metal contaminants may come from other sources, such as stormwater, these values still suggest that investigation into leaching from instream structures is important.

A literature review (see Appendix A), completed by Marshall and Margetts (2020) to support this research, focused on the effects of associated leaching from three of the most commonly used materials for instream structures. These materials are, CCA treated timber, galvanised steel, and concrete. External processes also take place with these materials on structures outside of the water, such as contact with atmospheric carbon dioxide on galvanised roofs (Portella et al., 2012). But because the project's focus was on leaching within the waterway, the literature review excluded these papers. This report now summarises the findings of the literature review completed by Marshall and Margetts (2020).

1.1 Chromated Copper Arsenate (CCA) Treated Timber

The literature review identified 38 articles that looked at either leaching alone and/or adverse effects on biota from CCA timber. The studies were completed in various locations that included the USA, Germany, Sweden, Canada, Ireland, the UK, Hong Kong and India.

Hingston, Collins, Murphy, and Lester (2001) argue that accurate quantification of leaching rates from CCA timber cannot be made due to insufficient data. Others argue that CCA treated timber presents little hazard to waterways (Brooks 1993 as cited in Hedley, 1997) and Hedley (1997) suggested that, although freshly treated timber does leach, properly fixed[1] timber does not contribute significantly to background concentrations of heavy metals. This aside, there is ample field research which demonstrates that CCA timber leaches into the aquatic environment, with the highest assimilation rate by biota being of copper, followed by arsenic and then chromium (Weis & Weis, 1992b, 1993; Weis, Weis, & Couch, 1993; Weis, Weis, & Lores, 1993). The chemistry of water in Canterbury potentially provides ideal conditions to enable leaching of chromium and arsenic, but not necessarily copper (Marshall & Margetts, 2020; Marshall & Noakes, 2019).

Not only was leaching into the water column found to be an issue, Rice, Conko, and Hornberger (2002); Weis, Weis, and Proctor (1993); Wendt, Van Dolah, Bobo, Mathews, and Levison (1996) all demonstrated that metals leached from CCA treated timber could also accumulate in sediment. As a result leaching from CCA treated timber was found to have negative impacts on a range of biota such as algae, fiddler crabs and fish (Weis & Weis, 1992a, 1992b; Weis, Weis, & Coohill, 1991; Weis, Weis, & Couch, 1993; Weis, Weis, Couch, Daniels, & Chen, 1995; Weis, Weis, Greenberg, & Nosker, 1992; Wendt et al., 1996). Leaching also affected fertilisation and the development of larvae for some species, possibly damages species DNA, and in some cases resulted in mortality (Sreeja, 2008; Weis et al., 1991; Weis, Weis, & Couch, 1993; Weis et al., 1995). The potential for the effects to result in trophic transfer is still unclear (Chan, Wang, & Ni, 2003; Weis & Weis, 1992b, 1993, 1999), but leaching from timber in concentrated areas led to a lowered species richness, diversity, and abundance overall (Weis & Weis, 1992a).

Although studies varied in their conclusions, several factors were found to influence the rates of leaching. These were: "pH, temperature, salinity, surface-area-to-volume ratio, fixation method, quality of wood, time since fixation, and flushing of water in the environment" (Marshall & Margetts, 2020, p. 2). Marshall and Margetts (2020) conclude that coastal waters pose the most potential for leaching, "followed by estuarine environments and then freshwater" (p. 2). In particular the literature suggested that leaching could be reduced if timber were soaked for some time prior to use (Weis & Weis, 1994). This was based on the findings that leaching from CCA treated timber reduced over time.

1.2 Galvanised Steel

The literature review identified four studies that looked at the corrosion from galvanised steel in water. Most of them were laboratory studies and were undertaken in Turkey, Italy, South Africa, and South America.

The durability and resistance potential of galvanised steel means that it is commonly used for construction (Ilhan-Sungur, Cansever, & Cotuk, 2007). The literature review, however, demonstrated that there is currently limited data and research regarding the corrosion potential from instream structures made of galvanised steel.

Galvanised steel is a mild steel that has been coated with zinc. The zinc coating is used to add a cathodic layer of protection to increase resistance to corrosion (Steel, n.d.). Bednar's (1989) research concluded that corrosion potential was somewhat dependent on water hardness. Therefore, Marshall and Margetts (2020) infer that the chemistry makeup or hardness of the water in Canterbury, is likely to be of sufficient levels to resist corrosion. But they also suggest that in areas where the water is not of sufficient chemistry, there may be a potential for zinc contamination into the waterway.

Based on the findings in the literature where galvanised steel is used with H5 and H6 class timber, pre-soaking of the timber may reduce the corrosion of galvanised steel (Baker, 1992; Kear, Wú, & Mark, 2009; Marshall & Margetts, 2020; Zelinka, Sichel, & Stone, 2010). Furthermore, the review also found that the rate of leached zinc sulphide may increase when galvanised steel is exposed to anoxic sediment (Costello, 1974; Ilhan-Sungur et al., 2007). Other than avoiding the use of galvanised steel in anoxic sediment altogether, the review does not make any suggestions for how leachates may otherwise be reduced or avoided, as these structures are not considered to pose an environmental risk when used in a suitable environment.

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[1] Fixation: where timber is appropriately stored to enable copper chromated arsenate to adhere and fix to the timber cells (Red Stag Timber, n.d.). This should take place before use of the timber and aims to prevent the leaching of contaminants (New Zealand Timber Preservation Council, n.d.-a).

1.3 Concrete

The literature identified four studies that looked at leaching from concrete in waterways. Most of them were laboratory studies and were conducted in Sweden, Australia, and Turkey.

Due to the release of calcium hydroxide, the increase of water pH is the most common concern and risk associated with concrete (Taylor, 1997, as cited in Setunge, Nguyen, Alexander, & Dutton, 2009). Factors that influence the alkalinity in regards to concrete include the velocity of water in contact with the surface, the period of time that the concrete had been exposed to the water, the aggressiveness of the water, the freshness of the concrete cast and chemistry makeup of the water (Ekström, 2003; Law, Dutton, Adamson, & Setunge, 2013; Setunge et al., 2009).

The review also found that nickel, zinc and chromium are associated with various concrete types and that there was a positive relationship between the leaching of these material and water acidity (Basar & Aksoy, 2012). Marshall and Margetts (2020) suggest that considering the pH level of Canterbury waterways, there is a potential for the leaching of zinc and chromium to occur.

1.4 Objectives

The literature review recommended various methods and precautions that could be undertaken to reduce leaching and environmental effects on water, but if, and to what extent these methods are practised is currently unknown. The additional research that was suggested in the review included a survey to better understand the current practices within the industry, and an assessment of how difficult it would be to implement the literature review recommendations. Therefore, this summer student research sought to survey industry stakeholders to understand what precautions contractors who install instream structures are using, and what methods are used to prepare the materials prior to supply. It also sought to determine the user's awareness of environmental damage from such materials, and how achievable the recommendations from the literature review were deemed to be. The following objectives for this summer research project were developed, and the interview guide structured to answer each one:

1. How aware are individuals of the potential adverse effects on biota due to leaching from CCA treated timber, galvanised steel, and concrete structures within waterways?
2. What methods are currently used to prevent leaching from CCA treated timber, galvanised steel, and concrete structures within waterways?
3. How difficult would it be to achieve the recommendations in the literature review to reduce leaching of CCA treated timber, galvanised steel, and concrete?

2.0 Method

2.1 Location and Time of Study

The research was commissioned by the Christchurch City Council, and a summer student from the Lincoln University completed the project under supervision. The project also had to be conducted between November 2020 and February 2021, which presented the following barriers:

- Time and budget limitations meant that the researcher could not travel to other parts of the country to collect data.
- Requesting the details of contractors and suppliers used by other councils in different locations would have been variable and time-consuming.

Although the research was initially intended to be completed nationwide, due to the barriers listed above, participants were narrowed down to include contractors of the Christchurch City Council only. The results of the research may, therefore, only be representative of the Christchurch City Council work programmes.

2.2 Project Design

It was felt that in-depth, detailed, and variable responses were needed from the relatively small sample size of participants to sufficiently address the objectives. Therefore, a qualitative design was deemed suitable for the research questions, setting and context of the research. The qualitative interview guide enabled the delivery of semi-structured interviews with open-ended questions. The qualitative style of data collection allowed flexibility about the discussion of CCA treated timber, galvanised steel, and concrete. It allowed the participants to expand on their thoughts and give detail they may have otherwise thought not relevant if answering a questionnaire. It also allowed for a relationship and trust to build between the interviewee and participant; this was helpful as some of the questions were sensitive, such as company practices, and these questions required caution when asked. The semi-structured nature of the application also allowed the interviewer to expand on, or even ask new questions, if the participant said something that warranted further investigation.

The disadvantage of using a qualitative style is that the representativeness of the data is limited due to the small sample size (Ochieng, 2009). Data analysis is complex and time consuming for many reasons, such as the vast quantity of in-depth data produced from the interviews (Newton Suter, 2012). In some cases, parts of the questions were contentious which presented challenges in keeping the participant engaged in the intended outcome.

Regardless, a qualitative style was still deemed to be the best approach. The interview guide was piloted once, and feedback was sought from an academic expert. The questions went through a final stage of amendments and the final interview guide can be seen in Appendix B. The project was then granted Human Ethics Approval by the Lincoln University Human Ethics Committee (Application 57).

The interview guide was divided into five themes: 1) background information on participants; 2) questions relating to CCA treated timber; 3) questions relating to galvanised steel; 4) questions relating to concrete; 5) catch-all questions. Interviews lasted approximately 30 minutes, and participants were asked questions that related to the materials that they used. For example, manufacturers of concrete were only asked the questions from Themes 1, 4 and 5.

Questions that asked directly about the effects of the materials on the environment were thought to be sensitive and ethically unjust to ask. Therefore, these questions were drafted to ask if the participant knew of any issues or problems with using the material in general.

To sufficiently address the project objectives, the following questions were asked:

<u>Objective 1:</u> How aware are individuals of the potential adverse effects on biota due to leaching from CCA treated timber, galvanised steel, and concrete structures within waterways?

The same questions were asked in Themes 2, 3 and 4. The aim was to tease out whether participants were aware of any issues or problems associated with each material. Questions of relevance were 16, 23, and 32 (see Appendix B).

These questions were open-ended, so that the participant did not feel led to answer in any particular way (e.g., by answering with the environment in mind). In questions 17, 24 and 33, the participants were given the same list of topics. They were asked to identify the top three, if any, that they felt were challenges faced when using the material in question, 'environmental protection' was one of the options. This question was designed to see how highly the thought of 'environmental protection' ranked in comparison to the other options. In Theme 5, participants were asked how they thought the leaching of contaminants could be prevented regarding any of the materials discussed. The aim of the question was to give the participants the breadth to discuss anything they wished about environmental protection from the use of the materials.

Objective 2: What methods are currently used to prevent leaching from CCA treated timber, galvanised steel, and concrete structures within waterways?

To sufficiently answer this objective, the questions needed to be open-ended to allow for varying details, but they differed in each Theme. In Theme 2, questions 6 – 11 were designed to gather in-depth data on how contractors use the different classes of CCA treated timber and why, what methods are used to prepare it either at the production stage or on-site, and what relevant guidelines are adhered to regarding timber in the industry. In Theme 3, questions 19 and 20 were designed to find out about the precautions that are taken around using galvanised steel, in or around waterways and with other materials. The questions did not need to enquire about the production process of galvanised steel because this was not identified as a concern in the literature review (Marshall & Margetts, 2020). In Theme 4, questions 26, 27 and 29 were designed to explore what precautions users and suppliers of concrete take when using it this material, and what methods they use to prepare the material, with specific attention on wet concrete, concrete wash, and dust around waterways.

Objective 3: How difficult would it be to achieve the recommendations in the literature review to reduce leaching of CCA treated timber, galvanised steel, and concrete?

The same questions were asked throughout Themes 2, 3 and 4. Questions 12, 14, 15, 21, 22, 28, 30 and 31, were designed to find out how the user or supplier might implement the recommendations from the literature review, and what barriers might exist to achieving them. These questions were open-ended so that the participant had the flexibility to think about the materials and methods that would be required for implementation (e.g., 'the soaking of concrete'), and for them to be able to identify the challenges that would be associated with the recommendations.

2.3 Data Gathering

Key informant sampling was used to gain in-depth knowledge about the practices and procedures regarding the relevant materials (Crossham & Johanson, 2019; Lavrakas, 2008; Marshall, 1996; UCLA Center for Health Policy Research). The selection process was carried out in four steps, shown in Figure 1.

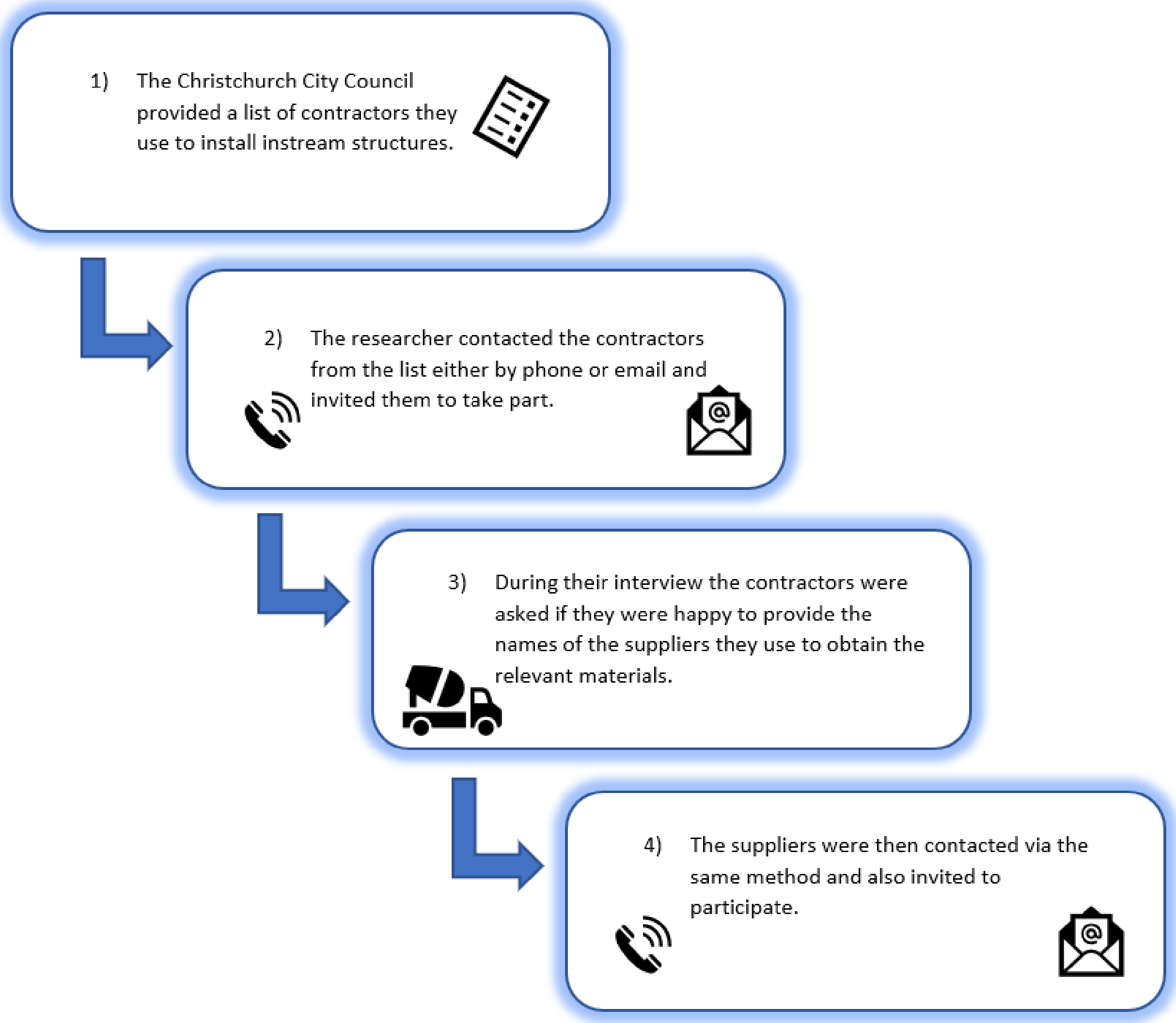

Figure 1. Selection Process

Twelve out of seventeen companies agreed to participate in the survey (a response rate of 64.7 %). Eleven interviews were conducted with thirteen participants, as two of the interviews had two participants present. Two interviews took place over the phone and nine were face-to-face. Six companies were suppliers and six were contractors. Exactly which materials they represented will not be reported, as this may breach ethical guidelines with such a small number of participants.

The criteria for participants were that they either used the materials in waterways or manufactured the material that was purchased by a user. It was essential to speak to both contractors and suppliers of the materials, as they use the products in different ways which are both relevant to the research objectives. The contractors use the material at the site of installation (i.e., in the waterway), so information was sought on what methods or precautions were used at the installation stage, and the effect of the material on the environment. Whereas the suppliers, treat and prepare the material from its raw state to a state that is ready to be used by the contractor. For example, CCA treated timber arrives at the manufacturing yard raw, and is then treated with a CCA chemical solution and various other processes before it is sold to the contractor to be used.

Ethical considerations were accounted for by asking participants to read the research information sheet before giving their consent to participate in the research. Consent prior to participation was achieved from all participants either via an online form or written form. Great caution was taken around protecting the anonymity of the participant's specific contributions from the Christchurch City Council throughout the entire research process and in the final report. Although codes were assigned to the raw data, neither pseudonyms nor codes are referred to in the reported data. All data that is reported is done so anonymously.

2.4 Data Analysis

Interviews were transcribed verbatim, printed, and then divided according to their Themes. As Themes for the data had already been determined, the interviews were coded and analysed using a deductive approach. A deductive approach is possible when there is a predetermined data analysis framework (Treasure, Chadwick, Gill, Stewart, & Burnard, 2008).

It was important for this research to keep the responses in context to each question. And so, the responses to each question have been collated and reported along with the interview guide in Appendix B. During analysis, responses that were found to be relevant to another Theme, were moved to the relevant Theme and then processed in the same way. Text that was not relevant for any Theme but important to the research was moved to a new Theme named 'other'. Responses that were crucial to an objective, but not directly relevant to any particular question were moved to the relevant objective. Once each Theme had been worked through, the objectives were addressed individually. Drawing on data from all of the Themes collectively, and any data that was not particularly relevant to a question, the responses were used to answer each Objective, 1, 2 & 3 in Section 3.0.

Since the interviewer also completed the data analysis there is a risk of bias in the reporting of the results. There is also a risk of loyalty in wishing to be protective of sensitive information that may have been shared in the raw data. These are both issues that the researcher was cognisant of throughout the data analysis and write up. The researcher has done their best to avoid reporting any bias and has sought advice where needed.

3.0 Results & Discussion

This section summarises the responses to the interviews in Appendix B, in the context of the three research objectives. Overall, it was considered that sufficient information was obtained to address each objective, although additional information for CCA treated timber would have been useful.

3.1 Objective 1:

> How aware are individuals of the potential adverse effects on biota due to leaching from CCA treated timber, galvanised steel, and concrete structures within waterways?

Responses around this topic were varied and there appeared to be great knowledge on all three materials regarding leaching and contamination of waterways. No participants actually discussed the ways in which aquatic biota could be affected itself, but many were able to discuss what the effects could be on water chemistry.

CCA Treated Timber

Contractors who used CCA treated timber demonstrated a reasonable awareness about potential leaching from the material. The level of awareness varied, and only one participant listed the names of the leachates that were potentially harmful. The contractors in general were of the understanding that as long as the correct preservation class of timber had been specified, and the timber had been prepared adequately by the supplier, that it was suitable for the determined use and subsequently presented little leaching potential.

The manufacturer of CCA treated timber who participated, was well aware of the associated leaching issues. They were certain that leaching was only an issue if the timber had not been fixed properly, or that the incorrect preservation class of timber had been used. This is in line with the research by (Hedley, 1997) and (Brooks 1993 as cited in, Hedley, 1997). The manufacturer was aware of relevant research, such as the distance that leachates might be able to spread from CCA treated timber posts. One example of their awareness was research completed by Begbie, Wright, and Rait (2018), regarding 'micro hot-spots' that immediately surround CCA treated timber posts. However, this research more specifically related to leachates in soil and groundwater, and not waterways.

Both manufacturers and contractors who use CCA treated timber, were likely unaware of exactly how the leached metals might interact with the water chemistry or affect aquatic biota. One participant's understanding was that within waterways any potential leaching that may occur, becomes "trapped in the sediment [and] it's not available to anything". Leached contaminants can accumulate in sediment, but this comment demonstrates, that the participant's awareness of potential suspended leaching in the water column may be limited or should have been enquired about further (Rice et al., 2002; Weis, Weis, & Proctor, 1993; Wendt et al., 1996).

'Environmental protection' for the use of CCA treated timber was the second most commonly raised challenge, by all participants who contributed to this Theme. Whilst the rationale for this response is unclear from Appendix B, it demonstrates that, for people who are using this material, environmental protection is something that they do consider.

Galvanised Steel

Contractors showed extensive awareness about the use of galvanised steel in the appropriate environment. Overall, they were quite certain that galvanised steel would not be the chosen material in the environments suggested in the interview. For example, the interview questions (Appendix B) implied that the use of galvanised steel would be along with H5 and H6 class timber, inferring that it would be in saltwater or estuarine environments. The contractors discussed that in most applications, stainless steel would be their material of choice to remove the risk of corrosion entirely; showing that they were aware of corrosion risks in this application. However, despite their preference of material, they were keen to point out that the decision regarding which material to use is not their own, it is instead the project designer's.

Regardless, there were still many other times when they had used galvanised steel in an appropriate environment. One contractor showed awareness of leaching because they discussed the water testing of groundwater that must be completed, after using galvanised spears to remove water. Several participants also named zinc as being the potential risk of leached or corroded material. All of the participants in this Theme seemed to be well aware that there are risks of corrosion involved with using galvanised steel, but that these were reduced in non-corrosive environments.

'Environmental protection' was named by only one participant as a challenge for the use of galvanised steel. Mostly, it was contractors who contributed to this Theme. Contractors commonly indicated that they follow the specification for a job closely, and that the specification will detail which materials to use. At the design stage of the specification, the most appropriate materials are chosen according to the environment. Since the decision regarding which material to use is therefore out of their hands, it seems reasonable to expect the contractors would not need to consider environmental protection when using galvanised steel.

Concrete

Both contractors and suppliers were confident that leaching itself is not an issue with properly cured concrete. Although they were aware that there could be a sediment issue with dust that is not suppressed on-site. There was in-depth awareness about the risk of increasing the pH level in water, but that this risk was associated with bad practice and wet concrete spills. It seemed clear that all of the participants who used concrete were knowledgeable and well informed on this issue. At least two participants went into great detail about the exact effects of concrete on the water chemistry. They were able to go into depth about how these effects can be avoided and reduced. Although they did not specifically address what the effects on aquatic biota might be if precautions were not taken, they did demonstrate awareness that there could be negative ecological effects. For example, one participant said,

> "Concrete has a high pH, in the order of pH12, which if allowed to get into the waterways [is] not good at all, it's bad. But that's when it's in a fresh state, you know. So, within our industry, it's well known and there's a whole lot of industry yes/no practices that says, 'you never discharge wet concrete into a waterway'. Because you know you will increase the pH and that will have detrimental effects on the ecology of [the] stream".

This extract is a good example and summary of the leaching awareness of concrete from participants. Overall, it was clear that the participants knew of the potential detrimental impacts that concrete could have, but that these are only an issue if concrete is not prepared, used, and disposed of according to industry-standard practice. The discussion around concrete provoked the most responses from all participants, suggesting it is a more commonly used material for the industry as a whole.

'Environmental protection' was the most commonly raised challenge for the use of concrete. Whether the participant was a supplier or manufacturer, it seemed that there were significant procedures and protocols that needed to be adhered to with the use of concrete. Therefore, it is logical that environmental protection was so commonly chosen.

3.2 Objective 2:

> What methods are currently used to prevent leaching from CCA treated timber, galvanised steel, and concrete structures within waterways?

As expected, the methods used to prevent leaching differed greatly between each material. Two methods were identified that applied to the use of all three materials. One is that of memberships to organisations and councils. Councils such as the Timber Preservation Council, Fencing Contractors Association NZ (FCANZ), the Concrete Pipe Association of Australasia (CPAA), BITCO and similar industry bodies, was said by the participants, to assist them in keeping up to date with legislation change and to ensure that they are following industry best practice. A second method is that sometimes the job specifications also specify which supplier is to be used. This highlights that preparation and treatment may slightly differ across suppliers and therefore, this is another method used to prevent leaching, but is one that is made at the design stage of a project.

CCA Treated Timber

In regard to CCA treated timber and the user, the data showed that it is common practice to ensure that the correct H class of treated timber is used in each application. There was a clear understanding from both contractors and manufacturers that the different grades of treated timber were suitable for certain environments only (e.g., H6 class timber is the most suitable for a marine environment).

Contractors were not entirely knowledgeable of the methods that are used to prepare timber at the manufacturing yard, and they are not required to undertake many other methods on-site. The contractors are under the impression that the timber purchased for the job meets the requirements of the specifications. They also assume that it has been prepared according to the relevant standards and guidelines in the industry. Apart from ordering what they believe to match the material in the job specifications, the only other method that they use to prevent leaching is the retreating of cut timber on-site. Retreating is done by spraying or painting a sealant over the new and exposed cut surface.

Prior to arrival at the construction site, the timber undergoes a methodical process to prevent leaching. There are several treatment steps that include peeling, steaming, cooling, and submerging in a CCA chemical solution. After this preparation, heat fixation and Merck tests are used in the final stage, to ensure that the timber is ready to be used in the appropriate environment. Fixation and Merck testing are standard procedure for the manufacturer in this project, but it cannot be determined whether this is representative of the industry as a whole. Fixation is a method that is used to ensure that the chemicals in the CCA treatment, have adhered and secured properly inside the timber cell structure (Cooper & Ung, 1993). If completed properly, this stage has been shown to prevent the leaching of contaminants into the waterway (Hedley, 1997). For the manufacturer of timber in this project, fixation was said to be an absolutely crucial step, and Merck tests are completed periodically or when required, to ensure that fixation has occurred and is consistent. As they have a standard treatment procedure that is followed every time, Merck tests are no longer required to test every piece of treated timber. The participants had heard of experiences in the wider industry where fixation may not have been completed, which reiterates that this data may not be representative of other manufacturers. It also demonstrates the importance of ensuring that purchased timber is properly fixed, or at least, is purchased from an accredited and trademarked supplier from a licensed industry body (e.g., a WOODmark® licensed plant).

Although the contractors pointed out that they are not responsible for deciding which material is to be used, when asked, they said that they would question the designer if they thought that the incorrect material had been specified. One contractor recognised that they held the responsibility to ensure that the product was suitable, and they said that, "we would challenge it if we thought it was one way or the other". On the contrary, another contractor, when asked if they enquired about the fixation process, said that they source their materials from the standard timber merchants and that, "I can only assume whether or not they did it, but it wasn't a question we would have asked, or we were required to ask by our contract". One participant highlighted that the request for properly fixed timber is becoming more common, and the manufacturer of timber in this research, said that proof of fixation is available upon request. These findings still suggest that either, proof of fixated timber needs to be specified in the job details at all times, or become standard practice, to ensure that leaching is limited as much as possible, on all structures that involve the use of timber in waterways.

Another method identified was adherence to standards and guidelines when using and preparing CCA treated timber, but the storing of timber was not a method that was identified to be required. Contractors believed that once the timber had been purchased it was ready to be used straight away. The manufacturers ensure that after the treatment process is complete, the timber is ready to be used.

Galvanised Steel

Few methods were used at the installation stage to reduce leaching from galvanised steel. Methods appeared mostly to be applicable at the design phase, whereby, if the intended environment posed a corrosion risk, then galvanised steel is not to be used at all. The manufacturing of galvanised steel was not relevant considering the findings from the literature review by Marshall and Margetts (2020), and so information was not sought on the methods used during the process of applying the zinc coating.

One method that the literature review by Marshall and Margetts (2020) raised, was precautions around using galvanised steel with H5 and H6 treated timber. This application of the materials was thought to pose a potential corrosion risk, but the timber manufacturers deemed this to no longer be an issue. This is because the CCA solution used to treat the timber no longer contains salt; salt would have been the likely cause of corrosion. One participant considered the addition of salt in the CCA solution was phased out in the 1990s, and the CCA solution now contains an oxide instead. No contractors were aware of the potential risk of using galvanised steel with H5 and H6 class timber.

Again, like in the responses to CCA treated timber, contractors do not specify the material that is going to be used for the job; although they may question the incorrect application of the material, or whether there was a mistake in the design. This meant that enquiring about the use of galvanised steel in anoxic environments in this survey became somewhat redundant, because it was not a method that was in the control of the participants. Therefore, methods that apply to the use of galvanised steel that may prevent leaching are solely down to the designer. Further knowledge is needed regarding the selection of galvanised steel at the design phase of a project.

Concrete

The data revealed three independent categories of risk and associated rules with the use of concrete. Each requires different methods to prevent the leaching of contaminants into waterways. The categories are:

1) Ensure that concrete dust is suppressed.

Dust was identified to be an issue when contractors needed to cut concrete on-site. All contractors that contributed to this Theme discussed how it was standard industry practice to prevent dust from circulating or being produced at the worksite. They listed a variety of different ways that dust could be suppressed (e.g., using water, using a vacuum, using silt booms etc).

2) Ensure that wet concrete and concrete wash does not enter waterways.

The risk of wet concrete and concrete wash entering waterways was mostly applicable to contractors, as they are working at the construction site. Contractors listed a variety of measures and precautions that were undertaken to ensure that contamination of the waterway does not happen. Any equipment, including vehicles that have been in contact with wet concrete, are washed off-site, or at a purpose-built wash facility, which is normally back at the company yard. Any excess wet concrete on-site is bunded, left to go hard and disposed of via appropriate means, such as trade waste. The contractors were clear that this is standard industry practice, and that the awareness of not allowing wet concrete or concrete wash into waterways is well known.

3) Ensure that water does not come into contact with concrete that is not properly cured.

This category was relevant to both the suppliers and contractors and the findings were mostly consistent between both. At the supplier/manufacturing side, it is standard practice that concrete pipes do not leave the site until they are properly cured. Properly cured means that the concrete has been through the process of hydrating while the concrete gains its strength (Taylor, 2014). For concrete structures however, it is unclear whether they are hydrated during the curing period, although they are certainly left for the full curing period before distribution. Various factors influence the curing period, but on average the minimum period of time that concrete takes to cure is 7 days, and some projects require the concrete to cure for longer to increase its strength (BRANZ, 2010; Burg, 1996; Cement Concrete & Aggregates Australia, 2006). All participants were well aware of this.

Manufacturers were adamant that products would not leave the yard before they are cured, as they are at risk of cracking or chipping. Contractors who use the pre-cast concrete structures assume them to be ready for installation when they are delivered.

Although in general casting was done at the manufacturing yard, it would sometimes be completed on-site. When completed on-site, methods that were used to prevent leaching included diverting streams, disconnecting water lines, and using a cofferdam to keep the work area dry. Contractors who did this on-site were in agreeance, that 7 days was the minimum curing time. The point at which participants thought that water could come into contact with the concrete after curing, was at least after 7 days but varied up to 28 days.

Concrete pipes are kept wet in the initial 24 hours after casting, but the results of this project were not able to determine if this is a mandatory procedure that is also completed on all concrete structures. Two participants who were contractors, one of which casts concrete in situ, were able to detail how the methods used to cure concrete on-site involved keeping it wet for several days after casting. To do this they may use a hose, a wax, curing compound, or hessian bags to keep it damp. For example, one contractor said,

> "we would always go and wet the concrete daily, or maybe every three hours to help the concrete cure. Or you would put a curing compound on it, which is like a wax type of material, that you would apply on top of your concrete the day after, and that will help the moisture that's inside it, will basically keep it inside and so the moisture can't escape".

The same participant also said that it is their preference for the concrete to be exposed to water, for the whole seven days during the critical curing period. A participant that was involved in projects that cast in situ described how there was a lot of risks involved, and that contractors casting concrete on-site will always err on the side of caution. Whilst reassuring, it does not mean that getting concrete structures wet in the initial curing period is protocol across all companies. It was not well understood during data collection whether pre-cast concrete structures are also soaked. One participant, who represented the manufacturing of concrete, was not sure whether the pre-cast concrete structures were kept wet during the curing phase or not. Which highlights that firstly, this may not be a standard practice throughout the entire industry, and secondly, that it may not be required in the relevant New Zealand building standards.

Two participants, who are experts in this industry were adamant that the exposure of concrete to CO^2 and drying after the curing period is critical. This exposure allows the calcium hydroxide in the concrete to absorb CO^2 resulting in the formation of calcium carbonate. This exposure stage is what results in alkalinity being present on the surface, but the formation of the calcium carbonate blocks up the pores in the concrete, which prevents leaching. Several participants said that it is crucial for the concrete to be left out to dry before being installed. And that the longer the concrete is left, the stronger it becomes, and less prone to anything leaching out of the pores.

The details regarding concrete strength and curing time are set out in the job specifications. It appears that the time between curing and contact with waterways may vary according to the concrete and environmental characteristics. For this survey, it means that a single answer is not yet available as to how long the concrete should avoid contact with the waterway.

More generally, the storing of concrete was related to its required curing time, therefore no other storage time is deemed necessary. Participants who use concrete identified that their job-specific Environmental Plans, adherence to standards and guidelines, and adherence to the job specifications, were other methods that they use to prevent contaminants from concrete leaching into waterways.

<u>3.3 Objective 3:</u>

> How difficult would it be to achieve the recommendations in the literature review to reduce leaching of CCA treated timber, galvanised steel, and concrete?

Overall, the participants were in agreeance; anything that became mandatory, they would find a way to achieve it, no matter what the barriers. Despite this, it was still generally difficult for all participants to imagine how the recommendations could be achieved, because they are not something they currently do, and many of them could not justify or understand why you would do them (e.g., soaking concrete prior to use). New legislation and practices were said to be uncommon in the industry, and therefore easy to be aware of when implemented. One participant highlighted that the use of a legal consultancy firm also helped to ensure that they are following the correct regulations. However, they had experienced an incident when the legal consultancy firm had made a mistake. This mistake highlighted to the company, that if professionals in legislation were able to misinterpret the standards and guidelines, then there could certainly be times when it would be difficult for themselves to understand new ones, especially if they were unclear and subjective. This is likely to be relevant to the entire industry.

<u>CCA Treated Timber</u>

For CCA treated timber, participants were asked to think about soaking the timber prior to use. They imagined that it would need to be in some sort of container or tube, where the timber could be prevented from floating. The lack of space, access, and safe work area on-site, seemed to be a significant barrier that would make soaking at the site of installation difficult. As some structures are lengthy, contractors identified issues in terms of using infrastructure that was long enough, to avoid cutting the timber and trying to reconnect it. They also thought it would be time-consuming and were concerned about how the water could be disposed of after. They, therefore, could not imagine this being done easily at the worksite and that to achieve efficiency it would be best done at the manufacturing yard.

All participants were adamant that they would do what was required. But since there seemed to be little justification as to why they would need to soak the timber, if the correct material had been used to begin with, they felt that it would not be something they would do without legislation enforcing it. The participants did not feel that soaking was very achievable, with the biggest barriers being cost, and the customer's willingness to pay if it were not mandatory.

Other methods used to prevent leaching by contractors included using the correct grade of treated timber and adherence to industry standards, which were all thought to be highly achievable. The contractors did not consider that there were barriers to achieving these, as this was standard practice. Likewise, the manufacturer of CCA treated timber also thought that fixation and adherence to industry standards were easily achievable, and that this was also standard practice. Fixation was believed to be a critical stage in the preparation of timber. Although fixation is achieved every time, completing a Merck test every time to demonstrate this was thought to be somewhat challenging and not necessary by the manufacturer. This is because the timber undergoes a standardised and consistent process that achieves the same results. The manufacturer suggested that batch testing fixed timber could be a reasonable alternative to Merck testing each piece of timber if this were requested.

The data highlighted that fixation was not something that was well understood by the contractors, and that it is not something required across the industry, although it is done by the manufacturer who participated in this research. Therefore, to better achieve the recommendations in the literature of using properly fixed timber, the following would be required:

- Ensure that users of CCA treated timber are aware of the process of fixation.
- Ensure that purchasers of CCA treated timber, know how to check that their timber is from an accredited and trademarked timber merchant who ensure fixation.
- Ensure in the design specifications for the job that CCA treated timber to be used is properly fixed – with evidence available on request.
- Ensure the current proposed changes to the New Zealand Standard 3640 (NZS 3640), make the process of fixation and proof of fixation mandatory (Standards Council, 2003).

<u>Galvanised Steel</u>

The data revealed that the precautions recommended by the literature review in relation to galvanised steel were not in the control of the participants in this project.

The literature recommended that galvanised steel is not used in anoxic environments. The decision for which material is to be used is not one made by the contractor or supplier; it is made by the designer. Therefore, it is not achievable for the manufacturer to change the material if galvanised steel is the product that has been specified to be used. The contractors, however, did say that they would raise concern or question a design, if they thought that there had been a mistake.

The project designer will have information that details the work site's environmental characteristics in-depth, but only some of this information is passed on to the contractor. For example, when discussing the risks associated with corrosion at sites where there are anoxic environments, one participant said that they do receive a draft environmental plan, which details the consents for the project, and associated risks. They said that they also commonly received information about boreholes, that details the water table and, "even potentially the settlement makeups, whether it's sand or what, but it never goes into that level of detail", regarding an environment that is anoxic or not, and whether there is a subsequent risk of corrosion. This participant also highlighted that even if the information is provided, because they do not commonly make decisions over which material to use, they would be unsure of how to interpret the information, because it seems to be irrelevant. Most of the contractors who participated, said that their preferred material to use was stainless steel in an environment that had a corrosion potential, to reduce the associated risks.

In regard to using galvanised steel with timber that is treated with CCA grade H5 and H6, this also seems to no longer be a recommendation that can be achieved by the contractors. Firstly, the contractors did not think that these materials would be used together in any case. They felt the environment that was implied by using H5 and H6 grade timber, was estuarine and saltwater and that therefore, stainless fixings would be used instead. Secondly, salt that was in the past, part of the CCA treatment solution, no longer is. The addition of salt could have, in the past been the cause of corrosion in this application, and may still be for existing structures, where the timber was treated with a CCA solution that contained salt. Participants in this research did not think that this recommendation was relevant to current practice.

In terms of achieving methods that prevent the risk of leaching, the use of alternative products such as stainless steel was commonly discussed. The biggest barrier to the use of other materials were their costs and the limited supply of variable materials on the New Zealand market.

<u>Concrete</u>

The literature review recommended that concrete structures were soaked prior to installation in waterways. The interview guide asked the participants to think about how the soaking of concrete structures could be achieved.

Similarly, to soaking timber, participants were reluctant to engage in this question because they could not justify why the soaking of concrete would be necessary if it had been properly cured. They felt that soaking the concrete structure prior to installation would be counterproductive, because drying is required in the final stage of the curing process.

Participants felt that soaking concrete would be very difficult to achieve, because structures such as headwalls are large and heavy. They thought that there would be increased safety risks resulting from extra handling of the structures. Difficulties that participants raised included, obtaining sufficient infrastructure, increases in manufacturing time, disposal of contaminated water, and costs that were associated with all of the mentioned barriers. All participants were unanimous that should it become required, then they would find a way to do it. And so, the suggestions for methodology included, spraying with a hose, or using a pit that would hold both the water and structure. Spraying is similar to the process already used by two participants in this project, who spray the concrete after casting in situ and during the curing period, although it may be possible that not all contractors do this, and that it may not be done at the manufacturing yard. Participants were certain that it would be most practical if soaking were done at the manufacturing yard, as there are spatial restrictions on-site. Manufacturers also felt that there would be spatial limitations at the yard, especially as not all of the yards were owned by the company currently using them.

Furthermore, the literature review highlighted that precautions should be taken to limit dust when using concrete, and to prevent wet concrete from entering waterways. There are a variety of methods currently used to do this and all were deemed to be standard industry practice. Participants thought that the precautions were not difficult at all, with one participant commenting that they thought they were "entirely reasonable". As a result, the participants did not raise any barriers that made limiting dust and managing wet concrete difficult to achieve.

4.0 Limitations and Future Research

Whilst the data that was collected and analysed was done so methodically and critically, limitations were unavoidable.

Firstly, the data was collected and analysed by the same researcher. Bias may therefore exist within the interpretation of the results and its presentation. To address this, responses were not omitted, even if they were felt to be irrelevant. Responses that were thought to be incorrect, were also still reported, but questioned by existing literature. The large quantity of data was difficult to process and organise accordingly. Despite methodically coding, the process could have benefited from a more thorough analysis if time had permitted. Furthermore, research in the future regarding this topic could be improved by piloting the interview questions on experts in the field, before carrying them out on genuine participants. This would help to better define the questions for the participant to understand, highlight areas that required more explanation, and identify where questions could have targeted industry practices at a deeper level.

As the report was close to conclusion, it was noted that sufficient data was not obtained regarding concrete structures. It is unknown whether concrete structures used or produced by all of the participants are exposed to water during the critical curing stage. Future research would be beneficial to determine whether this is standard industry practice or not.

There was only one company who represented the manufacturing of CCA treated timber. Despite this limitation of data, there was still a high level of detail provided by the two participants who represented the company. The participants described how membership to the Timber Preservation Council and the certification of the WOODmark® licensed trademark, required the company to produce treated timber that met a minimum of requirements. This is supported by the information via the New Zealand Timber Preservation Council (n.d.-c) website. They detail that WOODmark® licensed plants must: meet the NZS 3640 treatment standards; manufacture and operate according to requirements; be audited and have products tested by the Council; and follow all relevant regulations. Although timber fixation is not yet a requirement under the treatment standards, it may become so in the future, and is something that the Timber Preservation Council encourages their members to do (New Zealand Timber Preservation Council, *personal communication*, February 2021). Licensed plants who fail to meet these requirements face penalties. From this information, it is reasonable to assume that all manufacturers who are members of the New Zealand Timber Preservation Council and who have the WOODmark® trademark are abiding by these standards. It means that although the exact data in this project about timber preparation may not be fully representative of other manufacturers, the standard of treated timber should be similar. The selection process, as detailed in Figure 1, identified one other timber manufacturer, however they were unable to participate in the survey. But their timber products also have the WOODmark® licensed trademark, and therefore the data found in this project is likely to be representative of all timber structures purchased by Christchurch City Council.

Finally, it is important to note that participants were aware that the project was funded by the Christchurch City Council. In some cases, participants demonstrated caution regarding their responses, and felt that they would not want to say something that damaged their company's reputation, which is understandable. Although complete anonymity was given to participants, some may have still felt they could not answer as fully as they would have liked, potentially biasing the results.

5.0 Conclusion and Recommendations

Overall, the project revealed a lot of potentially unknown information to the general public. The findings are positive and highlight clearly where better standards and regulation are required. It appears that industry practice could be improved in several areas but that overall, the contractors and suppliers are well aware of the potential for these materials to harm the environment. The participants also demonstrated a keen interest in preparing and using materials in a way that minimalised or avoided environmental harm.

If new standards and guidelines, such as soaking, are to be implemented, it is essential that they are clear and understandable. Participants in the research also felt that they needed to be incorporated into the job specifications, to become relevant to the construction work. It is evident that any new protocol must be adaptable to barriers that the industry faces, such as space and site access limitations, and that they must consider whether the cost is a price that the customer is willing to pay. The price must be considered against the potentially beneficial environmental outcomes, which are possibly still a little uncertain with relevance to Christchurch City waterways. For example, the water chemistry of waterways in Christchurch City, potentially do not pose a high risk of corrosion for the use of galvanised steel to begin with (Bednar, 1989; Marshall & Margetts, 2020). Furthermore, engagement with contractors and suppliers, would help to ensure that, if new guidelines are to be developed, they are achievable and practical for the industry.

It is clear that the choice of which materials to use for structures in Christchurch City waterways are not made by the contractor or supplier. If leaching is to be prevented at the outset, it must be determined how designers select the specified materials, and whether these are the most appropriate. Despite the emphasis and the need to protect the environment, participants highlighted that designers must also consider the longevity of materials, availability of products in New Zealand, and the cost to local government and taxpayers.

The discussion on CCA treated timber, highlighted that customers are becoming more aware of the need to use properly fixed timber and are requesting it. But the data also revealed that it is not mandatory in the industry, and may not be a treatment process used by all manufacturers (although fixation is used by the manufacturer that participated in this project). The manufacturer of CCA treated timber believes, that if modern practices are employed, especially that of heat fixation, and if the correct grade of timber is used, then the residual risks of leaching from CCA treated timber can be reduced or avoided. This is supported by Hedley (1997) who states that properly fixed timber poses little environmental risk.

The importance of using the appropriate materials in the right application, regardless of cost, became a reoccurring topic throughout the research. For example, where environments are potentially corrosive, galvanised steel, which is cheaper than stainless steel, should not be used. The same can be said for concrete and CCA treated timber (e.g., a timber product that is treated to CCA grade H6 is only marginally more expensive than H5, but it is the most appropriate to use in a marine environment).

There appears to be some uncertainty about the recommendations regarding soaking concrete in the literature. The literature review concluded, by recommending that concrete structures are washed or soaked for at least 24 hours prior to installation (Marshall & Margetts, 2020). After review of the relevant literature, it appears that the experiments used freshly cast concrete for immersion, that may or may not have cured for a full seven days, and may not have been hydrated while curing (Law et al., 2013; Setunge et al., 2009). These are crucial variables. It means that the concrete used in the research; if it had not been properly cured, would certainly have raised the levels of pH in the water body. This is not reflective of current practices regarding the use of fresh concrete, which as discussed in-depth by the participants, is always cured for the full period. Where the literature recommended 'soaking' in their papers, it appears that they may have meant, hydrating the concrete during the curing stage, which is common industry practice. Therefore, the recommendation in the literature review to soak concrete may not be relevant.

One final aspect to be considered, is that whilst a material may be deemed to have negative environmental effects in one part of its life-cycle, it may have far lesser impacts at other stages. For example, of the three materials, CCA treated timber was found in the literature to pose the greatest risk of leaching and subsequent effects on aquatic biota. Whilst this may be the case when timber is not properly fixed or used in the correct application, timber may have less detrimental impacts during its other life-cycle stages, in comparison to galvanised steel and concrete. For example, galvanised steel and concrete emit larger quantities of CO^2 during manufacturing. Whereas timber, at least for the manufacturer in this research, has a carbon negative output during its entire lifecycle. This variance in CO^2 emissions are supported by the research (Latawiec, Woyciechowski, & Kowalski, 2018; Mass, De Gijt, & Dudok Van Heel, 2011). Also to be considered is where and how materials are sourced, and their other potential impacts; for example, human health, and mineral resource depletion in the case of mining iron ore, which is needed for the production of galvanised steel (Ferreira & Leite, 2015). Finally, it is also important to consider what happens to the material at their end-of-life phase, whether they are disposed of as waste, can biodegrade, or whether they can be repurposed.

6.0 Benefits of the Scholarship

In the early stages of my project, I was tasked with completing and submitting the Human Ethics Application to undertake my research. Whilst this was a daunting process, I had great contacts at the university who were able to support me. Although it held me back in undertaking the research, I utilised my time efficiently, so that later down the track I could make up for the waiting period. I really enjoyed the entire process. I was able to learn in-depth how to complete the application form, the steps involved and the level of detail and foresight that was required. I made more connections around the University, and I sought help that expanded my knowledge in the areas of research design and Māori consultation. For example, with guidance, I decided to change my supervisor's survey design from quantitative to qualitative to help to gain more meaningful and rich data. I also needed to go deeper and explore better options to consult with Māori, as our original intentions were not sufficient.

The process of data gathering was extremely enjoyable. In the beginning, I was nervous that my intended participants would not be interested in taking part, and that I would therefore have little to no findings to report on. However, I found it to be quite the opposite. Most of the companies that I contacted agreed to participate. I mostly went to their offices to complete the interviews; they were very engaging and revealed a lot of information. I was very lucky to have two tours of manufacturing plants that enabled me to gain a better understanding of the materials of my project. I learnt a phenomenal amount of information about how the materials were used and handled. I learnt about some of the industries struggles, regarding cost and the ability to source different materials in such a small market. Most importantly, I learnt that people were willing to take part if I respected them, took a gentle approach and was flexible. I was extremely conscientious to follow all of the protocols to ensure the anonymity of my participants. This meant that they were very open with me and agreed to share their company's names to declare their contribution to the research.

In the report writing stage, it was difficult. I was under pressure to meet the deadline because I had needed to wait for human ethics approval, which was just before the Christmas break. Most of my participants were about to go on holidays and were busy. Therefore, several of my interviews did not take place until mid-late January. Nothing could be done to change this. The lack of available time near the end may have hindered my ability to seek and then receive help in the data analyses phase. I always like to get advice from academics and professionals, and to have my writing checked thoroughly, but I lacked the time to do this. Even with pulling extra workdays and hours, this was not within my control.

My biggest concern is that I now have to hand my data over. It was me who gave the participants my word and it is my name that they associate with this research. When I leave the University, despite the data being with an academic whom I trust, the data is still no longer in my care. This is a factor, that is again out of my control, but one that is still on my mind.

This project allowed me to work with an employee of the Christchurch City Council and demonstrate my professional abilities to a member of the academic staff at the university, which I am very grateful for. It allowed me to improve my researching skills, data analyses and report writing. It also facilitated me to meet industry professionals and learn about topics and materials that I thought were of little interest to me, and they clearly now are.

This project has helped to prepare me for my new temporary contract as a research assistant at the University. During this contract, I will be able to decide which project I would like to focus the subject of my research master's on. I now have a good idea of what to expect from undertaking postgraduate study, and an understanding of the skills that will be needed for me to be successful, for which I am very grateful.

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Appendix A. Literature Review

Literature review of potential effects of leaching from instream structures on waterways (Marshall & Margetts, 2020).

MEMORANDUM

27 August 2020

By: **Winsome Marshall (Environmental Consultant, Aquatic Ecology Limited)**

Dr Belinda Margetts (Principal Waterway Ecologist, Christchurch City Council)

Subject: **Literature review of potential effects of leaching from instream structures on waterways**

Introduction

A number of temporary and permanent instream structures are used within waterways to allow the construction of things such as bridges, culverts, linings and retaining walls. Some of these structures have the potential to leach contaminants into waterways, negatively affecting both water quality and biota. To understand the potential effects of using instream structures, this memorandum assesses the information in the literature on the effects of three commonly used materials: copper-chrome-arsenate (CCA) treated timber, galvanised steel, and concrete. This review does not include literature pertaining to runoff from manmade structures outside of waterways, such as galvanised roofs, due to other processes not present within waterways, such as oxidisation from contact with atmospheric carbon dioxide (Pacific Northwest Pollution Prevention Resource Center, 2014).

Literature review

CCA Treated Timber

The leaching of CCA treated timber and subsequent environmental effects is well documented in both laboratory and field studies (34 papers; Table 1). These indicate that leachates from CCA treated timber may have negative impacts on biota, such as algae, barnacles, mussels, oysters, snails, sea urchins, fiddler crabs and fish (Table 1). These include effects on fertilisation and larval development, with some studies also recording mortality (Weis, Weis and Coohill, 1991; Weis *et al*., 1992; Sreeja, 2008). There is also evidence that exposure to CCA treated timber may cause damage to the DNA of resident biota (Weis, Weis and Couch, 1993; Weis *et al.*, 1995). Trophic transfer of copper, chromium and arsenic through the ecosystem may occur, although results are inconsistent (Weis and Weis, 1992b; Weis and Weis, 1993; Weis and Weis, 1999; Chan, Wang and Ni, 2003). Metal concentrations in benthic organisms near bulkheads have also been shown to lower species richness, total abundance and species diversity (Weis and Weis, 1992a; Weis and Weis, 1994; Wendt *et al*., 1996; Weis, Weis and Proctor, 1998). The most harmful effects on biota appear to be due to copper (Chan, Wang and Ni, 2003; Weis and Weis, 2004). However, the form of chromium (Cr(VI)) used in CCA treated timber is also highly genotoxic (Weis and Weis, 2004).

Four literature reviews investigating the leaching of CCA treated timber were identified. One of these reviews by Hingston *et al*. (2001) concluded that insufficient data existed to allow accurate quantification of leaching rates from CCA treated timber. However, another review considered that properly treated CCA timber presents little hazard to the aquatic environment (Brooks, 1993 *in* Hedley, 1997). Hedley (1997) concluded that leaching does occur from freshly treated wood, but most studies indicate it adds little to background water and sediment levels of copper, chromium and arsenic, with issues typically arising when the wood is used before it is properly fixed. However, there are abundant field-based studies which indicate that CCA treated timber leaches into the environment, with copper, chromium and arsenic assimilated by biota (Weis and Weis, 1992b; Weis and Weis, 1993; Weis, Weis and Couch, 1993; Weis, Weis and Lores, 1993). Assimilation rates in environments with CCA treated timber were typically highest for copper, followed by arsenic and then chromium (Weis and Weis, 1992b; Weis and Weis, 1993; Weis, Weis and Couch, 1993; Weis, Weis and Lores, 1993). In addition to dissolved contaminants leaching into the water column, metals from CCA treated timber can accumulate in sediment (Weis, Weis and Proctor, 1993; Wendt *et al*., 1996; Rice, Conko and Hornberger, 2002).

Leaching may be more severe in field experiments due to increased physical stress, such as abrasion, cracking and borer (Merkle, Gallagher and Soldberg, 1993 in Hingston et al., 2001), which allow water to penetrate further into the wood. Leaching rates are typically impacted by pH, temperature, salinity, surface area-to-volume ratio, fixation method, quality of wood, time since fixation, and flushing of water in the environment, as discussed further below.

Maximum leaching of chromium and arsenic has been shown to occur under neutral conditions and initial loss of copper has been shown to increase with higher acidity (Van Eetvelde *et al.*, 1995b in Hingston et al., 2001; Van Eetvelde *et al.*, 1995a in Hingston et al., 2001). Christchurch waterways are typically neutral or slightly alkaline (Marshall and Noakes, 2019). This suggests optimal conditions for leaching of chromium and arsenic, but not copper. The effect of temperature on leaching appears to be variable, with some studies reporting lower leaching rates for copper, chromium and arsenic at lower temperatures, while other studies indicate that arsenic leaching may be lower at higher temperatures (Van Eetvelde *et al.*, 1995b in Hingston et al., 2001; Van Eetvelde *et al.*, 1995a in Hingston et al., 2001; Breslin and Adler-Ivanbrook, 1998). Increasing salinity appears to increase leaching rates, although one study found that brackish water did not increase copper loss (Irvine, Eaton and Jones, 1972 in Hingston et al., 2001; Plackett, 1984 in Hingston et al., 2001). This suggests that leaching rates are likely to be highest in coastal waters, followed by estuarine environments and then freshwater. The surface area-to-volume ratio (i.e. the amount of timber in contact with the water) also appears to be an important factor in leaching rates, with large blocks leaching less than small ones (Hayes, Curran and Hynes, 1994). Sreeja (2008) also found panels that were dip treated leached more quickly than those that were pressure treated.

Newly treated CCA timber leaches the fastest and is therefore the most toxic (Weis and Weis, 2004). Breslin & Adler-Ivanbrook (1998) reported that metals leached continuously throughout a 90-day study, but at a decreasing rate with time. One study found that barnacles growing on one-year-old CCA treated timber had copper concentrations 80 times higher than the reference site, compared to the aged wood which was 10 times higher than the reference site (Weis, Weis and Lores, 1993; Weis and Weis, 2004). Environmental impacts could be substantially lessened if wood was soaked for several months prior to use in aquatic environments (Weis and Weis, 2004; Weis and Weis, 1996). The fixation process is both time and temperature dependant and therefore wood should never leave the treatment site for at least two weeks (Hedley, 1997). However, if wood is stored outside in winter, complete fixation may take months (Hedley, 1997). Poor quality timber can also leach substantially more than higher quality timber (Hayes, Curran and Hynes, 1994). The quality of timber, and its suitability for treatment is complex; however, dense wood is generally of higher quality and fast grown wood of lower quality, due to a higher proportion of earlywood compared to latewood (Hayes, Curran and Hynes, 1994; Jane, 1970 *in* Hayes, Curren and Hynes, 1994; Wise and Jahn, 1952 *in* Hayes, Curren and Hynes, 1994). Conifers (e.g. pine) are likely to have high leaching rates due to the form of their earlywood (i.e. more preservative may be absorbed but not properly fixed, and therefore would be more readily leached) (Hayes, Curran and Hynes, 1994). This highlights the need for New Zealand based research, as it is possible this use of pine/conifers is greater than overseas.

Tidal inundation can influence metal concentrations in sediments, with concentrations higher in areas that are more frequently inundated (Weis and Weis, 2002). In reasonably flushed areas, leachates from new pilings have been shown to have negligible effects on estuarine ecology, while those from new bulkheads or those in poorly flushed areas may have impacts that can be detected for several years (Weis, Weis and Proctor, 1998). In poorly flushed areas and/or those with a high surface area of CCA treated timber, elevated metal concentrations have been seen in algae, barnacles, mussels, oysters, fiddler crabs and fish (Weis and Weis, 1992b; Weis and Weis, 1993; Weis, Weis and Couch, 1993; Weis, Weis and Lores, 1993).

Galvanised steel

Galvanised steel is coated in zinc to prevent corrosion of the structure (Yadav, Nishikata and Tsuru, 2004), and is frequently used in construction due to its resistance to corrosion and biofouling (Ilhan-Sungur, Cansever and Cotuk, 2007). However, there is little research available on the effects of leaching from instream steel structures (4 papers; Table 2). One detailed study of culvert durability and erosion from South America recorded the most important factors affecting corrosion to be water chemistry (pH, TSS, hardness and alkalinity), degree of water agitation, temperature, and time of water contact (Bednar, 1989). Galvanized steel pipe was considered sufficiently durable to be used in most soft waters; however, care should be taken in very soft, low conductivity water, where little dissolved salts are present in the water (Bednar, 1989). This is because the prevention of corrosion of galvanised steel is partially dependent on appropriate water hardness to form a protective scale over the metal (Bednar, 1989). This study does not investigate leachate; however, if a correlation is drawn between durability (i.e. resistance to corrosion) and the potential source of instream zinc contamination, then galvanised steel installed in waters with low corrosive potential are likely to contribute little to instream pollution. Based on the conclusions in Bednar (1989), it would seem plausible that Christchurch waterways are of appropriate water chemistry (hardness, pH) to prevent high corrosion. However, other regions, such as the West Coast that has some naturally acidic and/or soft streams (Winterbourn and McDiffett, 1996; Greig *et al.*, 2010; Horrox, Chaney and Eaves, 2015), may not have appropriate water chemistry to prevent corrosion.

There is also some indication that treated timber may corrode the galvanised steel angle/plates and nails that hold the timber in place (Kear, Wú and Jones, 2009; Zelinka, Sichel and Stone, 2010; Baker, 1992). In which case, pre-soaking H5 and H6 timber to reduce environmental damage may also substantially reduce galvanised steel corrosion rates.

Sulphur Reducing Bacteria (SRB) reduce inorganic sulphate to hydrogen sulphide, which can increase corrosion of steel (Costello, 1974; Ilhan-Sungur, Cansever and Cotuk, 2007). A study by Mor, Beccaria and Poggi (1974) found that in artificial seawater with a pH >7.2, corrosion of zinc was accelerated in the presence of sulphides. SRB are considered widespread in nature and are found in anoxic marine environments with excess sulphate and from freshwater lake sediments (Widdel and Bak, 1992 in Nielsen, Liesack and Finster, 1999; Jørgensen and Bak, 1991; Bak and Pfennig, 1991). Anoxic sediment refers to sediment that has been depleted of oxygen, as typically occurs in slow waterways with little flushing flows and high detrital inputs. Given the above, corrosion of galvanised steel structures could be expected to be accelerated when in contact with anoxic, sulphate rich sediments, which could lead to an increase in zinc sulphide released to the environment.

Concrete

All the literature on concrete was based on laboratory studies investigating direct concentrations of leachates (5 papers; Table 3). The main risk posed by concrete is the increase of water pH to a highly alkaline state, via the release of calcium hydroxide (Taylor, 1997 *in* Setunge, 2009). Concrete wash and dust should never enter a waterway or stormwater system, with 100,000 litres of water required to dilute 1 litre of concrete wash, with filtering having no effect (Environment Canterbury, undated). Velocity appears to have a substantial impact on peak pH, with lower velocities causing higher pH peaks and for longer durations (Setunge *et al.*, 2009; Law *et al.*, 2013).

For fresh cast concrete, both Law *et al.* (2013) and Setunge *et al*. (2009) found that the time between casting and immersion in water did not materially affect changes in pH, with Setunge *et al*. (2009) finding that all samples followed the same pattern of peaking around pH 11, and slowly falling over the following 30–35 days. However, fresher concrete typically had slightly higher pH peaks and declines were slightly more protracted (Setunge *et al.*, 2009; Law *et al.*, 2013). After immersion, peak pH may occur around one day in very slow water, but in around 15–30 minutes in faster water (Setunge *et al.*, 2009; Law *et al.*, 2013). Aggressiveness of the water (soft water, or water containing corrosive substances, such as those high in carbonic acid) can increase leaching (Ekström, 2003). This may mean that concrete in soft water catchments, such as the Styx and Ōtūkaikino Rivers (Marshall and Noakes, 2019) may leach more readily than other river catchments in Christchurch. Seawater typically has more carbonic acid than freshwater, therefore marine grade concrete should be used in coastal areas (Paul Woods, CCC, personal communication, 27 May 2020). Bulk leaching can also occur in porous concrete (Ekström, 2003).

Basar and Aksoy (2012) found that nickel, zinc and chromium concentrations in eluate from various concrete types were typically lowest in slightly acidic conditions (pH 5.5). The results of this study were compared to the Canterbury Land and Water Regional Plan 90% species protection levels for these metals (Environment Canterbury, 2018) and the following exceedances were found (Table 3):

- at pH 5.5, zinc eluate occasionally exceeded the guideline level and chromium eluate always exceeded the guideline
- at pH 9.0, zinc and chromium eluate from all concrete types were above the respective guideline levels
- at pH 4.0, nickel and zinc eluate exceeded the respective guidelines for most concrete types, and chromium eluate always exceeded the guidelines

Christchurch waterways typically record pH values between 6.5–8.0 (Marshall and Noakes, 2019). Therefore, leaching effects on biota from zinc and chromium may occur in these waterways, although dilution within the streams may reduce or eliminate this effect.

A study by Tippler *et al.* (2014) found that in an acidic sandstone catchment, changes in stream geochemistry were attributable to urban development, particularly the concrete stormwater infrastructure. A similar phenomenon was found by Kaushal, McDowell and Wollheim (2014) when they conducted a literature review assessing urban impacts on ecosystem services. They concluded that widespread coverage of concrete and aging cement infrastructure can contribute to river alkalinisation (Kaushal, McDowell and Wollheim, 2014). Given the urban nature of Christchurch city, there may be similar effects. However, New Zealand based experiments may be important as Christchurch waterways are circumneutral or slightly alkaline (Marshall and Noakes, 2019).

Conclusions and recommendations

The greatest environmental threat appears to be from CCA treated timber, with this risk increased through the use of newly treated timber, timber with a high surface area, and the use of timber within poorly flushed waterways, or estuarine and coastal waters. This draws attention to the high number of timber lined drains in Christchurch waterways, particularly those in estuarine areas and those with 'threatened' or 'at risk' sediment living biota, such as kākahi/freshwater mussels (*Echyridella menziesii*) and kanakana/lamprey ammocoetes (*Geotria australis*) (Dunn *et al*., 2018; Grainger *et al*., 2018). Christchurch waterways likely have appropriate water chemistry to prevent accelerated corrosion and therefore leaching of galvanised steel, so the environmental risks of using these structures are low. There are some risks with the use of concrete structures, but as with CCA treated timber, it is possible to reduce these risks by following design standards and considering whether the environment the structure is to be used in is more likely to cause leaching.

When considering the use of these instream structures, the following is recommended:

- CCA treated timber
  - After treating, timber should be free of any extraneous surface deposits ('sludge') (Hedley, 1997) and held on the Timber Treatment Pad until it is drip free, then moved to a storage area until such time as fixation is achieved (Jeff Ilott, New Zealand Timber Preservation Council, personal communication, 26 June 2020). Storage time should also be provided by suppliers.
  - Fixation should be determined as per the relevant New Zealand Standards and the Best Practice Guideline for the safe use of Timber Preservatives and Anti Sapstain Chemicals[2], and using a Merck test or equivalent (Hedley, 1997; Standards New Zealand, 2003; New Zealand Timber Preservation Council Inc, 2005; Standards Australia and Standards New Zealand, 2006). Fixation time can vary, as this is a function of time and temperature. Therefore, baseline testing should be undertaken to ascertain fixation times at various times of the year (Jeff Ilott, New Zealand Timber Preservation Council, personal communication, 26 June 2020). In summer, fixation may take as little as two weeks; however, if wood is stored outside in winter this may take months (Hedley, 1997).

[2] At the time of publication, this is a best practice guideline and not a compliance requirement specified in any Standard. However, the New Zealand Timber Treatment Standard (NZS 3640) is currently being revised and the issue of fixation will become a compliance matter (Jeff Ilott, New Zealand Timber Preservation Council, personal communication, 26 June 2020).

  - Timber is treated to Hazard Class 5 (H5) for freshwater environments, or to Hazard Class 6 (H6) for use in sea water or estuarine ground (Standards New Zealand, 2003).
  - Timber intended for use in aquatic environments is pressure treated to minimise potential adverse environmental effects (Sreeja, 2008). This currently occurs for H5 and H6 timber (Jeff Ilott, New Zealand Timber Preservation Council, personal communication, 17 June 2020).
  - Timber is soaked for several months prior to installation in aquatic environments. This is particularly important in areas where CCA treated timber will be used in coastal or estuarine waters, in waterways that are poorly flushed, or where a large volume of timber is required relative to the size of the waterbody (Weis and Weis, 1992b; Weis and Weis, 1993; Weis, Weis and Couch, 1993; Weis, Weis and Lores, 1993). Exactly how long timber should be soaked to prevent environmental effects is not defined in the literature. This practice may also be difficult to achieve on site. As such, research is required to determine whether this is necessary in the context of Christchurch and Banks Peninsula environments, and if so, how long timber should be soaked for, and how this soaking would be achieved.
- Galvanised steel
  - Galvanised steel should not be used where there is highly anoxic sediment.
  - Where galvanised steel is used with H5 and H6 CCA treated timber, the timber should be pre-soaked to reduce corrosion of the steel.
- Concrete
  - Given the peak in pH observed after immersion of concrete in water, prefabricated concrete structures should be used where possible and washed/soaked for at least 24 hours before installation in waterways (Setunge *et al.*, 2009; Law *et al.*, 2013). Particular care should be taken to pre-soak concrete to be used in waterways with low velocity. It is unlikely that soaking is currently a standard practice in New Zealand and this could potentially be difficult to achieve with large structures. Research should be carried out to determine whether this is necessary for Christchurch and Banks Peninsula streams and how this could be achieved if so.
  - If concrete can only be poured, cured and soaked in-situ, this must occur in isolation from the waterway (e.g. within a dry cofferdam). Soakage water should be pumped out and removed. Research is recommended to investigate the effects of different water to concrete ratios and how often soakage water should be replaced - as well as how this could be practically achieved.
  - Storage time should be provided by suppliers.
  - Bulk leaching is high in porous concrete (where pores are interconnected) (Ekström, 2003); therefore, dense concrete (i.e. concrete with low porosity) should be used. In New Zealand, concrete pipes are typically machine made, producing dense, high strength concrete with low permeability (Concrete Pipe Association of Australasia, 2013). As such, soaking may only be required for other concrete structures, such as headwalls.
  - Heavily cracked and damaged concrete should be replaced to minimise leachates released into the environment, and to ensure the functionality and integrity of the structure.
- Additional research to that mentioned in the recommendations above is carried out to assess the effects of leaching from these instream structures on surface water quality and biota of Christchurch and Banks Peninsula waterways. In particular:
  - To establish what timber type should be used to address the issue of more leaching from fast grown wood of lower quality.
  - To determine whether the high use of pine in New Zealand means that the risks of leaching from CCA treated timber is greater than that recorded overseas and whether other wood products can be used to reduce environmental effects.
  - A survey (likely with anonymous participants) is carried out of current practices, comparisons between expected industry practice, what practices installers actually carry out and whether they believe they are following the guidelines, as well as an assessment of how difficult the recommendations in this memo would be to achieve.

  - Research into changes in stream geochemistry and whether this is attributable to urban development and concrete infrastructure.
  - Quantification, assessment and remediation prioritisation of old, heavily cracked and damaged concrete structures (e.g. pipes, outlets, piers), due to the increased risk they provide of leaching.
- The recommendations in this memo and from future research are incorporated into relevant Christchurch City Council (CCC) documents (e.g. Infrastructure Design Standard and Waterways Wetlands and Drainage Guide) and disseminated to other interested parties (e.g. industry and Regional Council's).

Table 1 Summary of each study investigating the leaching of Copper-Chrome-Arsenate (CCA) treated wood, including country where the study was undertaken, year of study, reference details, focus of the study and the main points from the study

Country of Origin	Year	Reference	Focus	Main Points
Germany (?)	1972	(Irvine, Eaton and Jones, 1972) *in* (Hingston *et al.*, 2001)	Leaching of CCA timber in marine water	• Marine water was found to increase copper and chromium loss compared to freshwater and sewage effluent. • Salinity from 0–24 ppt had no increased loss of copper.
Sweden	1984	(Plackett, 1984) *in* (Hingston *et al.*, 2001)	Laboratory study of leaching of CCA timber in salt solutions	• Wood soaked in salt solutions leached more copper than in deionized control water. • Leaching rates increased with higher salt concentrations.
Canada	1990	(Warner and Solomon, 1990)	Laboratory study of leaching of CCA timber in acidic conditions	• Low pH solutions resulted in very high leaching rates. • At pH 3.5, up to 100% of copper was leached.
United States of America	1991	(Cooper, 1991)	Laboratory study of leaching of CCA timber in acidic conditions	• In response to Warner & Solomon (1990), the strong result of leaching in acidic conditions was due to the citric acid buffer, and when a mineral acid was used, no consistent effect was found at pH 3.5–5.5.
United States of America	1991	(Weis, Weis and Coohill, 1991)	Laboratory study on the effect of CCA wood on aquatic biota	• Fiddler crabs (*Uca pugilator*) had their limbs removed and were placed in containers with variously sized treated wood or control wood. The rate of limb regeneration was inhibited in a dose-dependent manner and mortality occurred with the treated wood, reaching 100% in the tank with the largest piece of wood. • Mortality was recorded in mummichog (*Fundulus heteroclitus*) embryos that developed in culture dishes with CCA-treated timber. Mortality was recorded to a smaller extent in those with untreated wood.

Country of Origin	Year	Reference	Focus	Main Points
				• Within a few days of immersion in containers with CCA treated timber, chlorophyll content of algae (*Ulva lactuca*) reduced, and snails (*Nassarius obsoletus*) became moribund and died. In the controls containing untreated wood or no wood, no such effects were seen. • Copper was primarily responsible for algal bleaching and snail mortality. • Toxic effects from wood that had previously leached for several weeks were much less severe.
United States of America	1992	(Weis and Weis, 1992a) *in* (Weis and Weis, 2004)	Field study on the effect of CCA wood on aquatic biota	• CCA treated timber that was submerged in an estuary had lower species richness and diversity, and barnacles were less common and had reduced growth. • One species of bryozoan (*Bugula turrita*), was found in higher density on the treated wood.
United States of America	1992	(Weis and Weis, 1992b)	Laboratory and field study on the effect of CCA wood on aquatic biota	• Green algae (*Enteromorpha intestinalis* and *U. lactuca*) from CCA treated wood (c. 3 year old bulkheads and floating docks) had approximately four and three times as much copper respectively, two and three times as much chromium, and four and nine times as much arsenic, as algae from nearby rocks. • Snails (*N. obsoletus*) were fed green algae from CCA treated wood and after four weeks all snails were either retracted into their shells or dead. All control snails fed algae from nearby rocks remained active. • However, snails fed on algae collected from CCA treated timber did not have elevated metal concentrations in their tissue. • Metal concentrations were higher in older parts of the plant and lowest in the fast-growing tips. • Oysters (*C. virginica*) collected from a reference site, open water dock and a CCA timber lined canal. Compared to the reference site, copper levels were elevated in both the dock (two times) and canal (12 times) populations, but only the canal population had elevated arsenic. Chromium was below detection in all oysters. • Benthic living fiddler crabs (*Uca panacea* and *U. pugilator*) were also found to have elevated copper and arsenic concentrations in areas with CCA treated timber. Chromium levels in *U. panacea* did not vary across sites; however, levels in *U. pugilator* were elevated in association with CCA treated timber.
United States of America	1992	(Weis *et al.*, 1992)	Laboratory study on the effect of CCA	• Limb regeneration was depressed in fiddler crabs (*U. pugilator*) exposed to CCA treated timber.

Country of Origin	Year	Reference	Focus	Main Points
			wood and recycled plastic on aquatic biota	• One- and three-day leachate from CCA treated timber reduced sea urchin (*Arbacia punctulata*) fertilisation by 90% and completely inhibited larval development in the remaining 10%. A smaller piece of wood did not have significant effect of fertilisation or development. • With 1–3 weeks of leaching from the smaller piece of CCA treated timber, no fertilisation was seen in sea urchins. • Snails (*N. obsoletus*) and algae (*U. lactuca*) were exposed to CCA leachates for two months, and this caused 100% mortality in snails and chlorosis of the algae.
N/A	1993	(Brooks, 1993) *in* (Hedley, 1997)	Literature review of CCA and ACZA wood	• "Even with this very conservative approach to assessing the risks involved, this analysis indicates that the levels of contaminants associated with the use of properly treated CCA and AZCA [ammoniacal zinc copper arsenate] wood products are well below regulatory standards and will produce concentrations far below those causing acute or chronic stress in even the most sensitive taxa".
United States of America	1993	(Merkle, Gallagher and Soldberg, 1993) *in* (Hingston *et al.*, 2001)	Leaching of CCA timber	• Leaching may be more severe in field experiments due to increased physical stress, such as abrasion, cracking and borer.
United States of America	1993	(Weis and Weis, 1993)	Laboratory and field study on the effect of CCA wood on aquatic biota	• Copper concentrations in carnivorous snails (*Thais haemastoma*) fed oysters (*C. virginica*) collected from a CCA treated wood lined canal increased approximately four-fold compared to snails fed oysters collected from the reference site. These snails attained levels comparable to snails collected from a CCA bulkhead in open water. Snails were not found within the canal. • Snails fed oysters collected from CCA wood grew and gradually ate less than the control snails. • Fish (*Leiostomus xanthurus* and *Lagodon rhomboides*) collected from inside a CCA lined canal had five and seven times as much copper and arsenic than reference fish. *L. xanthurus* collected from the canal had elevated levels of chromium, however L. *rhomboides* had lower levels compared to the reference site. • Fish fed worms collected from adjacent to a CCA bulkhead facing open water had a non-significant trend of lower survival than those fed reference worms, and there was no significant difference in growth or CCA body burdens.

Country of Origin	Year	Reference	Focus	Main Points
United States of America	1993	(Weis, Weis and Couch, 1993) *in* (Weis and Weis, 2004)	The effect of CCA wood on aquatic biota	• Copper concentrations in oysters collected from within a CCA timber lined canal were 12 times higher than the reference site, while arsenic was about double the reference site. • Oysters collected from within a CCA timber lined canal were often greenish in colour. • A negative correlation between oyster weight and copper concentration indicates that levels dilute as they grow, which may have negative implications for predators that preferentially feed on smaller oysters. • Oysters collected from within a CCA timber lined canal had an elevated incidence of a pathological condition of the digestive diverticula. This condition did not appear in control oysters that were transplanted into the canal for three months.
United States of America	1993	(Weis, Weis and Lores, 1993)	Field study on the effect of CCA wood on aquatic biota	• Algae (*Ceramium* sp.) growing on a CCA treated timber dock in open water had approximately double the copper and arsenic concentrations of the reference site. Algae was not found in the canal. • Barnacles (*Balanus eburneus*) growing on a CCA treated dock had copper concentrations approximately three times higher than those on nearby rocks, while those in a CCA timber treated canal had levels approximately 10 times that of the reference site rocks. Barnacles attached to new wood in the canal had concentrations approximately 80 times higher than the reference. Chromium and arsenic were also elevated in the canal, particularly in barnacles attached to the new wood. • Mussels (*Brachydontis recurvis*) collected from the canal had elevated copper concentrations (c. 7 times) compared to the reference site. It is likely that the increase in chromium (from below to above detection) is biologically significant.
United States of America	1993	(Weis, Weis and Proctor, 1993)	Field study of CCA timber leaching in estuarine sediment	• Metals were found to accumulate in fine sediment, such as silt or clay. • Metals were found in higher concentrations in the newest bulkhead. • Poorly flushed areas had higher metal concentrations than in more open water environments. • Copper concentration was always much higher than chromium or arsenic.
United States of America	1994	(Cooper, 1994) *in* (Hingston *et al.*, 2001)	Leaching of pressure treated CCA wood	• Studies typically use small blocks of wood, which have a high surface area available for leaching. • High concentrations of humic acid in surface water may increase leaching.

Country of Origin	Year	Reference	Focus	Main Points
Ireland	1994	(Hayes, Curran and Hynes, 1994)	Field study of leaching of CCA timber in coastal waters	• The poor-quality timber (Lodgepole pine: *Pinus contorta*) leached more metals than the better-quality timber (Douglas fir: *Pseudotsitga menziesii*). • Arsenic was more readily leached than copper or chromium. • Larger blocks leached less than smaller blocks.
United States of America	1994	(Weis and Weis, 1994)	Field study on the effect of CCA wood on aquatic biota	• Metals were elevated in subtidal benthic worms living adjacent to CCA treated bulkheads and decreased with distance from the bulkhead. • Compared to reference sites, the benthic community adjacent to the bulkheads had lower species richness, total abundance and species diversity.
Belgium/ Sweden	1995	(Van Eetvelde *et al.*, 1995b; Van Eetvelde *et al.*, 1995a) *in* (Hingston *et al.*, 2001)	Leaching of CCA timber in acidic conditions	• Maximum leaching of chromium and arsenic was recorded under neutral conditions; however, initial loss of copper increased with higher acidity. • Leaching rates were lower at lower temperatures.
United States of America	1995	(Weis *et al.*, 1995)	Field study on the effect of CCA wood on aquatic biota	• Oysters (*Crassostrea virginica*) living inside a canal lined with CCA treated timber bulkheads had twice as many micronuclei in gill cells as reference oysters and had significantly more metaplastic degeneration in digestive gland diverticula. • The number of micronuclei in control oysters transplanted into the canal significantly increased after three months; however, they did not show increased digestive gland metaplasia. • Other possible stressors in the canal (e.g. boat exhaust, gardening chemicals) could be involved.
United States of America	1996	(Weis and Weis, 1996)	Field study on the effect of CCA wood on aquatic biota	• When the epibiota from the CCA treated timber was removed after one month and the timber returned to the water, the subsequent epibiota differed less compared to the control. On the third submersion, there was no statistically significant difference between the treatment and control. This indicates that toxicity reduced after a period of soaking. • However, growth of algae (*Enteromorpha* sp.) and a bryozoan (*Conopeum* sp.) was still impacted. • Study provides evidence that timber would have reduced environmental impact if it were soaked prior to leaving the treatment facility.

Country of Origin	Year	Reference	Focus	Main Points
United States of America	1996	(Wendt *et al.*, 1996)	Field study on the effect of CCA wood on aquatic biota	• In some cases metal concentrations were higher in sediments and oysters (*C. virginica*) immediately adjacent to docks; however, sediments from most sites had concentrations below the level reported to cause biological effects. • No significant difference was seen in sediments between creeks with high numbers of docks compared to those without docks. • Copper concentrations were significantly higher in oysters growing directly on dock pilings than those at least 10 m away; however, there was no significant difference in the physiological condition. • In a four day experiment, there was no significant difference in percent survival of mummichogs (*F. heteroclitus*), mud snails (*Ilyanassa obsoleta*), juvenile red drum (*Sciaenops ocellatus*), and juvenile white shrimp (*Penaeus setiferus*) between sites near to and distant from newly constructed docks. • There was no significant difference in percent survival, growth, or bioaccumulation of metals in oysters (*C. virginica*) after six weeks of exposure to newly constructed docks (4–12 months old). • The results indicate that in estuarine environments (tidal range 1.5-2.0 m) CCA leachates from dock pilings do not have acutely toxic effects on four common estuarine species, nor do they affect the short-term survival or growth of juvenile oysters.
N/A	1997	(Hedley, 1997)	Literature review of CCA wood	• Some leaching occurs from freshly treated wood, but most studies indicate this adds little to background levels. • The fixation process is time and temperature dependant, and CCA wood should never leave the treatment site for at least two weeks. • Issues tend to arise when quality assurance requirements are not complied with. •
United States of America	1998	(Breslin and Adler-Ivanbrook, 1998)	Laboratory study of Leaching of CCA timber in estuarine water	• Metals leached continuously, but at a decreasing rate throughout the 90-day study. • Leaching rates of arsenic were lower at higher temperatures (4°C and 20°C). • Studies where the leachate solution is replaced infrequently may inhibit the diffusion of elements from the wood.

Country of Origin	Year	Reference	Focus	Main Points
United States of America	1998	(Weis, Weis and Proctor, 1998)	Field study of CCA timber leaching on estuarine the benthos	• Leachates from new pilings have negligible ecological effects in reasonably flushed areas. • Leachates '…from bulkheads, particularly new ones and those in poorly flushed regions, have effects that can be seen in some cases out to 10 m and for a number of years'. • Metal concentrations in benthic organisms generally paralleled levels within the surrounding sediment. • Concentrations were typically elevated 0-1 m from the bulkheads; however, in some cases extended to 10 m. The inconsistent reduction up to 10 m out was attributed to a variety of factors such as age of the bulkhead, energy of the environment and the nature of the sediments.
United States of America	1999	(Weis and Weis, 1999)	Field study on the effect of CCA wood on aquatic biota	• In a three month caged field experiment, epibiota from CCA treated timber had elevated copper and arsenic, while amphipods also had elevated copper when compared to the control. • Caged grass shrimp (*Palaemonetes pugio*), naked gobies (*Gobiosoma bosci*) and mummichogs (*F. heteroclitus*) did not have elevated metals. • Trophic transfer was not demonstrated to the consumers, indicating that the treated wood did not present a hazard to higher trophic levels.
United Kingdom	2000	(Tupper, Pitman and Cragg, 2000)	Field study on the effect of CCA wood on aquatic biota	• A marine isopod (*Limnoria* spp.) was able to bore through CCA treated timber by storing copper in inert granules in their digestive caecae and therefore did not suffer toxic effects. • Neither chromium nor arsenic were elevated in granules or the digestive caecal cells.
United Kingdom	2001	(Brown and Eaton, 2001)	Field study of leaching of CCA timber on aquatic biota in coastal waters	• After 6, 12 and 18 months, epibiotic communities on CCA treated timber were similar to untreated wood.
N/A	2001	(Hingston *et al*., 2001)	Literature review of CCA wood	• Insufficient data exists to allow accurate quantification of leaching rates and there is a need for standardised leaching protocols. • Factors affecting leaching rates included pH, salinity, surface area-to-volume ratio, treatment and leaching test protocols.

Country of Origin	Year	Reference	Focus	Main Points
England	2001	(Prael, Cragg and Henderson, 2001) *in* (Weis and Weis, 2004)	Laboratory study on the effect of CCA wood on aquatic biota	• Early veliger stage of larval oysters (*Crassostrea gigas*) avoided concentrated leachate. • Three- and seven-day old larvae swam faster in leachate than in clean sea water, they also moved up and down more in the leachate.
United States of America	2002	(Rice, Conko and Hornberger, 2002)	Field study of anthropogenic sources of metals in a lake	• Metal concentrations in lake sediment from CCA treated lumber accounted for 50% of the arsenic and 4% of the copper present.
United States of America	2002	(Weis and Weis, 2002)	Field study of CCA timber leaching on saltmarshes	• Metal concentrations were highly elevated up to 10 m away, the maximum extent of the sampled area. • Concentrations were more elevated under the new (3 years) walkway than the old (15 years) walkway but had not dispersed as far. • Accumulation was generally highest in the low marsh, where tidal inundation was most frequent. • Accumulation patterns in saltmarsh plants were similar to sediments; however, elevated levels did not disperse as far and did vary depending of the age of the walkway.
Hong Kong	2003	(Chan, Wang and Ni, 2003)	Laboratory study of cadmium, chromium and zinc assimilation through trophic levels	• Macroalgae (*Enteromorpha crinita*) with various elevated levels of chromium were fed to the herbivorous marine rabbitfish (*Siganus canaliculatus*). Metals were assimilated at appreciable levels regardless of metal concentration within the algae.
United States of America	2004	(Weis and Weis, 2004)	Literature review of effects of CCA wood on biota	• CCA treated timber contains Cr(VI), which is highly genotoxic. • Newly treated CCA timber leaches the fastest and is therefore the most toxic. • Environmental impacts from the use of CCA treated timber could be considerably reduced if timber was soaked for a few months before being released to the market.

Country of Origin	Year	Reference	Focus	Main Points
				• There have been no studies investigating ecosystem level impacts in the aquatic environment. • Most harmful effects appear to be due largely to copper. •
India	2008	(Sreeja, 2008)	Laboratory study on the effect of CCA wood on aquatic biota	• Six types of CCA treated timber ('treatments') were submerged into still freshwater tanks for six months and the effects on fish were assessed. A control tank with untreated timber was also used. • Highly acidic CCA treated wood did not cause a significant change in pH. • In all treatments fish showed excess mucus secretion, but not the control. • The highest accumulation of all three metals was in the liver, while the lowest was in muscle. • All three metals were detected in the gills of the control group. • Fishes exposed to CCA timber showed an increase in metal concentrations when compared to the control samples, although there was some overlap. • Laboratory studies may overestimate the impacts of metals due to limited dilution. • Dip treated panels leached more quickly than pressure treated.

Table 2. Summary of each study investigating corrosion of galvanised steel, including country where the study was undertaken, year of study, reference details, focus of the study and the main points from the study

Country of Origin	Year	Reference	Focus	Main Points
South Africa	1974	(Costello, 1974)	Laboratory study on sulphur reducing bacteria	• The production of hydrogen sulphide by sulphur reducing bacteria may be causing corrosive effects rather than sulphur reducing bacteria themselves, as has been proposed elsewhere.
Italy	1974	(Mor, Beccaria and Poggi, 1974)	Laboratory study on impact on corrosion of annealed zinc bars	• In artificial seawater with a pH >7.2, corrosion of zinc was accelerated in the presence of sulphides.
South America	1989	(Bednar, 1989)	Field study on corrosion of galvanised steel pipes/culverts	• Most issues are around durability and accelerated waterside corrosion. • Most important factors in corrosion are water chemistry (pH, TSS, hardness and alkalinity), degree of agitation, temperature and time of water contact. • “Hardness and alkalinity salts common to natural waters tend to form partially protective mineral scales or films that hinder corrosion of reactive metals like zinc and steel which otherwise would tend to corrode excessively”. • “Soft, pure low-conductivity waters containing very little of any type of dissolved salt, including hardness/alkalinity salts, tend to be fairly corrosive because they possess no scaling tendency and they lack the buffering capacity that leads to pH lowering.” • “The balance between hardness and alkalinity on one hand versus acidity and chloride/sulfate salts on the other is critical in determining whether protective scaling or excessive corrosion will occur”. • Soft water in drier temperate climates is less harsh than soft water in warm, wet tropical climates.

Country of Origin	Year	Reference	Focus	Main Points
				• Galvanized steel pipe is sufficiently durable to be used in most soft waters, and certainly for limited life requirements. • "Excessive free CO_2 suppresses scaling and directly accelerates corrosion, and the combined effect of excess CO_2 and higher conductivity can be very severe. Slow flowing streams in areas with somewhat impeded drainage are more likely to be rich in free C02 because higher velocity greatly aerates the water and drives off C02". • Physical steel erosion processes can be worsened as high velocities slough off the protective scale.
Turkey	2007	(Ilhan-Sungur, Cansever and Cotuk, 2007)	Laboratory study on galvanised steel corrosion by sulphur reducing bacteria	• Galvanized steel is frequently used in construction due to its resistance to corrosion and biofouling. • Sulphur reducing bacteria reduce inorganic sulphate to hydrogen sulphide. • Study demonstrated that sulphur reducing bacteria are able to corrode galvanized steel.

Table 3. Summary of each study investigating concrete effects, including country where the study was undertaken, year of study, reference details, focus of the study and the main points from the study

Country of Origin	Year	Reference	Focus	Main Points
Sweden	2003	(Ekström, 2003)	Thesis on durability and strength of concrete	• Corrosion can be caused by water itself, or by matter dissolved in the water. • Calcium-silicate-hydrate (a product in concrete) is soluble in water, and the most important factors influencing leaching are aggressiveness of the water and permeability of the concrete. • Bulk leaching is high in porous concrete (where pores are interconnected), but low through cracks. However, localised leaching (e.g. in a crack) is often very high. Permeability is considered the most important property affecting concrete durability.
Australia	2009	(Setunge *et al.*, 2009)	Laboratory study on leaching of fresh cast concrete	• Early contact with water after casting (up to the study maximum of 120 hours) can result in pH levels of up to 11, which is similar to levels in pore water of freshly cast concrete. • Time since casting (20, 48 and 120 hours) did not materially affect changes in pH, with all samples following the same pattern of peaking around pH 11, and slowly falling over the following 30–35 days. • Even after 35 days, pH did not reduce below 8.5. However, the experiment was conducted in low velocity water. • For normal concrete to water ratios as observed in bridges and culverts, peak pH can be expected to occur about one day from initial contact.

Turkey	2012	(Basar and Aksoy, 2012)	Laboratory study on leaching of cast concrete	• Eluate concentrations for all three tested metals (nickel, zinc and chromium) were typically lowest at pH 5.5.
				• To provide context for CCC waterways, metal concentrations in eluate from this paper were compared to the Canterbury Land and Water Regional Plan (Environment Canterbury, 2018) guideline concentrations as below:
				  ○ Nickel: All eluate at pH 5.5 and 9.0 were below the 90% and 99% Species Protection Level (SPL) of 0.013 mg/L, but not at pH 4.0.
				  ○ Zinc: Generally, eluate at pH 5.5 was just below the 90% SPL of 0.015 mg/L. However, levels were above the SPL at pH 4.0 and 9.0.
				  ○ Chromium: No value was recorded below the 90% SPL of 0.006 mg/L.
				• It is unclear whether metals given are totals or dissolved – if totals, comparisons to the SPL will be conservative.

Australia	2013	(Law *et al.*, 2013)	Laboratory study on	• Concrete either one or four days after casting was immersed in water and exposed to two velocities.

Country of Origin	Year	Reference	Focus	Main Points
			leaching of fresh cast concrete in slow flowing streams	• Velocity was the most significant factor in peak pH and the time until peak pH. The volume of the sample was also a significant factor in peak pH. • Slower velocity resulted in pH peaking higher, later and for longer. • In slower velocities, peak pH was recorded at over an hour after immersion, while at the faster velocity peak pH was recorded between 15–30 minutes. • Although not significant, concrete immersed one day after casting had a higher mean peak pH than those immersed after four days.
New Zealand	N/A	(Environment Canterbury, undated)	Planning document on concrete wash and dust	• Concrete wash and dust is trade waste and must be disposed of correctly, and never into a waterway. • 100,000 L of water would be required to dilute 1 L of concrete wash, and filtering has no effect on toxicity.

References

Bak, F. and Pfennig, N. (1991) 'Sulfate-reducing bacteria in littoral sediment of Lake Constance', *FEMS Microbiology Letters,* 85(1), pp. 10.

Baker, A. J. (1992) 'Corrosion of nails in CCA-and ACA-treated', *Forest Products Journal,* 42(9), pp. 39.

Basar, H. and Aksoy, N. (2012) 'The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete', *Construction and Building Materials,* 35, pp. 8.

Bednar, L. (1989) 'Durability of plain galvanized steel drainage pipe in South America: criteria for selection', *Transportation Research Record,* 1231, pp. 8.

Breslin, V. and Adler-Ivanbrook, L. (1998) 'Release of copper, chromium and arsenic from CCA-C treated lumber in estuaries', *Estuarine, Coastal and Shelf Science,* 46(1), pp. 15.

Brooks, K. (1993) *Literature review and assessment of the environmental risks associated with the use of CCA and ACZA treated wood products in aquatic environments*, Vancouver, WA, United States of America: Western Wood Preservers Institute.

Brown, C. and Eaton, R. (2001) 'Toxicity of chromated copper arsenate (CCA)-treated wood to non-target marine fouling communities in Langstone Harbour, Portsmouth, UK', *Marine pollution bulletin,* 42(4), pp. 9.

Chan, S., Wang, W. and Ni, I. (2003) 'The uptake of Cd, Cr, and Zn by the macroalga *Enteromorpha crinita* and subsequent transfer to the marine herbivorous rabbitfish, *Siganus canaliculatus*', *Archives of environmental contamination and toxicology,* 44(3), pp. 9.

Concrete Pipe Association of Australasia (2013)*: Guide to Understanding AS/NZ 4058:2007.*

Cooper, P. (1991) 'Leaching of CCA from treated wood: pH effects', *Forest Products Journal,* 41(1), pp. 3.

Cooper, P. (1994) 'Leaching of CCA: is it a problem? Environmental considerations in the manufacture, use and disposal of pressure treated wood', *Forest Products Society.*

Costello, J. (1974) 'Cathodic depolarization by sulphate-reducing bacteria', *South African Journal of Science,* 70(7), pp. 3.

Ekström, T. (2003) *Leaching of concrete: the leaching process and its effects.* PhD, Lund Institute of Technology, Lund, Sweden.

Environment Canterbury (2018) *Canterbury Land and Water Regional Plan*, Christchurch, New Zealand: Environment Canterbury.

Environment Canterbury (undated) *Concrete washwater; what you need to know.*

Greig, H., Niyogi, D., Hogsden, K., Jellyman, P. and Harding, J. (2010) 'Heavy metals: confounding factors in the response of New Zealand freshwater fish assemblages to natural and anthropogenic acidity', *Science of the Total Environment,* 408(16), pp. 11.

Hayes, C., Curran, P. and Hynes, M. (1994) 'Preservative leaching from softwoods submerged in Irish coastal waters as measured by atomic absorption spectrophotometry', *Holzforschung,* 48, pp. 11.

Hedley, M. (1997) *An assessment of risks associated with use of CCA-treated timber in sensitive environments and options for its substitution with alternative timber materials*, Wellington, New Zealand: Department of Conservation154).

Hingston, J., Collins, C., Murphy, R. and Lester, J. (2001) 'Leaching of chromated copper arsenate wood preservatives: a review', *Environmental Pollution,* 111(1), pp. 14.

Horrox, J., Chaney, E. and Eaves, A. (2015) *West Coast surface water quality report*, West Coast, New Zealand: West Coast Regional Council14001).
Ilhan-Sungur, E., Cansever, N. and Cotuk, A. (2007) 'Microbial corrosion of galvanized steel by a freshwater strain of sulphate reducing bacteria (*Desulfovibrio* sp.)', *Corrosion Science*, 49(3), pp. 13.
Irvine, J., Eaton, R. and Jones, E. (1972) 'The effect of water of different ionic composition on the leaching of a water borne preservative from timber placed in cooling towers and in the sea', *Material und Organismen*, 7, pp. 27.
Jane, F. (1970) *The structure of wood. Revised by Wilson, K. and White, D.* London, England: Adam and Charles Black, p. 478.
Jørgensen, B. and Bak, F. (1991) 'Pathways and microbiology of thiosulfate transformations and sulfate reduction in a marine sediment (Kattegat, Denmark)', *Appl. Environ. Microbiol.*, 57(3), pp. 10.
Kear, G., Wú, H.-Z. and Jones, M. (2009) 'Weight loss studies of fastener materials corrosion in contact with timbers treated with copper azole and alkaline copper quaternary compounds', *Corrosion Science*, 51(2), pp. 11.
Law, D., Setunge, S., Adamson, R. and Dutton, L. (2013) 'Effect of leaching from freshly cast concrete on pH', *Magazine of Concrete research*, 65(15), pp. 9.
Marshall, W. and Noakes, K. (2019) *Surface Water Quality Monitoring Report for Christchurch City Waterways: January – December 2018*: Christchurch City Council.
Merkle, P., Gallagher, D. and Soldberg, T. 'Leaching rates, metals distribution and chemistry of CCA treated lumber: implications for water quality monitoring'. *Forest Product Society's Symposium, Environmental Considerations in the Use of Pressure-Treated Wood*, Maddison, Wisconsin, United States of America, 10.
Mor, E., Beccaria, A. and Poggi, G. (1974) 'Behaviour of zinc in sea water in the presence of sulphides', *British Corrosion Journal*, 9(1), pp. 4.
New Zealand Timber Preservation Council Inc, Department of Labour and Zealand, E.R.M.A.N. (2005) *Best practice guideline for the use of timber preservatives & anti-sapstain chemicals.* Wellington, New Zealand.
Nielsen, J., Liesack, W. and Finster, K. (1999) '*Desulfovibrio zosterae* sp. nov., a new sulfate reducer isolated from surface-sterilized roots of the seagrass *Zostera marina*', *International Journal of Systematic and Evolutionary Microbiology*, 49(2), pp. 7.
Pacific Northwest Pollution Prevention Resource Center 2014. Emerging best management practices in stormwater: a ddressing galvanized r oofing Seattle, Washington, United States of America.
Plackett, D. (1984) *Leaching tests on CCA treated wood using inorganic salt solutions (IRG/WP 3310)*, Stockholm, Sweden.
Prael, A., Cragg, S. and Henderson, S. (2001) 'Behavioral responses of veliger larvae of *Crassostrea gigas* to leachate from wood treated with copper-chrome-arsenic (CCA): a potential bioassay of sublethal environmental effects of contaminants', *Journal of Shellfish Research*, 20(1), pp. 7.
Rice, K., Conko, K. and Hornberger, G. (2002) 'Anthropogenic sources of arsenic and copper to sediments in a suburban lake, northern Virginia', *Environmental science & technology*, 36(23), pp. 6.
Setunge, S., Nguyen, N., Alexander, B. and Dutton, L. (2009) 'Leaching of alkali from concrete in contact with waterways', *Water, Air, & Soil Pollution: Focus*, 9(5-6), pp. 381.
Sreeja, A. (2008) *Chromated copper arsenate (CCA) treatment for rubber wood preservation and its impact on the aquatic biota.* Doctor of Philosophy, Cochin University of Science and Technology, Cochin, India.

Standards Australia and Standards New Zealand (2006) *AS/NZS 2843.1:2006: Timber preservation plants. Part 1: timber preservation plant site design*. Jointly published in Sydney, Australia & Wellington, New Zealand: Standards Australia & Standards New Zealand

Standards New Zealand (2003) *NZS 3640:2003: Chemical preservation of round and sawn timber*. Wellington, New Zealand: Standards New Zealand.

Taylor, H. (1997) *Cement chemistry.* Thomas Telford London.

Tippler, C., Wright, I., Davies, P. and Hanlon, A. (2014) 'The influence of concrete on the geochemical qualities of urban streams', *Marine and Freshwater Research,* 65(11), pp. 9.

Tupper, C., Pitman, A. and Cragg, S. (2000) 'Copper accumulation in the digestive caecae of *Limnoria quadripunctata* Holthius (Isopoda: Crustacea) tunnelling CCA-treated wood in laboratory cultures', *Holzforschung,* 54(6), pp. 7.

Van Eetvelde, G., Homan, W., Militz, H. and Stevens, M. 'Effect of leaching temperature and water acidity on the loss of metal elements from CCA treated timber in aquatic conditions. Part 2: semi-industrial investigation'. *The challenge: safety and environment*, Cannes-Mandelieu, France: The International Research Group on Wood Preservation, Stockholm., 13.

Van Eetvelde, G., Orsler, R., Holland, G. and Stevens, M. 'Effect of leaching temperature and water acidity on the loss of metal elements from CCA treated timber in aquatic applications, 1: Laboratory scale investigation', *The International Research Group on Wood Preservation, Sweden*.

Warner, J. and Solomon, K. (1990) 'Acidity as a factor in leaching of copper, chromium and arsenic from CCA-treated dimension lumber', *Environmental Toxicology and chemistry,* 9(11), pp. 7.

Weis, J. and Weis, P. (1992a) 'Construction materials in estuaries: reduction in the epibiotic community on chromated copper arsenate (CCA) treated wood', *Marine Ecology Progress Series*, pp. 9.

Weis, J. and Weis, P. (1992b) 'Transfer of contaminants from CCA-treated lumber to aquatic biota', *Journal of Experimental Marine Biology and Ecology,* 161(2), pp. 11.

Weis, J. and Weis, P. (1993) 'Trophic transfer of contaminants from organisms living by chromated-copper-arsenate (CCA)-treated wood to their predators', *Journal of Experimental Marine Biology and Ecology,* 168(1), pp. 10.

Weis, J. and Weis, P. (1994) 'Effects of contaminants from chromated copper arsenate-treated lumber on benthos', *Archives of Environmental Contamination and Toxicology,* 26(1), pp. 7.

Weis, J. and Weis, P. (1996) 'Reduction in toxicity of chromated copper arsenate (CCA)-treated wood as assessed by community study', *Marine Environmental Research,* 41(1), pp. 11.

Weis, J. and Weis, P. (2002) 'Contamination of saltmarsh sediments and biota by CCA treated wood walkways', *Marine Pollution Bulletin,* 44(6), pp. 7.

Weis, J. and Weis, P. 'Effects of CCA wood on non-target aquatic biota'. *Environmental Impacts of Preservative-Treated Wood.*, Florida Center for Solid and Hazardous Waste Management, Gainesville, FL., 13.

Weis, J., Weis, P. and Proctor, T. (1998) 'The extent of benthic impacts of CCA-treated wood structures in Atlantic coast estuaries', *Archives of Environmental Contamination and Toxicology,* 34(4), pp. 10.

Weis, P. and Weis, J. (1999) 'Accumulation of metals in consumers associated with chromated copper arsenate-treated wood panels', *Marine environmental research,* 48(1), pp. 9.

Weis, P., Weis, J. and Coohill, L. (1991) 'Toxicity to estuarine organisms of leachates from chromated copper arsenate treated wood', *Archives of Environmental Contamination and Toxicology,* 20(1), pp. 7.

Weis, P., Weis, J. and Couch, J. (1993) 'Histopathology and bioaccumulation in oysters *Crassostrea virginica* living on wood preserved with chromated copper arsenate', *Diseases of aquatic organisms,* 17(1), pp. 6.

Weis, P., Weis, J., Couch, J., Daniels, C. and Chen, T. (1995) 'Pathological and genotoxicological observations in oysters (Crassostrea virginica) living on chromated copper arsenate (CCA)-treated wood', *Marine Environmental Research,* 39(1-4), pp. 4.

Weis, P., Weis, J., Greenberg, A. and Nosker, T. (1992) 'Toxicity of construction materials in the marine environment: a comparison of chromated-copper-arsenate-treated wood and recycled plastic', *Archives of Environmental Contamination and Toxicology,* 22(1), pp. 8.

Weis, P., Weis, J. and Lores, E. (1993) 'Uptake of metals from chromated-copper-arsenate (CCA)-treated lumber by epibiota', *Marine Pollution Bulletin,* 26(8), pp. 3.

Weis, P., Weis, J. and Proctor, T. (1993) 'Copper, chromium, and arsenic in estuarine sediments adjacent to wood treated with chromated-copper-arsenate (CCA)', *Estuarine, Coastal and Shelf Science,* 36(1), pp. 9.

Wendt, P., Van Dolah, R., Bobo, M., Mathews, T. and Levisen, M. (1996) 'Wood preservative leachates from docks in an estuarine environment', *Archives of environmental contamination and toxicology,* 31(1), pp. 14.

Widdel, F. and Bak, F. (1992) 'Gram-negative mesophilic sulfate reducing bacteria', in A. Balows, H.T., M. Dworkin, W. Harder, K Schleifer (ed.) *The Prokaryotes*. New York: Springer Verlag.

Winterbourn, M. and McDiffett, W. (1996) 'Benthic faunas of streams of low pH but contrasting water chemistry in New Zealand', *Hydrobiologia,* 341(2), pp. 11.

Wise, L. and Jahn, E. (1952) *Wood Chemistry. American Chemical Society Monograph Series* 2nd edn. New York, United States of America: Reinhold.

Yadav, A., Nishikata, A. and Tsuru, T. (2004) 'Electrochemical impedance study on galvanized steel corrosion under cyclic wet–dry conditions—influence of time of wetness', *Corrosion Science,* 46(1), pp. 13.

Zelinka, S., Sichel, R. and Stone, D. (2010) 'Exposure testing of fasteners in preservative treated wood: gravimetric corrosion rates and corrosion product analyses', *Corrosion Science,* 52(12), pp. 6.

Appendix B. Interview Guide and Reponses

Appendix B provides the aggregated responses for each question. Questions that were not answered and do not require comment have been removed. Some specific details during the manufacturing stage have been left out for ethical considerations.

THEME #1: INFORMATION ON BACKGROUND OF INTERVIEWEE

1. Organisation Type

   The participants represented a range of organisations that included: civil construction companies; manufactures of CCA treated timber and concrete; management of stormwater, freshwater and potable water; earthworks; pipework; and structure maintenance. All were often involved in million-dollar projects and all had experienced some involvement in the installation of instream structures.

2. Role

   The participants held a variety of roles such as managers, support staff, company representatives and environmental liaison officers.

3. How long you have been in the sector?

   The period that the participants had been in the sector ranged between 3 and 30 years.

4. Interest in the sector?

   A range of interests were identified by the participants as to why they had become involved in the sector. Many commented that they enjoyed the work and its outcomes, some sought work in the sector because it was challenging, and others stated that their career was a natural progression from education. Some also described how their role had progressed as a result of family history and involvement in the sector over many years.

THEME #2: CHROMATED COPPER ARSENATE (CCA) TREATED TIMBER

5. We are interested in how companies use CCA treated timber, either temporarily or permanently in Canterbury waterways for structures such as waterway linings or retaining walls. Have you ever used this material in waterways?

- If so, can you tell me about the types of structures and where you have used them?

All of the contractors who participated had used CCA treated timber in waterways in various ways that included drainage, retaining walls, weir structures, fences, boardwalks, walkways, and cycleways. Many had completed the work for the council, and all of them stated that these types of jobs are tenders that have already been designed and specified.

6. In freshwater environments do you use H4 class timber, if so, can you tell me about that?

Participants that had used H4 class timber described it as being part of the materials used for structures, such as retaining walls or for the platform component of a boardwalk over wetlands. It was clear that the reason for using H4 class timber was because it had been detailed in the specifications of the job, and that this was the material to be used due to its location on the structure, (e.g., because it may have been the part of the structure that was not in contact with water).

7. In estuarine or coastal environments do you use either H5 or H6 class timber, if so, can you tell me about that?

H6 class timber had most commonly been used by contractors in marine areas, examples included wharves and weirs. It was difficult for the contractors to be exactly sure when they had used H5 as opposed to H6 from memory. But they were aware that it was dependent on whether the timber was going to be submerged in water and in what type of water that was going to be (i.e., freshwater or saltwater). Like in the responses to question 6, it was clear that the reason for using the varying types of timber class, was because it had been detailed in the specifications of the job, and that they were not involved in deciding which material was going to be used.

8. When using CCA treated timber do you ensure that fixation[3] has been achieved according to the relevant New Zealand standards and guidelines[4], for example using a Merck test or equivalent, if so, what can you tell me about that?

It appeared that most representatives of the contractors, apart from one, had no awareness of the fixation process or the Merck test. The one contractor who did was aware of this because they had been to a timber manufacturing yard to learn about the process of preparing the timber. The site visit was to assist the company, in deciding which supplier to use to supply timber for a large project that they were completing. After the tour, they were satisfied that the process at the supply yard sufficiently met the relevant standards, they felt confident to go ahead with the order, and have subsequently used this manufacturer ever since. The general reason for the contractors being unaware of fixation or the Merck test, was said to be because they do not complete that part of the process themselves. They assume that the timber is adequately prepared for the use they have purchased it for, which is in accordance with the supplier's product description. For example, if they purchase timber from a supplier that was listed as marine grade H6 then they assume that this timber has been prepared to this standard, and that the product is ready to be used. One participants also said that whether the supplier manufactures the timber according to the standards is not something that they ask.

The representative of the manufacturing and supply of timber was instead, knowledgeable, and familiar with the process of fixation and the Merck test. This step is a crucial part of their manufacturing process. The process of fixation and the Merck test are the final stages of preparation. The details of the prior treatment (e.g., preparation and conditioning) are described in the response to question 9. During this final stage of preparation, a heat fixation process is used which induces the chemical reaction to occur. During this time heat is applied to the timber which they say allows a chemical reaction to occur. They described how this reaction properly fixes the CCA treatment in place. More simply: fixation is a chemical reaction that happens between the elements in that chemical. The fixation process has to occur for that chemical to be locked in. The participants said that the last chemical to change state

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[3] CCA (copper chrome arsenate) fixation is where timber is held in a bunded area to ensure the CCA solution is fully fixed to the timber cells prior to use, to prevent leaching of chemicals. Most CCA treated timber is produced by a process that accelerates the fixation mechanism and which leaves the timber surfaces clean and relatively dry. Hence, the potential for leaching of elements is reduced and the impact on the environment when the timber goes into service is minimised.

[4] These include:

- New Zealand Timber Preservation Council Inc, Department of Labour and Zealand, E.R.M.A.N. (2005) Best practice guideline for the use of timber preservatives & anti-sapstain chemicals. Wellington, New Zealand.
- Standards Australia and Standards New Zealand (2006) AS/NZS 2843.1:2006: Timber preservation plants. Part 1: timber preservation plant site design. Jointly published in Sydney, Australia & Wellington, New Zealand: Standards Australia & Standards New Zealand.
- Standards New Zealand (2003) NZS 3640:2003: Chemical preservation of round and sawn timber. Wellington, New Zealand: Standards New Zealand.

and fix in the process is chrome, this is supported by the research from Cooper and Ung (1993) and Radivojevic and Cooper (2010).

The manufacturers were clear that fixation is a crucial part of the process to prevent the timber from leaching. They said that it is a relationship between time and temperature, the lower the temperature the longer the process will take. This is consistent with the literature (Kazi & Cooper, 2000; Nasheri, Pearson, Pendlebury, Drysdale, & Hedley, 1999). And so, if a manufacturer does not use a heat treatment then the timber may take weeks or months to become fixed before it can be sold, which is supported by the work of Kazi and Cooper (2000). For this participant, a Merck test is used to check if the timber has fixed. A core sample from the timber is taken, and a solution is applied to it. A colour change takes place because the state of the element changes and the sample can be compared to a colour chart. The colour change will represent whether the timber is fixed, this is very similar to the process described by Cooper and Ung (1993).

The manufacturers described how historically fixation had been achieved naturally, which is time and temperature dependent. They now heat-fix using machinery and therefore the process is consistent and achieves the same standard every time. And so, during the initial development of the procedure using machinery, they would check every time using a Merck test to determine whether the timber was fixed. They said that the timber is either fixed; or not fixed (Cooper & Ung, 1993). Once they had reached a scenario where 100% of their tests showed that the timber had been fixed, they reduced their Merck testing frequency. This is because they are sure that the same standard and consistency of fixation is achieved every time when the timber goes into the machinery. They now sometimes complete the Merck test during an audit period, randomly, or when a client requests it. The participants described how the treatment does not penetrate through to the heartwood, which is the very core of the timber. This is the reason why the contractors that need to cut timber at the site of installation need to retreat the newly exposed timber, which is described in the responses to Question 9.

9. Are there any other methods you use to prepare the timber? / What are the methods (if any) you use to prepare the timber that you supply?

All of the participants who represented the contractors were clear that the only preparation that they might need to do on-site is to cut the timber. In the case of cutting the timber, it is most likely detailed in the job specifications that the newly exposed wood must be retreated with a sealing agent. There appeared to be a variety of sealing agents, as some described it as a paint-on solution and others described it as a spray. One respondent gave an example of a product that they might use for this called CD50. One participant also described how they might have to steam the timber to enable it to be formed if it is being cast in situ (on-site); it seems reasonable to assume that this is to allow the timber to bend. Other than retreating the cut timber, the participants were very clear that there are no other methods that they have used in the past or present, that are needed to prepare the timber on-site.

At the manufacturing end of this topic, the response, like question 8, was quite different from that of the contractors. The participant gave a step-by-step account of the processes that are used to prepare the wood in the manufacturing yard. Firstly, the raw timber arrives and is peeled to remove the cambium layer; this is to allow the CCA treatment to penetrate. The peeled timber is then cut into varying lengths according to demand. The logs, as they are now called then go to the steam, treat, and fix area. The steaming stage is used to get the timber cell structure ready, so that the CCA can be impregnated. It does not matter if the logs are wet or dry. The logs are trundled into a tube where both ends are sealed, the time in the tube depends on the diameter of the logs which can vary between 2 to 12hrs (e.g., the thinner the logs, the less steaming time required). The tubes are filled with steam for the required period of time. When the steam is released the 'shock' to the timber opens the cells to release water and resins, leaving the cell structure open. The participant described this as a conditioning process that allows the timber to retain some moisture but removes enough to allow 'space' for the CCA treatment to infiltrate. The logs then sit in the dry shed for 8 to 10 days, this allows them to cool and release more water. The logs are then ready for the CCA treatment to be applied. The CCA treatment is a concentrated chemical solution that is mixed with water when used. The higher the concentration of the CCA treatment to water, the higher the H class of timber will be. For this treatment stage, the logs go into another cylinder and are then submerged entirely in the

CCA solution. They are put under pressure in the cylinder, the pressure forces the solution into the cell structure. The pressure is adjusted accordingly. In the final stage, a vacuum is applied to draw out the excess treatment. The vacuum seals the cells shut. The logs are now ready to go to the fixation stage as described in the response to question 8.

10. If you soak[5] CCA treated timber prior to use are you able to tell me about how you do that and for how long?

None of the participants had ever soaked timber prior to use, knew of anyone else who did, or were aware of any reason as for why you would.

11. Do you ensure that other requirements of the relevant New Zealand standards and guidelines[6] are implemented, if so, which ones and how?

The contractors were consistent in their responses in that they follow the details of the job's specifications. If the specifications ask them to refer to another guideline or standard, they would. If the specifications ask them to get timber that complies with a particular standard, they would. They otherwise assume that the design and specifications of the job are already in accordance with the relevant New Zealand standards and guidelines.

For the supplier, they were adamant that following the requirements of the relevant New Zealand standard and guidelines was crucial to their company reputation and environmental safety from leaching of any contaminants. They provided a booklet of the standards and guidelines that they follow, which include the Building Industry Standards NZ, the Treatment Standards NZ and, AS / NZS 4676, AS / NZS 3640, AS / NZS 3605, AS / NZS 3604, AS / NZS 3603, which are all applicable to the supplier. They also belong to the New Zealand Timber Preservation Council (NZTPC). The NZTPC are an independent body that audits the timber treatment process of its members. Furthermore, the participants are part of the Wood Mark Scheme, which is the New Zealand timber industry's registered trademark for assurance and treatment quality. To gain the Wood Mark Scheme trademark, and be part of the NZTPC, you must complete timber treatment and fixation to the required standards (New Zealand Timber Preservation Council, n.d.-b).

12. If you were required to pre-soak CCA timber prior to use, do you have any advice as to how this would be achieved?

The participants appeared reluctant to engage with this question because they knew of no justification for why this would be necessary. Regardless, they imagined that this would be done in some sort of container, bath, or cylinder. They all thought that this would need to be done at the manufacturing or supplier's yard, with the justification that it would need some sort of factory set-up to take place. Many respondents were clear that anything that could be achieved offsite is beneficial to the job. This was justified by comments about the barriers present on construction sites, such as access, confined areas, and sensitive environments. Some thought that the process might be somewhat dependent on how long the timber needed to be soaked. One suggested that evidence of soaking would need to be provided by the supplier if this were required. Due to the length and size of some of the timber structures (e.g., the poles used in the marine environment for bridges), the participants thought that considerable space would

[5] Soaking would need to be off-site, otherwise this would be an environmental risk in itself. The researcher assumed it implied soaking in freshwater.

[6] These include:

- New Zealand Timber Preservation Council Inc, Department of Labour and Zealand, E.R.M.A.N. (2005) Best practice guideline for the use of timber preservatives & anti-sapstain chemicals. Wellington, New Zealand.
- Standards Australia and Standards New Zealand (2006) AS/NZS 2843.1:2006: Timber preservation plants. Part 1: timber preservation plant site design. Jointly published in Sydney, Australia & Wellington, New Zealand: Standards Australia & Standards New Zealand.
- Standards New Zealand (2003) NZS 3640:2003: Chemical preservation of round and sawn timber. Wellington, New Zealand: Standards New Zealand.

be needed to do it. For example, one contractor who tried to think of a way that soaking could be achieved also thought of the subsequent challenges that it would cause; they said,

> "Trying to find something that you could, actually long enough to actually fit them in. And especially if you're using bearers along for the boardwalk. And if it's H4, if you've got to soak them, they could be 6 metres long. You'd have to kind of cut them into shorter little bits to try and sort them".

This indicates that space on site and methodology may be somewhat challenging.

13. How long do you typically store timber for before selling/using?

Contractors who had purchased and were using the timber preferred to use the product as soon as possible. This is because site space is limited and storing materials on the site unnecessarily increases their risk of damage. Despite this, they described how sometimes jobs became delayed or altered, which can result in the storing of timber until it can be used. Therefore, the storing period could vary anywhere between 1 day and several months. If they need to store it for long periods, two participants said that they would cover it to help to protect it from damage.

At the manufacturing yard, the timber can start to be processed and treated as soon as it arrives. Once treated and fixed, the timber can sit out in the open yard until it is purchased, as the timber is designed to be used outdoors. Historically, fixation was achieved naturally, and therefore dictated by climatic conditions. In the past, it would be necessary for the suppliers to hold many months' worth of stock, to ensure it has fixated before sale. However, because they now have a standardised process for fixing the timber, which is repeatable, traceable and ensures proper fixation, the timber can be used straight after the treatment process, and therefore the holding if stock is no longer necessary. The timber for this particular company is accompanied by a performance guarantee for a period of time from the day of purchase.

In short, there is no 'storing' period for timber, other than the processes it undergoes during the treatment stage described in question 9.

14. How achievable do you feel that these methods above (e.g., class, fixation, soaking and adherence to standards) are when using CCA treated timber?

Responses varied for this question. Overall, the participants were uniform in stating that the industry will do whatever is required.

In regard to soaking, the participants did not feel it was very achievable with the biggest barrier being cost and the client's willingness to pay.

In regard to fixation, installing the correct grade of timber and adhering to the relevant standards, the participants deemed them all to be highly achievable and did not think there was an option not to implement them.

The supplier felt that providing a Merck test every time would be somewhat challenging, time-consuming, and perhaps not necessary. They deemed it not necessary, because the heat fixation that they use, is a standardised process that achieves the same results every time. They suggested that batch testing more often could be an option to ensure quality control for the consumer, and that if this were required every time, they would just have to do it.

15. What barriers do you feel (if any) exist to using these methods (e.g., class, fixation, soaking and adherence to standards) when using CCA treated timber?

Cost / Resources / Labour / Time / Lack of Priority / Other, please state:

The most commonly selected barrier from the list was *cost,* associated with the client's willingness to pay, and the need to be associated with a significant contract to absorb the costs. This was followed by the *time* required to do it, and the *resources* available on-site. Participants also mentioned that there would be additional *safety risks* for staff with another treatment process, considerable *space* would be required, and there were concerns raised about the *disposal of water* (i.e., you could not soak timber in situ, and water used for soaking would be difficult to dispose of). Collectively, participants felt that there were significant barriers, and one felt that it was almost impossible, highlighting the simple barrier that *wood floats*.

16. Are you aware of any issues or problems with using CCA treated timber?

One participant felt that trees were better off growing than being cut down and that alternatives should always be used. Some were aware that there was leaching associated with timber, with one participant actually stating the three contaminants of risk: copper, arsenic and chromium. This participant in particular said:

> "Obviously, there is chromium, copper, arsenic which aren't good. And there was something about schools not using it, potential leaching or something".

It is not that CCA treated timber should not be used at schools, it is instead that a level of compliance and awareness is required around the use of the material at schools (Ministry of Education, 2020). One participant said they had heard of times when timber had deteriorated long before it should have. But this was word of mouth and would require further exploration to determine if the correct timber had been used initially and whether the timber had been fixed properly.

Two participants said that they were aware of issues and problems with using CCA treated timber, but *only* if it was not fixed properly. For example, the manufacturer said,

> "If that chemical has not been heat fixed into the wood, and that wood goes out to a site, then potentially that chemical can leach out".

17. I have a small list of challenges that we thought may be of importance to companies when using CCA treated timber. Which of the following (if any) do you think would be in your top three?

    - Cost
    - Company reputation
    - Human safety
    - Environmental protection
    - Adherence to the standards and guidelines
    - Company protocol
    - Māori cultural concerns
    - Other ______

The most common response to question 17 was *safety,* in regard to human safety when handling heavy materials or timber that had not been treated and fixed properly. This was followed by *environmental protection*, and *adherence to standards and guidelines,* which was said to drive and *company reputation*. *Cost* was also mentioned, but was thought by two participants to be a challenge faced equally by all users.

THEME #3: GALVANISED STEEL

18. We are interested in how companies use galvanised steel, either temporarily or permanently in Canterbury waterways such as angles, nails, ladders, and grates. Have you ever used this material in the waterways?

- If not, can you tell me about why that is?

One participant was adamant that they did not design or use galvanised steel in waterways. They said they would only use it in this application if it was embedded inside a concrete structure. The rationale for this was because the zinc would burn off too quickly if galvanised steel were used in a waterway. If they need to use steel, they will use stainless steel instead.

- If so, can you tell me about the types of structures and where you have used them?

All of the other contractors that contributed to this Theme had used galvanised steel in or around the waterways. For temporary structures, contractors had used galvanised spears to dewater areas for site preparation. They said that the spears do have a short-term influence on water chemistry, and so they have to test the water for contamination. They said that testing is a requirement of the job's specification when using spears. The results of the test will determine how they are able to dispose of the water, (e.g., whether that be via stormwater or wastewater infrastructure). They did say, however, that the spears are not really in the waterways themselves, but they are in contact with groundwater for a period of two to three weeks. Another example given for using galvanised steel, was for temporary retaining walls (e.g., sheet piling). Temporary retaining walls help in situations where, for example, they may need to cast concrete in situ in a river and water is held back by the wall to protect the waterway.

For permanent structures, the participants had used galvanised steel in a large variety of ways. For example, steel grates/grills for the inlets or outlets to pump stations and concrete stormwater chambers; as conduits to service cross stations of rivers; for ladders and utility hole covers; as wingwalls; and for bolts and nails. One participant said that the company commonly installed well points that consisted of 40mm diameter galvanised pipes between 4.5m to 9m in length. One participant said that the use of galvanised steel was because it is strong, resistant to rusting and lasts a long time.

All contractors discussed how they would potentially use stainless steel or another material instead of galvanised steel, depending on the surrounding environment and the type of water present (e.g., saltwater, or freshwater). But again, like in Theme 2, they were very clear that the materials to use would be determined in the tender specifications.

Despite the questions not being relevant at the manufacturing end in Theme 3, one supplier of galvanised steel discussed the material to some degree. They said that one option for when galvanised steel may come in to contact with water is to use Denso Tape. Denso Tape can be wrapped around galvanised steel items such as bolts to protect it from corroding, but they highlighted that there will still be some exposure risks involved (i.e., that water could still seep through the tape and corrode the steel).

19. Some waterways have areas of highly anoxic[7] sediment, which is stinky, dark sediment. Where there is highly anoxic sediment what considerations or precautions do you take when using galvanised steel and why? If none, why is that?

All contractors were clear that this is not something that they are familiar with or understood in depth. They were certain that considerations regarding this would be up to the designer and detailed in the job specification. It seemed that like in Theme 2, they assumed that the designer and specifications would adhere to all standards and guidelines regarding a matter like this, unless stated otherwise. One participant responded:

> "Certainly none that I am aware of, because I'm unaware of what effect galvanised steel is in that environment"

Other participants who commented on this that were not contractors included suppliers, another who had been involved in the design stage, and one involved in wastewater management around anoxic environments. They said that they would never use this material in this environment. They said that the zinc coating would burn off very quickly and that this is why concrete would be used in an anoxic environment. They went on to describe how the galvanised steel could certainly be used inside the concrete to support the

[7] This is stinky, dark sediment that happens due to a lack of oxygen in the sediment.

internal structure, but that the concrete should be the only surface exposed, as it is largely inert. Other suggested alternatives to galvanised steel included PVC, stainless steel, and treated cast iron.

20. Where galvanised steel is used with H5 and H6 CCA treated timber, what precautions do you take to reduce corrosion of the steel?

The participants commonly said that they would refer back to the job specifications for details such as this. One response suggested that in this scenario, if there was a corrosion risk involved, maybe they would have to apply some sort of pack or protection to the galvanised steel. Others said that you just would not use it, and that the steel would have to be stainless in all cases. This is because they were under the assumption that the H5 or H6 treated timber was being used because it was in contact with water. But the participants otherwise did not seem to be familiar with the basis of the question or understand why this would happen if it were not in a corrosive environment.

One respondent in their response also said that they had been involved in court cases where galvanised steel had failed after 6 months. They said that you just could not use galvanised steel in this environment.

The participants that represented the manufacturing of timber were able to shed some more information on this topic. They said that in the past salt was used in the CCA chemical as part of the solution to treat the timber. They summarised it as being a 'salt-based copper chrome arsenate'. The addition of salt would cause increased corrosion in galvanised steel. Whether this is the reason salt was removed from the formula, the participants were not sure. Either way, the participants were adamant that salt is not in the solution now.

There is current concern that there is a risk of corrosion from galvanised steel, when used with H5 and H6 class timer (Dr Belinda Margetts, Christchurch City Council, *personal communication*, January 2021). Research found to support this concern was completed in 1992, 2009, and 2010 (Baker, 1992; Kear et al., 2009; Zelinka et al., 2010). This research could potentially now be outdated if salt is no longer used as the participants seemed to think. Existing structures may still be in place in waterways where galvanised steel is in contact with H5 and H6 class timber. Existing timber may well have been treated with a CCA solution containing salt. And, if so, the concern is completely justified. However, it can be concluded that salt is not a part of the CCA solution now, and timber referred to in this data, therefore, may not pose a corrosion risk when used with galvanised steel. Finally, if salt is no longer a component of the CCA solution, and has not been for some time, it would be reasonable to expect that the contractors may not be familiar of the risk with corrosion from it.

21. How achievable do you feel that these methods above (e.g., using steel in anoxic sediments and the precautions to take to reduce corrosion) are when using Galvanised Steel?

It became clear that this question was not entirely applicable. The contractors stated that they would follow the instructions in the specifications, unless they thought there was a mistake, in that case, they would question the designer. They were not able to comment whether these methods were achievable or not because they didn’t understand the risks involved in anoxic environments, and because they did not think that there would be a scenario where you would use galvanised steel with H5 and H6 treated timber.

22. What barriers do you feel (if any) exist to using these methods (e.g., using steel in anoxic sediments and the precautions to take to reduce corrosion) when using Galvanised Steel?

Cost / Resources / Labour / Time / Lack of Priority / Other, please state:

Cost was deemed to be a significant barrier in terms of using an alternative to galvanised steel and avoiding corrosion altogether; stainless steel was said to be the most preferred option, but more expensive by almost everyone. Three participants also commented about the *limited availability* of supply in the New Zealand market. One participant described how sometimes a material may be required in the specifications, but that if it is not available, the designer has to select an alternative. One participant also said that there are just three or four builders' merchants locally stocking mostly the same brands, which is a barrier. It was highlighted that several products have to be couriered internationally on a number of projects. This demonstrates that for materials such as galvanised steel, there may not only be a limit of supply but *limited resources* overall.

23. Are you aware of any issues or problems with using galvanised steel?

Two participants raised the issue of using opposing metals together in response to this question. They described how you need to separate some materials such as stainless steel and galvanised steel, and that some products react with each other. Bimetallic effects can be problematic, long-lasting and cause corrosion.

Another participant said that, although not common, there can be problems if the galvanising has not adhered properly. As a result, there may be corrosion occurring earlier than there should be.

Modifying an existing structure that has galvanised steel components was also said to be an issue. If a structure that is already in place needs to be cut and rewelded, then they have to try and grind the galvanised coating off first to be able to reweld. If they do not remove this layer, then the weld will not adhere.

One participant also said that the supply of the product can take a long time.

24. I have a small list of challenges that we thought may be of importance to companies when using galvanised steel. Which of the following (if any) do you think would be in your top three?

- Cost
- Company reputation
- Human safety
- Environmental protection
- Adherence to the standards and guidelines
- Company protocol
- Māori cultural concerns
- Other ____

Cost and *adherence to the standards and guidelines* were both mentioned by five participants as being a challenge involved with using galvanised steel. It seemed as though this was in relevance to the cost of using alternatives, as it did not seem that the cost of galvanised steel itself was thought to be too expensive. *Safety* was selected by three participants. One of the respondents said this was because galvanised steel is heavy and so caution needs to be taken regarding its weight when using it. *Company reputation* was selected once, and the participant said that this was because there were concerns with the corrosion risk of galvanised steel. *Environmental protection* and *company reputation* were also selected once each, with limited rationale provided as for why.

THEME #4: CONCRETE

25. We are interested in how companies use concrete, either temporarily or permanently in Canterbury waterways for structures such as bridges, waterway linings and pipe outfalls. Have you ever used this material in the waterways?

- If so, can you tell me about the types of structures and where you have used them?

All of the contractors had used concrete in various ways. A more extensive project given as an example was the concrete terraces in the Avon River in Christchurch City. Other large projects included bridges and box culverts. More commonly, participants said that their companies had built outlets for drainage that they described as concrete retaining walls with holes in it. The participants also regularly install treatment chambers, stormwater systems, pipework, utility holes, pump stations, precast scour slabs, bridges, concrete piles, foundation wells and many other concrete structures. The participants gave similar reasons for the use of concrete for these projects. On large scale structures that are required to last for a long time, participants thought that concrete was often chosen because it is largely inert and cheaper to use than, for example, CCA treated timber or galvanised steel.

One participant felt it necessary to highlight that, while they don't generally install their pipework in waterways, pipes do lead to waterways. However, as highlighted in the literature review, pipes are not likely to leach contaminants in the same way as the concrete structures listed above (Concrete Pipe Association of Australia, 2013), therefore pipes were not a focus for this survey.

Also, the participants were consistent in their response that most of the concrete structures that they install in waterways arrive at the site precast (i.e., they had already been designed and shaped to the job's specifications) and are then put into place. It is less common for them to be cast in situ.

26. Can you tell me about what precautions you take (if any) when using wet concrete, concrete wash, and dust around waterways?

The participants discussed in depth how they rarely needed to cut or cast concrete on-site. Most items came to the job site precast. And so, the remaining details for this question are mostly related to the less common scenario of cutting and casting on-site.

It was clear that all of the participants and their companies took extensive precautions around the use of wet concrete, concrete wash, and dust, at all times. Each job has an Environmental Plan that details the processes that the company will undertake to manage environmental and health hazards when using concrete, such as dust. They were well aware that it is industry standard practice and company protocol to limit dust. Participants were also aware that they needed to follow certain procedures, to dispose of wet concrete and wash down machinery that had been in contact with concrete.

The generation of dust at a site would most likely be caused by the cutting of concrete (e.g., if a pipe needed to be cut to fit in place). One participant said that their company protocol is to not generate dust at all. There was a general awareness and understanding that dust from concrete can have negative effects on the waterways. The most common ways that companies described limiting dust was by using a dust suppressor, such as spraying the concrete with water during cutting, or by using a dust vacuum. The use of silt booms, silt turbans, water carts, wet grinding catch pits and irrigation were other examples of how companies reduced dust at the site. The participants commonly raised the use of Personal Protective Equipment (PPE) for the staff who were involved in cutting the concrete, and one participant said that the rules around this were very strict.

If they are casting in situ and wet concrete is required, then trucks will be used to bring the ready-mix concrete to the site. Ready-mix is standard terminology that refers to pre-mixed concrete. Several participants described how when the trucks have finished offloading, they are sent back to the supplier yard to be washed down with the appropriate infrastructure. Others said that if this is not an option, trucks might be washed down in an area that is suitable, for example on a pad that filters the sediment, and in an area that is away from a waterway. Although they did not specify that a 'suitable area' was away from stormwater drains that discharge into waterways, they were clear that contaminants were not to enter waterways in general. The same process was given for the use of tools which were also said to be sent back to the yard for an appropriate wash-down. If there is excess wet concrete on-site, it is left in a bunded area to go hard and then be disposed of via trade waste. Participants were quite clear that they would not allow wet concrete to enter a waterway at any time, with one participant detailing how they might block stormwater drains and use sucker pumps to prevent this.

One participant, who was involved in building subdivisions, said that they generally try to do all of the work "offline". Meaning that water has been diverted, or is not yet running through the site, or that pipes leading to the area are not 'live'. They said that sometimes they may have to complete the work with water running 'live', but that in this scenario, they divert the stream and keep the area dry until the work is done, and the concrete has cured. They said that where water was running close-by, they build a sheet pile wall which is made with interlinked sheets of steel. The wall prevents the water from entering the work area. They will pour the concrete inside the steel sheets and again, wait until the concrete has fully cured before removing the sheets.

At the manufacturing and supplier yard, strict protocols are also followed to limit concrete from entering the environment. However, these details are less relevant to this survey and so they are only briefly described. Catch pits are used on and off-site to prevent sediment from entering the stormwater system. Catch pits on-site are cleaned biweekly or monthly depending on how full they are. Catch pits off-site are cleaned quarterly or according to the council consent. Water testing is also completed to ensure compliance with the resource consent. Finally, the supply yard also has settling ponds that have a four-stage process to recycle the water used on-site and tanks are cleaned periodically.

27. What methods (if any) do you use to prepare the concrete before using it?

If the contractors purchased the concrete to the site precast, they said that there was no preparation required to use it. They were adamant that the product would not be delivered until it had reached its full curing strength. The suppliers also said that they would not deliver a concrete product that had not reached its full curing strength. They said that this is because if the concrete has not fully cured, it is at risk of cracking and chipping, which is costly to the company, both in monetary terms and reputation.

There was also a general consensus that waterways were not exposed to concrete materials until the concrete had fully cured. The basis for this being the negative effect fresh concrete has on water quality.

In the case of concrete being poured and used on-site, the participants again were unanimous that they would not allow freshwater to come in contact with the structure until it was cured. One participant described how they might achieve this using a cofferdam to create a dry area while using concrete. Another method that may be used on-site to prepare concrete, was the application of a coating. Two participants referred to this and said that it may be specified if the concrete was going to be in contact with a corrosive material that might damage it.

The length of time required to cure the concrete is dependent on its required strength. In general, it seemed that seven days was the 'critical' curing period, and that in some cases longer may be required if the concrete needs to reach a higher strength. One participant said the relevant AS/NZS standards and the specifications on the job will determine what strength the concrete is required to reach. The strength is measured in Megapascals (MPa). Concrete curing periods on average varied between seven and twenty-eight days.

During the curing stage, water is applied to the concrete. It may either be applied as a spray, steam, by covering the concrete with hessian bags and keeping them damp, or by applying a wax. The methods vary according to the size and location of the cast (e.g., if casting in situ, the hessian bags or wax are a practical method; if casting in the factory, a steam room is a practical method). All of these methods help the concrete to retain its moisture during the critical curing period, as it reaches high temperatures during this time. This was said to enable the concrete to cure evenly from the inside out, preventing cracking on the outer surface which cures faster. One participant, who is an expert in this field, described how the water is necessary and allows a chemical reaction to occur. And that by increasing the heat the speed of the reaction subsequently increased. After the critical curing stage, concrete casts need to be left outside to dry and to build up their residual strength. Two experts in the field describe how during this drying period, the concrete absorbs CO_2, which will react with the calcium hydroxide in the concrete and result in the formation of calcium carbonate. One of them said that this stage is what results in alkalinity being present on the surface, but that the formation of the calcium carbonate blocks up the pores which prevents leaching. Several participants said that it is crucial for the concrete to be left out to dry before being installed. They stated that the longer the concrete is left to dry, the stronger it becomes, and less prone to anything leaching out of the pores.

Another important step to preparing concrete pipes that many respondents referred to was 'soaking the pipe'. This is a procedure that is standard practice and required prior to completing an air pressure test. Once a concrete pipe has been laid, the pipe is bunded at both ends, filled with water, and left for 24 hours. This step is necessary because the concrete is porous. The water during this 'soaking the pipe' stage fills the pores, as a result, the pressure will not drop during the air pressure test and the pipe will pass. The pressure test that occurs after this is done to make sure that there are no leaks and that the seal is sufficient. Sometimes, for pipes over a certain size, the contractors may also have to complete a hydrostatic test, which is similar to an air pressure test, but it is with water instead.

28. If you were required to pre-soak concrete structures prior to use do you have any advice as to how this would be achieved?

Despite "soaking the pipe" as described in the responses to question 27, none of the participants that responded to this question had heard of soaking, currently do it, or knew why you would do it. Again, like in the details given in question 27, soaking seemed to be counterproductive, because the drying of the concrete and absorption of CO_2 was said to be a critical component of preparing the concrete.

They said there would be significant challenges to do this, as the structures are big and heavy, such as head walls. All participants felt it would be really difficult to soak them. Suggestions for soaking included spraying them with a hose, using some sort of water holding structure, using a reusable pit, a swimming pool, a trench, or large steel bins.

Like in question 12, the participants appeared reluctant to engage because they knew of no justification for why soaking would be necessary.

One participant had an example of when concrete had needed to be soaked which could be of relevance. They described how a pool designed to hold a salmon farm had to be filled, left for a few days, and then drained before the salmon were put in. This was because the salmon are extremely sensitive to pH levels. The water was drained onto the ground and could be because it is said to act as a fertiliser. But the difference between this example and the water in relevance to this project, is that the salmon pool is a still body of water, as a result, alkalinity would have accumulated in the pool. The pool most likely had to be cast in situ meaning that other challenges would have been present, for example spraying during the curing period. The cost of filling the pool with water and draining it would have been much less than the risk of losing an entire stock of salmon.

29. How long do you typically store concrete structures for before selling/using?

Storing times differed between contractors and suppliers. Storing time was also generally thought to be related to the curing time.

Contractors who purchased precast structures deemed them to have already been through the curing stage and that they were ready to be used. They, therefore, preferred to store them on-site for as little time as possible to reduce the risk of damage. One participant said that they sometimes order specific items for a job but that when they arrive, they still might sit on-site for a couple of months, so it was difficult for them to give a single answer.

Suppliers could store stock items at the yard for any period of time (e.g., a year), after they had at least reached their curing period. Responses ranged from seven – fifty-six days for the curing period, to allow structures to reach their required strength.

Several respondents emphasised that the minimum curing period would never be less than seven days to ensure that it had reached a satisfactory strength. They were mostly concerned about the concrete being up to the correct strength, and less so about environmental harm. It was their understanding that if the concrete had reached the required strength it was safe to be used in the environment. Some participants mentioned that structures could then be used from that time. Others did not comment whether structures could come into contact with the water after the seven days, but before the full curing period had ended. One participant said that it could be up to 28 days until contact with water is allowed.

30. How achievable do you feel that these methods (e.g., precautions around waterways and preparation prior to use) are when using concrete?

The responses varied in relation to each method. The methods required to manage dust, wet concrete and concrete wash were thought to be extremely achievable by both the contractors and the suppliers. They were also confident that they already achieve all of these methods as standard practice. One participant commented on the industry as a whole, saying that it was just "business as usual", and that everyone should be eliminating dust and concrete wash to reduce risks to human and environmental health. Another participant said that the precautions are "entirely reasonable".

Soaking the concrete was thought to be much more challenging. Participants were concerned about the weight and size of the structures that would now need extra lifting and handling, consequently increasing the risk to employee safety. One participant said that if it became mandatory then, of course, they would do it, but they thought it would be difficult. The participants would need much clearer details on the length of time and level of submergence the concrete would need to be exposed to water for. It was clear that a lot of infrastructure would be required to do it. One participant said that a new facility would need to be set up and that new manufacturing times and costs would need to be allowed for. Many participants commented on how this would need to be done at the manufacturing site because of space limitations at the worksite.

Another challenge that was highlighted would be the need to capture the wash-off, if this water were thought to be contaminated. They said it would need to be done over a filter cloth, and again more infrastructure would be needed to do this.

31. What barriers do you feel (if any) exist to using these methods (e.g., precautions around waterways and preparation prior to use) when using concrete?

Cost / Resources / Labour / Time / Lack of Priority / Other, please state:

Barriers were not discussed regarding dust, wet concrete, and concrete wash because these were already said to be easily achievable and every day practices. The barriers listed were therefore referring to the soaking of concrete.

Cost was a significant one that was mentioned by eight participants. *Cost* was said to be a barrier in terms of setting up new infrastructure, the willingness of clients to pay, and the extra costs of increased risk and subsequent damages to concrete structures. *Space* was also commonly mentioned, in that a large amount of space would be needed to set up the new infrastructure and that this would need to be done back at the manufacturing yard. *Space* was also thought to be a barrier in regard to location and the area the work is being completed in. Some mentioned that *environmental regulation* would be a barrier (i.e., if it were not regulated, it would not be done). *Time* was mentioned by three participants. The rationale for *time,* was that the length of the manufacturing time would now be much more, and that the time between soaking and delivery at the site project would also increase. *Infrastructure* was mentioned once, in terms of the permanent infrastructure that would be required when some manufacturers only lease the manufacturing yard. Increase in *safety risk* was thought to be a barrier, as the employees would be exposed to increased risks from the extra handling and lifting. *Engineering* was another risk mentioned, in that the engineering required to move the structures in this way would be substantial. *Lifting* was mentioned because concrete structures are heavy. *Methodology* was mentioned as it was difficult for the participants to imagine how the process would be done. And finally, the *disposal* of water was also mentioned, as they were unsure of how you would dispose of the water afterwards.

32. Are you aware of any issues or problems with using concrete?

The issues and problems associated with concrete were varied. They included the weight of concrete, which was said to be an issue in terms of lifting and freighting structures around the country. One participant was also highly concerned about the human health risks, they were worried that the cases of silicosis were going to dramatically increase in the future. Other safety concerns included the risk of eye and skin burns from contact with concrete. Another said that there was certainly an issue of using concrete in corrosive environments like sewers and, that there can be issues with concrete coming up to strength.

Most of the participants were well aware of the risk of increasing pH levels in waterways, but they often associated this with using wet or fresh concrete. They said that this could be avoided by not letting wet concrete enter the waterways, although one participant acknowledged that there was still a risk of unintended spills. Another participant described how the risk of raising the pH level in waterways, could be avoided by ensuring that the concrete has been properly cured, exposed to oxygen, and allowed to carbonate. They also said that they consider the water in Christchurch is naturally soft, therefore calcium carbonate is the only thing that is leached at a very slow rate. They described how the concrete having been carbonated, in combination with the soft water, stabilises the carbonate species in the water, and that the pH will initially increase, but they considered this was not to a level that is dangerous to aquatic life.

Another issue with concrete that was raised multiple times, is the emission of CO_2 from the production of concrete. The participants raising this concern were aware that there is negative public perception about the emissions from CO_2, but this topic was not discussed at length.

Finally, one important issue that was raised by two participants, was that there are smaller companies around Canterbury who lay concrete, but do not follow the correct protocols and procedures around wash-off and dust elimination. The participants who raised this said it is easy to trace spills and mistakes back to the big companies, and so the big companies are adhering to the guidelines very closely to avoid this. The smaller contractors, they said, are untraceable. The example given was when homeowners have exposed aggregate driveways laid. They described how the wet concrete surface is washed off straight into the nearest stormwater to expose the pebbles. Although the focus of this project is instream structures, it is still worth noting this for future environmental concerns around the use of concrete.

33. I have a small list of challenges that we thought may be of importance to companies when using concrete. Which of the following (if any) do you think would be in your top three?

- Cost
- Company reputation
- Human safety
- Environmental protection
- Adherence to the standards and guidelines
- Company protocol
- Māori cultural concerns
- Other

Environmental protection was mentioned by seven participants, justified by the associated CO_2 emissions and risk of spills and contamination; *company reputation* was also mentioned in association with this challenge. *Human safety* was a challenge that was mentioned by five of the participants. This was in relation to lifting, dust exposure and burns. *Cost* was mentioned by four participants, especially in relation to PPE. *Adherence to the standards and guidelines* was also mentioned by four participants, who said that there is a particular way of doing things. One contractor concluded by saying that all of the challenges are applicable and the same for everyone, but that they might differ between jobs.

THEME #5: CATCH ALL QUESTION

34. Where do you source your information regarding best practice for using these materials, would you find it useful to have a guidance document?

In general, the contractors were consistent in their response to this question. Several of them said that the job specifications detail the best practice or the code of practice for using the specified materials. They also said that safety data sheets come with the materials from the suppliers. Some commented that most of their practices were company protocol and policy.

Other responses for sourcing information included: via the Best Practice Network; referring to the AS / NZS standards and guidelines; through memberships to organisations such as the Fencing Contractors Association NZ (FCANZ), the Concrete Pipe Association of Australasia (CPAA), and the Timber Preservation Council; through the Building and Construction Industry Training Organisation (BITCO) and similar industry bodies; and finally, via their own organisation's health and environmental safety department.

For a guidance document to be useful and relevant, one participant said that it would need to be written into the job specification. They also said that unless it became regulated it would probably be slow on the uptake. Although one participant thought that there was already a document that covered the majority of the information, another thought it would be useful to have a guidance document that manufacturers should adhere to. They thought that this document should set a minimum standard of treatment that must be met at all sites. However, they felt that the process to achieve this should not be specified, as this allows them the flexibility to innovate.

35. Do you think that Christchurch City Council puts enough emphasis on environmental protection or consider it when contracting works that use these materials?

Although there were a small number of participants who felt that they could not comment on this, there was still a variety of responses. Participants' responses which indicated that they felt the Christchurch City Council did put enough emphasis on environmental protection are summarised below:

- They make sure that the product is treated to the right levels and adheres to the standards.
- They ask questions about our environmental management plans for tenders that we must respond to and these get reviewed again.
- They have taken large steps in a short period to improve on environmental concerns.
- They certainly do from a constructability point of view.
- They have some good and general specifications.

Participants' responses which indicated that they did not feel that the Christchurch City Council put enough emphasis on environmental protection are summarised below:

- Although they consider it, they are ultimately driven by cost.
- They are targeting the wrong people for adherence to standards and guidelines, they should be considering the works that unlicensed contractors undertake.

One comment that did not fit the criteria above is that tenders are now awarded based on company attributes and not cost alone. The participant indicated that the Christchurch City Council considers several factors that may be important and not only environmental protection, such as longevity and company reputation, to ensure that a job is completed to a high standard.

36. Do you think that Christchurch City Council puts enough emphasis or consideration on protecting the Māori cultural values of waterways, such as mahinga kai, when contracting works that use these materials?

A larger number of participants than in question 35, felt that they were not able to answer this question. But the participants did discuss their experiences with cultural concerns, which indicated they felt that there was some consideration from the Christchurch City Council regarding this.

Participants talked about; having a cultural induction; their awareness of the archaeological/accidental discovery protocols; the standards that they have seen on council specifications regarding culture; having a kaumātua on-site to oversee work; the consideration of culturally sensitive areas in the design phase of projects; notification of culturally sensitive areas; and finally, limitations for when work can be completed in waterways (e.g., during fish spawning seasons).

Only one participant commented that they rarely saw information regarding cultural concerns. And another commented that they thought the Christchurch City Council did consider it, but that the council are probably unaware that a lot of work is subcontracted. They felt that there was a risk and lack of awareness from subcontractors regarding council requirements on this matter.

37. One of the things we are interested in is preventing leaching of contaminants into the waterways, how do you think this can be achieved when using these materials?

Many commented that materials should be used in the correct application, have had the correct preparation, and be used under the correct procedure (e.g., by using only properly cured concrete and by suppressing dust when using it). In general, participants indicated that more was not required if the materials were used and applied correctly. In particular to CCA treated timber, the respondents said that the Christchurch City Council should request that only heat-fixed treated timber (e.g., H4, H5 etc) is used. In the case that it is not available, they should at least ensure that proper fixation of the treated timber has been achieved, which may be by an alternative method.

If leaching is to be completely eliminated, some participants suggested using alternative materials such as vinyl, or finding a way to seal contaminants into the materials. It was clear that using alternatives needed to be done at the design phase of the project, or that the council would need to change their specifications if this were to happen. Increasing the occurrence of early contractor involvement could also help to ensure that the most appropriate materials are used, especially in challenging construction environments.

Participants reiterated that changes would need to be legislated for them to become standard practice. And finally, that the whole context of using the material should be considered, (i.e., the source to sink lifecycle of a product). Whilst a product might seem to have limited leaching or impacts when installed, it may have impacts further up the manufacturing stage that far outweigh what is thought to be offset later on and vice versa. For example, the manufacturing of timber has far lesser environmental impacts during its manufacturing stage in comparison to concrete and galvanised steel. Galvanised steel and concrete emit larger quantities of CO^2 during manufacturing, whereas timber, at least for the manufacture in this research, has a carbon negative output during its entire lifecycle, which is due to the timber's ability to sequester carbon prior to harvest. This variance in CO^2 emissions are supported by the research (Latawiec et al., 2018; Mass et al., 2011). However, the literature review by Marshall and Margetts (2020) indicated that CCA treated timber was the most concerning of all three materials when considering its effects in the waterways alone.

38. Do you have any other comments/advice/experience around these topics that you would like to share?

Comments included that:

- If the Christchurch Council City Council wants to ensure better infrastructure, then they should be willing to pay more.
- There is a misunderstanding from the wider public about how concrete contaminates water. That it is not the same as chrome, zinc and arsenic. The effects from concrete do not persist in the environment for a long time. It may raise the pH but only in a transient way.

- There is a misunderstanding from the wider public about the difference between properly fixed timber and fresh timber. Timber that is fresh has a far greater leaching potential than fixed timber that is thought to pose no risk, when used in the correct environment.
- There should be increased awareness about who should be able to use concrete, which should be related to having the right facilities, tools, and mentality.
- The industry needs to be mindful of the cost of doing a project now and the cost of repairing it or replacing it in the future. Projects should be completed correctly in the beginning.
- The topics of discussion in this document and interview have been discussed in the industry for 15 years already.

39. In our feedback to Christchurch City Council are we able to inform the council that your organization participated in the research? Your response will not be able to be linked by the council with the research and report?

    Yes/No

    See Acknowledgements.

40. Would you mind telling me your age?

    All participants ranged between the ages of 35 – 59 years.

41. Gender?

    All 13 participants identified as male.

References

Baker, A. (1992). Corrosion of nails in CCA-and ACA-treated. *Forest Products Journal, 42*(9).

Basar, H., & Aksoy, N. (2012). The effect of waste foundry sand (WFS) as partial replacement of sand on the mechanical, leaching and micro-structural characteristics of ready-mixed concrete. *Construction and Building Materials, 35*, 508-515. doi:10.1016/j.conbuildmat.2012.04.078

Bednar, L. (1989). Durability of plain galvanized steel drainage pipe in South America: Criteria for selection. *Transportation Research Record 1231*, 80-87.

Begbie, M., Wright, J., & Rait, R. (2018). *Making good decisions: Risk characterisation and management of CCA post hotspots at vineyards and kiwifruit orchards*: Waikato Regional Council. Retrieved from https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/TR201811.pdf

BRANZ. (2010, June). Curing concrete. *Builder's Mate* (42).

Burg, R. (1996). *The influence of casting and curing temperature on the properties of fresh and hardened concrete.* . Research and Development Bulletin. Retrieved from https://www.cement.org/docs/default-source/th-paving-pdfs/soil_cement/rd113-the-influence-of-casting-and-curing-temperature-on-the-properties-of-fresh-and-hardened-concrete.pdf

Cement Concrete & Aggregates Australia. (2006). *Curing of concrete*. Retrieved from https://www.ccaa.com.au//imis_prod/documents/Library%20Documents/CCAA%20Datasheets/DS2006Curing.pdf

Chan, S., Wang, W., & Ni, I. (2003). The uptake of Cd, Cr, and Zn by the macroalga Enteromorpha crinita and subsequent transfer to the marine herbivorous rabbitfish, Siganus canaliculatus. *Archives of Environmental Contamination and Toxicology, 44*(3), 298-306.

Concrete Pipe Association of Australia. (2013). *Guide to understanding AS/NZS 4058:2007*. Retrieved from https://www.cpaa.asn.au/images/publications/engineering_guidelines/Guide_AS_NZS_4058.pdf

Cooper, P., & Ung, Y. (1993). A simple quantitative measure of CCA fixation. *Forest Products Journal, 43*(5), 19-20.

Costello, J. (1974). Cathodic depolarization by sulphate-reducing bacteria. *South African Journal of Science, 70*(7), 202.

Crossham, A., & Johanson, G. (2019). The benefits and limitations of using key informants in library and information studies research. *iRinformationresearch 24*(3).

Ekström, T. (2003). *Leaching of concrete: the leaching process and its effects*. Lund Institue of Technology, Lund, Sweden.

Environment Foundation. (2018). *Water Quality.* Retrieved from http://www.environmentguide.org.nz/issues/freshwater/key-issues/water-quality/#:~:text=Water%20quality%20is%20highly%20variable,polluted%20of%20New%20Zealand's%20waterways.

Ferreira, H., & Leite, M. (2015). A life cycle assessment study of iron ore mining. *Journal of Cleaner Production 108, Part A*(108), 1081-1091. doi:10.1016/j.jclepro.2015.05.140

Freshwater Independent Advisory Panel. (2020). *Essential Freshwater.* Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/essential-freshwater-report-of-freshwater-independent-advisory-panel.pdf.

Hedley, M. (1997). *An assessment of risks associated with use of CCA-treated timber in sensitive environments and options for its substitution with alternative timber materials*. Wellington, New Zealand: Department of Conservation

Hingston, J., Collins, C., Murphy, R., & Lester, J. (2001). Leaching of chromated copper arsenate wood preservatives: a review. *Environmental Pollution, 111*(1), 53-66. doi:10.1016/S0269-7491(00)00030-0

Ilhan-Sungur, E., Cansever, N., & Cotuk, A. (2007). Microbial corrosion of galvanized steel by a freshwater strain of sulphate reducing bacteria (*Desulfovibrio sp.*). *Corrosion Science, 49*(3), 1097-1109. doi:10.1016/j.corsci.2006.05.050

Kazi, F., & Cooper, P. (2000). Kinetic model of CCA fixation on wood. Part I. The initial reaction zone. *Journal of the Society of Wood Science and Technology 32*(3), 354-361.

Kear, G., Wú, H., & Mark, S. (2009). Weight loss studies of fastener materials corrosion in contact with timbers treated with copper azole and alkaline copper quaternary compounds. *Corrosion Science, 51*(2), 252-262. doi:10.1016/j.corsci.2008.11.012

Larned, S., Scarsbrook, M., Snelder, T., Norton, N., & Biggs, B. (2004). Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research, 38*(2), 347-366. doi:10.1080/00288330.2004.9517243
Latawiec, R., Woyciechowski, P., & Kowalski, K. (2018). Sustainable concrete performance—CO2-emission. *Environments 5*(2), 27. doi:10.3390/environments5020027
Lavrakas, P. (2008). *Key Informant*. Retrieved from https://methods.sagepub.com/reference/encyclopedia-of-survey-research-methods/n260.xml.
Law, D., Dutton, L., Adamson, R., & Setunge, S. (2013). Effect of leaching from freshly cast concrete on pH. *Magazine of Concrete Research, 65*(15), 1023-1030. doi:10.1680/macr.12.00169
Margetts, B., & Marshall, W. (2020). *Surface water quality monitoring report for Christchurch City waterways: January - December 2019*. Retrieved from https://ccc.govt.nz/assets/Documents/Environment/Water/Monitoring-Reports/2019-reports/City-wide-surface-water-quality-report-2019.pdf.
Marshall, M. (1996). The informant technique. *Family Practice, 13*(1), 92-97. doi:10.1093/fampra/13.1.92
Marshall, W., & Margetts, B. (2020). *Literature review of potential effects of leaching from instream structures on waterways*. Memorandum. Christchurch City Council.
Marshall, W., & Noakes, K. (2019). *Surface water quality monitoring report for Christchurch City waterways: January - December 2018.* Retrieved from http://ccc.govt.nz/assets/Documents/Environment/Water/Monitoring-Reports/2019-reports/City-wide-surface-water-quality-report-2018.pdf.
Mass, T., De Gijt, J., & Dudok Van Heel, D. (2011). *Comparison of quay wall designs in concrete, steel, wood and composites with regard to the CO 2-emission and the life cycle analysis* (Master's Thesis). Delft University of Technology Delft, The Netherlands. doi:10.3850/978-981-08-7617-3
Ministry for the Environment. (1997). *The state of our water environment.* Retrieved from https://www.mfe.govt.nz/publications/environmental-reporting/state-new-zealand%E2%80%99s-environment-1997-chapter-seven-state-our-8.
Ministry for the Environment. (2019). *Our marine environment 2019*. Retrieved from https://www.mfe.govt.nz/node/25697.
Ministry for the Environment. (2020). *Our freshwater 2020: Summary.* Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Environmental%20reporting/our-freshwater-2020-summary.pdf.
Ministry for the Environment. (n.d.). *Coastal and estuarine water quality state 1973-2018*. Retrieved from https://statisticsnz.shinyapps.io/coastal_water_quality/.
Ministry of Education. (2020). *Chromated copper arsenate (CCA) treated timber in schools*. Retrieved from https://www.education.govt.nz/school/property-and-transport/projects-and-design/design-standards/materials/chromated-copper-arsenate/#:~:text=Using%20timber%20treated%20with%20chromated%20copper%20arsenate&text=CCA%20is%20a%20preservative%20made,a%20playground.
Nasheri, K., Pearson, H., Pendlebury, J., Drysdale, J., & Hedley, M. (1999). The multiple-phase pressure process: One-stage CCA treatment and accelerated fixation. *Forest Products Journal, 49*(10), 47-52.
New Zealand Timber Preservation Council. (n.d.-a). *CCA treated wood*. Retrieved from https://www.nztpc.co.nz/ccaTreatedWood.php.
New Zealand Timber Preservation Council. (n.d.-b). *The NZTPC is the proprietor of the WOODmark® programme, New Zealand's only nationwide quality assurance programme for treated timber.* Retrieved from https://www.nztpc.co.nz/.
New Zealand Timber Preservation Council. (n.d.-c). *Woodmark*. Retrieved from https://www.nztpc.co.nz/woodmark.php.
Newton Suter, W. (2012). Chapter 12: Qualitative data, analysis, and design. In *Introduction to Educational Research: A Critical Thinking Approach*: SAGE Publications.
Ochieng, P. (2009). An analysis of the strengths and limitation of qualitative and quantitative research paradigms. *Problems of Education in the 21st Century 13*, 13-18. doi:2538-7111
Portella, M., Portella, K., Pereira, P., Inone, P., Brambilla, K., Cabussú, M., . . . Salles, R. (2012). Atmospheric corrosion rates of copper, galvanized steel, carbon steel and aluminum in the metropolitan region of Salvador, BA, northeast Brazil. *Procedia engineering, 42*, 171-185. doi:10.1016/j.proeng.2012.07.408

Radivojevic, S., & Cooper, P. (2010). The effects of wood species and treatment retention on kinetics of CCA-C fixation reactions. *Wood Science and Technoogy, 44*(2), 269-282. doi:10.1007/s00226-009-0277-y
Red Stag Timber. (n.d.). *Treatment process*. Retrieved from https://www.redstagtimber.co.nz/processes/treatment-process/.
Rice, K., Conko, K., & Hornberger, G. (2002). Anthropogenic sources of arsenic and copper to sediments in a suburban lake, northern Virginia. *Environmental Science and Technology, 36*(23), 4962-4967. doi:10.1021/es025727x
Setunge, S., Nguyen, N., Alexander, B., & Dutton, L. (2009). Leaching of alkali from concrete in contact with waterways. *Water, Air, & Soil Pollution: Focus, 9*(5-6).
Sreeja, A. (2008). *Chromated copper arsenate (CCA) treatment for rubber wood preservation and its impact on the aquatic biota* (Doctoral thesis). Cochin University of Science and Technology Retrieved from http://hdl.handle.net/10603/3671
Standards Council. (2003). *New Zealand Standard 3640: Chemical preservation of round and sawn timber* (P 3640). Retrieved from https://www.standards.govt.nz/assets/Publication-files/BSP/NZS3640-2003+A1-5.pdf
Steel, N. Z. (n.d.). *Galvsteel*. Retrieved from https://www.nzsteel.co.nz/products/galvsteel/.
Taylor, P. (2014). *Curing Concrete*. London: Taylor & Francis.
Treasure, E., Chadwick, B., Gill, P., Stewart, K., & Burnard, P. (2008). Analysing and presenting qualitative data. *British dental journal 204*(8), 429-432. doi:10.1038/sj.bdj.2008.292
UCLA Center for Health Policy Research. *Section 4: Key Informant Interviews*. Retrieved from https://healthpolicy.ucla.edu/programs/health-data/trainings/Documents/tw_cba23.pdf.
Weis, J., & Weis, P. (1992a). Construction materials in estuaries: reduction in the epibiotic community on chromated copper arsenate (CCA) treated wood. *Marine Ecology. Progress series (Halstenbek), 83*(1), 45-53. doi:10.3354/meps083045
Weis, J., & Weis, P. (1992b). Transfer of contaminants from CCA-treated lumber to aquatic biota. *Journal of Experimental Marine Biology and Ecology, 161*(2), 189- 199. doi:10.1016/0022-0981(92)90096-S
Weis, J., & Weis, P. (1993). Trophic transfer of contaminants from organisms living by chromated-copper-arsenate (CCA)-treated wood to their predators. *Journal of Experimental Marine Biology and Ecology, 168*(1), 25-34. doi:https://doi.org/10.1016/0022-0981(93)90114-4
Weis, J., & Weis, P. (1994). Effects of contaminants from chromated copper arsenate-treated lumber on benthos. *Archives of Environmental Contamination and Toxicology, 26*, 103-109.
Weis, J., & Weis, P. (1999). Accumulation of metals in consumers associated with chromated copper arsenate-treated wood panels. *Marine environmental research, 48*(1), 73-81. doi:10.1016/S0141-1136(99)00028-8
Weis, P., Weis, J., & Coohill, L. (1991). Toxicity to estuarine organisms of leachates from chromated copper arsenate treated wood. *Archives of Environmental Contamination and Toxicology 20*(1), 118-124. doi:10.1007/BF01065337
Weis, P., Weis, J., & Couch, J. (1993). Histopathology and bioaccumulation in oysters Crassostrea virginica living on wood preserved with chromated copper arsenate. *Diseases of aquatic organisms 17*, 41-46. doi:10.3354/dao017041
Weis, P., Weis, J., Couch, J., Daniels, C., & Chen, T. (1995). Pathological and genotoxicological observations in oysters (Crassostrea virginica) living on chromated copper arsenate (CCA)-treated wood. *Marine Environmental Research 39*(1-4), 275-278. doi:https://doi.org/10.1016/0141-1136(94)00074-Y
Weis, P., Weis, J., Greenberg, A., & Nosker, T. (1992). Toxicity of construction materials in the marine environment: a comparison of chromated-copper-arsenate-treated wood and recycled plastic. *Archives of Environmental Contamination and Toxicology, 22*(1), 99-106. doi:10.1007/BF00213307
Weis, P., Weis, J., & Lores, E. (1993). Uptake of metals from chromated-copperarsenate (CCA)-treated lumber by epibiota. *Marine Pollution Bulletin, 26*(8), 428-430. doi:https://doi.org/10.1016/0025-326X(93)90529-S
Weis, P., Weis, J., & Proctor, T. (1993). Copper, chromium, and arsenic in estuarine sediments adjacent to wood treated with chromated-copper-arsenate (CCA). *Estuarine, coastal and shelf science, 36*(1), 71-79. doi:10.1006/ecss.1993.1006
Wendt, P., Van Dolah, R., Bobo, M., Mathews, T., & Levison, M. (1996). Wood preservative leachates from docks in an estuarine environment. *Archives of Environmental Contamination and Toxicology, 31*(42-37). doi:https://doi.org/10.1007/BF00203904

Zelinka, S., Sichel, R., & Stone, D. (2010). Exposure testing of fasteners in preservative treated wood: gravimetric corrosion rates and corrosion product analyses. *Corrosion Science, 52*(12), 3943-3948. doi:10.1016/j.corsci.2010.08.014