

## Investigations of 1080 leaching and transport in the environment

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Cover Photo: Hillslope study site and Wallaby Creek (Photo credit: Angelika Riegler, NIWA)

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# Contents

<b>Executive summary</b> .....	<b>5</b>
<b>1 Introduction</b> .....	<b>7</b>
1.1 Scope.....	7
1.2 Background.....	7
<b>2 1080, nitrate and chloride leaching from cereal baits under simulated rainfall</b> .....	<b>11</b>
2.1 Study objectives .....	11
2.2 Experimental set up .....	11
2.3 Statistical analyses.....	14
2.4 Results.....	14
2.5 Conclusions .....	20
<b>3 Site selection for field studies</b> .....	<b>22</b>
<b>4 Plot-scale transport of 1080 under simulated rainfall</b> .....	<b>27</b>
4.1 Study objectives and experimental set up .....	27
4.2 Results .....	30
4.3 Conclusions .....	32
<b>5 Hillslope-scale transport of 1080 under natural rainfall</b> .....	<b>35</b>
5.1 Study objectives and experimental set up .....	35
5.2 Results .....	37
5.3 Discussion.....	40
<b>6 Refinement of 1080-hydrology model</b> .....	<b>44</b>
<b>7 Acknowledgements</b> .....	<b>45</b>
<b>8 References</b> .....	<b>45</b>

## Tables

Table 2-1: Details on 1080 release data available from previously published studies.	12
Table 2-2: Best fit 1080 release equations for Wanganui No. 7 and RS5 cereal baits.	17
Table 3-1: Factors considered for the selection of sites for plot- and hillslope-scale field studies.	22
Table 4-1: Overland flow volumes and 1080 concentrations from plot-scale study.	31
Table 4-2: Soilwater 1080 concentrations for Wanganui No. 7 and RS5 baits.	33

Table 5-1: Details of water samples collected and analysed for 1080 during the hillslope-scale study.	39
Table 5-2: 1080 concentration in water samples returned positive during the hillslope-scale study.	40

## Figures

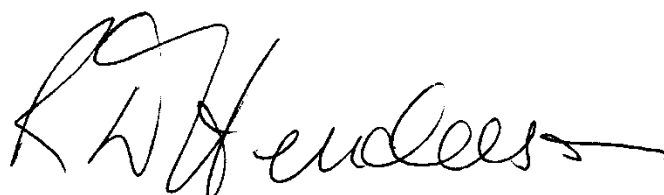
Figure 2-1: 1080 leaching from RS5 cereal baits using a rainfall simulator.	13
Figure 2-2: 1080 concentrations (in percentage w/w) in RS5 baits exposed to different rainfall conditions.	15
Figure 2-3: 1080 concentrations (in percentage w/w) in Wanganui No. 7 baits exposed to different rainfall conditions.	16
Figure 2-4: Comparison of 1080 release rate equations from published and current studies.	18
Figure 2-5: Comparison of percentage loss of 1080, chloride and nitrate from RS5 baits over time.	19
Figure 2-6: Comparison of percentage loss of 1080, chloride and nitrate from Wanganui No. 7 baits over time.	20
Figure 3-1: Location of field study site.	24
Figure 3-2: Field site hillslope - Wallaby Creek in the background.	25
Figure 3-3: Location of stream and plot and hillslope study sites.	26
Figure 4-1: Rainfall simulator and runoff plot arrangement - plot-scale study.	28
Figure 4-2: Schematic of plot and instrumentation arrangement - plot-scale study.	29
Figure 4-3: Observed 1080 concentrations in soilwater from lysimeters placed on the upper slope close to RS5 baits, and the lower slope (mean + 1 se).	34
Figure 4-4: Observed 1080 concentrations in lysimeters placed on the upper slope close to Wanganui No. 7 baits, and the lower slope (mean + 1 se).	34
Figure 5-1: Schematic of hillslope-scale study site.	36
Figure 5-2: Rainfall, flow and depth to the water table recorded during the natural rainfall study.	38
Figure 5-3: Soil profile at the plot-scale study site.	42
Figure 5-4: Soil profile at the hillslope-scale study site.	43

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## Executive summary

1. A series of sequentially arranged laboratory, and plot- and hillslope-scale field studies were conducted to investigate the influence of rainfall conditions on 1080 release rates from 12 g cereal baits and the transport of released 1080 in rainfall-runoff via surface and subsurface pathways to streams and groundwater.
2. Analysis of data from laboratory experiments examining 1080 release from RS5 and Wanganui No. 7 baits showed that release rates were independent of rainfall intensity for both types. This allowed us to develop a single 1080 release equation for each bait type.
3. Comparison of release behaviour showed that chloride and nitrate might be appropriate surrogates during the early part of rainfall events ( $\leq 2$  h) for RS5 baits. Within Wanganui No. 7 baits, chloride and nitrate release rates were consistently and significantly lower than that of 1080.
4. The plot-scale experiment using a rainfall simulator indicated that less than 0.5% of the total applied rainfall became overland flow, indicating that most rainfall infiltrated into the soil even at high rainfall intensities (12-15 mm h<sup>-1</sup>). The average 1080 concentration in overland flow was highly variable, and was not different to that in soilwater.
5. During the hillslope-scale experiment, the surface and subsurface transport of 1080 from RS5 baits (0.15% concentration) in rainfall-runoff was monitored. Overland flow amounted to less than 0.75% of the total rainfall. Samples collected at different times during and immediately after the rainfall event indicated that no 1080 contamination of overland flow, stream or groundwater had occurred. Six out of 31 soilwater samples analysed returned positive. However, the highest concentration observed (1.4  $\mu\text{g L}^{-1}$ ) was less than half the Ministry of Health standard for drinking water (3.5  $\mu\text{g L}^{-1}$ ).
6. The field studies (plot and hillslope) indicated that the potential of overland flow transporting 1080 from source (baits) to downslope areas and to streams diminished with distance. Even though a large proportion of rainfall infiltrated into the soil, likely carrying 1080 with it, no detectable (detection limit, 0.1  $\mu\text{g L}^{-1}$ ) contamination of groundwater was observed.
7. During the hillslope-scale experiment, absence of 1080 in groundwater and surface water indicated that little of the released 1080 leached through the soilwater to reach groundwater, and that lateral transport (surface as well as subsurface) of 1080 to streams was below detection limit. The field studies indicated that the potential for 1080 contamination of receiving waters is negligible even in the presence of large 1080 loads (2 kg of baits) in near-stream (25 m from stream) areas.



# 1 Introduction

## 1.1 Scope

In 2008, the Animal Health Board (AHB) had contracted NIWA to develop a 1080 transport model estimating the probable maximum concentration of 1080 in streams following aerial applications. NIWA developed a model that was based on a set of worse-case scenario conditions such as (1) all 1080 applied being available for transport; (2) rainfall occurring immediately following 1080 application; (3) conditions in the catchment being conducive for maximal 1080 transport via overland (the quickest pathway connecting land to water); and (4) no baseflow in the receiving stream. It was tested in a headwater catchment near Reefton, South Island, where Wanganui No. 7 baits were dropped prior to forecast rain. In contrast to the worse-case scenario model results, despite intensive sampling from the start to the end of the storm event, only a very small amount of 1080 ( $0.1 \mu\text{g L}^{-1}$ ) was detected in the stream two hours after the start of the rainfall. Potential reasons for the disparity included (1) the assumption that 1080 release from baits remained constant irrespective of rainfall intensity conditions might not be valid; (2) overland flow may not have transported as much 1080 into the stream as the model assumed; and (3) the stream had baseflow that could have diluted 1080 below detection limits.

Following the above work, AHB contracted NIWA in 2010 (current contract) to: (1) quantify the variability in 1080 release rates with respect to rainfall intensity; (2) examine the importance of 1080 surface transport pathways to streams; (3) include baseflow to the 1080 transport model, and (4) refine the original transport model to include the results of these investigations. A secondary aim of the work was to compare the behaviour of 1080 with chloride- and nitrate-laced cereal baits, to explore if further experimental work could use these cheaper tracers as surrogates for 1080. This report covers results from these investigations.

## 1.2 Background

In New Zealand, sodium monofluoroacetate (1080) is widely used by AHB to control vertebrate pests that can carry bovine tuberculosis (TB) bacteria, and by the Department of Conservation (DoC) to control pests such as mice, rats, possums and stoats that have a major deleterious effect on conservation values. While 1080 applications have greatly reduced the incidence of TB among farm animals, and have had positive effects on native species, public concern still exists on the use of this pesticide, particularly for aerial applications (PCE, 2011). These aerial applications are carried out using helicopters fitted with hoppers set to apply 1080 at a nominal rate, usually at 2 kg per ha. The boundaries of aerial operations are entered into the helicopter's GPS (Global Positioning System), and the area within these boundaries flown to ensure an even cover of bait is applied. Aerial operations are restricted to difficult and forest-covered terrain with often poor access, and where ground control is too expensive, takes long time, and is not able to consistently and evenly reduce possum, rat and stoat populations to a similar level to that of aerial applications. A very common characteristic of these areas is the presence of many small streams that flow from the mountains and merge into bigger streams, which eventually flow into large rivers.

One of the frequent causes of public concern is over the possibility of 1080 contaminating waterways: indeed observations by Suren (2006) showed that 1080 baits do land in small waterways during aerial applications. To help minimise any accidental discharge of 1080 into streams, many consenting authorities stipulate that no 1080 baits are allowed to be dropped within some defined distance from streams (Suren, 2006). To further alleviate concerns, many local councils require stream water samples to be collected after aerial operations to determine the extent and duration of any potential 1080 contamination. Data from these monitoring operations from 1990 to 2007 indicate that no significant or prolonged contamination of surface waters was detected (Booth et al., 2007). More importantly, no quantifiable 1080 contamination has been found in samples taken from drinking water supplies (Booth et al., 2007). From these results, scientists have concluded that prolonged contamination of waterways is not likely to occur, if the normal operating procedures are followed by pest control operators in the planning and execution of baiting procedures.

A number of scientific studies have also examined the fate of 1080 in baits exposed to rainfall, and the degree to which 1080 is lost from baits when exposed to simulated rain (Bowen et al., 1995; Thomas et al., 2004), or when submerged in streams (Suren, 2006). Other studies (Eason et al., 1993; Parfitt et al., 1994) have shown that 1080 bio-degrades naturally in water, suggesting that it is highly unlikely to persist in the environment. Finally, Eason and Temple (2008) suggested that 1080 would be diluted to ecologically insignificant amounts when it entered surface waters.

Despite these findings, it is apparent that public concern still exists over the fate of 1080 in the environment following aerial application. The recent Environmental Risk Management Authority (ERMA) review (ERMA, 2008) recommended that work be done to model predicted 1080 concentrations following aerial applications so that operational managers and consent authorities could better respond to concerns raised by the public. To help address these concerns, NIWA was contracted by the AHB to develop such a model (Srinivasan et al., 2009 & 2012a). An example of the type of problem to be solved is described below:

1080 cereal baits have been applied throughout a 15 ha headwater catchment in steep terrain with a small stream running through it. It rains following the aerial application. Questions to be examined are

- (i) how does this rainfall influence the release of 1080 from baits?
- (ii) how does the released 1080 reach the stream?
- (iii) what will be the likely 1080 concentration in the stream over time?

Solving this problem requires an understanding of 1080 release characteristics from baits, as influenced by rainfall, and an understanding of 1080 transport pathways at catchment scale. 1080 is highly water-soluble, and so once the baits become wet, 1080 will be released from the baits. However, it is not clear how 1080 release is influenced by rainfall characteristics. Does a longer rainfall event release more 1080 than a shorter one? Do high intensity rainfall events release 1080 quicker than low intensity events? Bowen et al. (1995) speculated that 1080 release from baits might be influenced by rainfall intensity and pattern in addition to total rainfall. No specific data are available to support or reject this. Does bait size influence 1080 release rates? While this last question has not been addressed in this study but work



by Thomas et al. (2004) suggested small (6 g) Wanganui No. 7 baits could be releasing 1080 quicker than large (12 g) baits.

The released 1080 is in a dissolved form, and it can either move downslope in overland flow or move vertically into the soil with infiltrating rainfall. The infiltrating 1080 can move vertically towards the groundwater, and then eventually to a stream, or move laterally within the unsaturated soil zone, downslope toward a stream.

Srinivasan et al. (2009 & 2012a), in their 1080-hydrology transport model used the catchment contributing area concept, wherein they assumed that as rainfall duration and amount increase, more areas within the catchment can become saturated, increasing the connectivity between land and stream. Such a scenario also increases the potential of dissolved solutes such as 1080 from these connected areas to be transported to the stream. There is thus a complex interplay between rainfall, the amount of 1080 released from baits, and the size of the catchment contributing to stormflow and transporting 1080 to stream.

Srinivasan et al. (2009) developed a 1080-hydrology transport model to describe a worse-case scenario 1080 contamination of surface water. A number of assumptions were made:

- a. 1080 was aerially applied to a wet catchment, where a rapid transfer of 1080 from land to water occurred via overland flow, the quickest pathway connecting land to streams;
- b. all stormflow resulted from rainfall-runoff and baseflow was zero; and
- c. 1080 leaching from baits was influenced by rainfall intensity – more 1080 leached at higher intensities ( $20 \text{ mm h}^{-1}$  and greater), and less at lower intensities ( $< 20 \text{ mm h}^{-1}$ ).

This model was tested in a headwater catchment near Reefton where baits were dropped prior to forecast rainfall event. The worse-case model predicted high 1080 concentrations ( $20 \mu\text{g L}^{-1}$ ) early during the rainfall event (for 45 min from the start of rainfall), lower concentrations (between  $0.1$  to  $3.5 \mu\text{g L}^{-1}$ ) for another 2.25 h, and concentrations below detection limits ( $0.1 \mu\text{g L}^{-1}$ ) after that.

In contrast to the worse-case scenario model results, despite intensive sampling throughout and following the rainfall event, only a very small amount of 1080 ( $0.1 \mu\text{g L}^{-1}$ ) was detected in the stream two hours after the start of the rainfall. Srinivasan et al. (2010 & 2012a) presented several possible reasons for these differences:

- (a) The rainfall intensity during the storm event studied never exceeded  $10 \text{ mm h}^{-1}$ , and 1080 release from baits were based on a rainfall intensity of  $20 \text{ mm h}^{-1}$ . It is unclear if rainfall intensity had influenced 1080 release from baits, resulting in less than predicted 1080 release rates.
- (b) The assumption that overland flow carries most 1080 to streams may have been incorrect. Srinivasan et al. (2010 & 2012a) observed several puddles in the study site that were connected to each other and to the stream, but these did not occur until much later during the rainfall event (12 h or greater after the start of the rainfall). The occurrence of these potential overland transport pathways did not coincide with the occurrence of high 1080 release periods (early during the rainfall period). Additionally, soilwater samples from near-stream areas ( $<10 \text{ m}$  from stream), drawn from the top-

30 cm of the soil profile, indicated that 1080 had leached into the soil. The worse-case scenario model would have assumed these near-stream areas as potential overland flow areas, and, hence, would have transported all released 1080 from these areas to the stream. 1080 leaching through soil has been studied under controlled laboratory conditions using soil cores by Srinivasan et al. (2010) and Parfitt et al. (1995) but it has not been investigated in catchments under natural rainfall conditions; and

- (c) The assumption of zero baseflow is unrealistic in many catchments where 1080 is regularly applied.

Release rates of 1080 from cereal baits were compared against cereal baits containing nitrate and chloride. The purpose of this comparison was to find a surrogate for 1080 that can be safely used during field experiments, as well as an alternative to 1080, as analysis of nitrate and chloride water samples are quicker and cheaper than those of 1080.

This report is presented in three sections. Firstly, we describe the development of 1080 release rate curves for Wanganui No. 7 and RS5 baits under varying rainfall intensity conditions. Results comparing the release rate characteristics of 1080, chloride and nitrate are also presented in this section. Secondly, we present results from a plot-scale study where 1080 transport in overland flow and soilwater was examined under simulated rainfall conditions. Thirdly, the results of a hillslope-scale field study comparing 1080 transport in overland flow and subsurface flow are presented. This last study also tracked 1080 contamination of surface water and groundwater under natural rainfall conditions. Results from the above three sections were used to refine the original worse-case scenario model developed by Srinivasan et al. (2009) to produce a revised model. Details on this revised 1080-hydrology model and a user manual are available in Srinivasan et al. (2012b).

## 2 1080, nitrate and chloride leaching from cereal baits under simulated rainfall

### 2.1 Study objectives

The goal of the study was to develop release rate curves for 1080, nitrate and chloride cereal baits under varying rainfall intensity conditions. Published data on 1080 release are available for Wanganui No. 7 and RS5 baits. These data sources and rainfall intensity conditions investigated are listed in Table 2-1. It is evident that for Wanganui No. 7 baits release data are available for a wide range of rainfall intensity conditions, while for RS5, it is available for only one intensity condition (see Bowen et al., 1995). Thus, the primary objectives of this simulated rainfall study were:

- (i) to investigate the release rates of 1080 from RS5 cereal baits (12 g baits, 0.15% 1080 concentration *w/w*) under two rainfall intensity conditions (medium and high); and
- (ii) to investigate the release rates of nitrate and chloride from cereal baits (RS5 and Wanganui No. 7; 12 g baits) under two rainfall intensity conditions (medium and high).

Following the completion of these primary objectives, we further considered two more objectives:

- (i) examine the influence of rainfall intensity on 1080 release based on current and previously published studies (listed in Table 2-1) for RS5 and Wanganui No. 7 baits; and
- (ii) compare the release rate characteristics of 1080, nitrate and chloride under varying rainfall intensity conditions.

### 2.2 Experimental set up

A portable rainfall simulator was used to simulate rainfall (Figure 2-1). During the experiment, a tipping-bucket rain gauge was deployed under the simulator to record rainfall rates. This gauge could measure rainfall as little as 0.2 mm. Release rates were studied at two rainfall intensities, 14 (medium) and 29 (high) mm h<sup>-1</sup>, and during each intensity study, rainfall was applied continuously for 8 h.

Wanganui No. 7 and RS5 baits impregnated with nitrate (5% potassium nitrate *w/w*) and chloride (5% sodium chloride *w/w*) were manufactured for this study by Animal Control Products in Wanganui. These baits were similar in size and shape to normal 1080 baits, had the same formulation. The surrogate baits were manufactured using the same machines as normal 1080 baits. We used 12 g baits in this study.

For the rainfall simulation experiment, we used RS5 1080, nitrate and chloride baits and Wanganui No. 7 nitrate and chloride baits. Wanganui No. 7 1080 baits were not used in this experiment, as 1080 release data are already available for a wide range of rainfall intensity conditions for that bait type (see Table 2-1). Baits were placed on a 47 mm disc of GF/C filter paper (one bait per filter paper), and the filter disc was then placed on an upturned plastic

**Table 2-1: Details on 1080 release data available from previously published studies.** Note, Thomas et al. (2004) studied 1080 release rates from 6 and 12 g Wanganui No. 7 baits under simulated rainfall conditions. Results from that study were included here as data were not available at the time of this study.

Study	Bait type used	Procedure used
Bowen et al. (1995)	RS5 (concentrations, 0.08 and 0.15% w/w); 6 g baits  Wanganui No. 7 (concentrations, 0.08 and 0.15% w/w); 6 g baits	20 mm h <sup>-1</sup> of rainfall applied continuously for 10 h.
Suren (2006)	Wanganui No. 7 (concentration, 0.15% w/w); 12 g baits	Baits left submerged in running water, to simulate a flowing stream effect, for 12 h.
Srinivasan et al. (2010)	Wanganui No. 7 (concentration, 0.15% w/w); 12 g baits	Baits rained on at a rate of 15-22 mm h <sup>-1</sup> for three hours, left to drain by gravity for an hour.
Srinivasan et al. (2010 & 2012a) <sup>1</sup>	Wanganui No. 7 (concentration, 0.15% w/w); 12 g baits	Bait samples collected during a natural rainfall event – rainfall intensity varied between 1.8 to 9.6 mm h <sup>-1</sup> , and was intermittent – a total of 60.6 mm rainfall received, with 38.35 h of rainfall period over a 219 h sampling period

<sup>1</sup> The only study to measure 1080 release under natural rainfall conditions.



**Figure 2-1: 1080 leaching from RS5 cereal baits using a rainfall simulator.** (Photo: J Wech, NIWA).

seedling tray, forming rows and covering the tray. Each tray (containing the baits) was then placed under the rainfall simulator.

Triplicate samples for each bait type (i.e., RS5 1080, nitrate, and chloride, and Wanganui No. 7 nitrate and chloride) were collected at each time point (i.e., the length of time exposed to rain). Time points for the  $14 \text{ mm h}^{-1}$  experiment were (in hours): 0.5, 1, 2, 4, 6, 8, 12, 18 and 24. Time points for the  $29 \text{ mm h}^{-1}$  experiment were: 0.5, 1, 2, 4, 8, 12, 18 and 24. Baits samples collected after 8h (after rainfall had ceased) remained wet, draining the excess moisture by gravity. The collected baits were placed in individual, labelled plastic bags. Samples were then frozen for further analysis.

Each frozen nitrate or chloride bait was placed into an Elkay plastic jar and 100 mL of deionised water was added. Each sealed Elkay jar was then placed onto a shaking table enabling sufficient mixing to occur so that the majority of anions would move into the water solution. Preliminary trials indicated that most anions were in solution after 24 h. After 24 h, the contents within the Elkay were allowed to settle and the solution was decanted ( $\sim 40 \text{ mL}$ ) into 50 mL test-tubes. These samples were then centrifuged (3000 rpm for 10 min), and the resulting supernatant syringe-filtered using a 0.45 mm cellulose filter ready for laboratory analysis. The filtered sample was analysed by the Hills Laboratory (Hamilton) for nitrate and chloride. On filtered chloride samples, Ferric thiocyanate colorimetry test was run (method detection limit,  $0.5 \text{ g m}^{-3}$ ). Filtered  $\text{NO}_3$  samples were analysed using ion chromatography (method detection limit,  $0.05 \text{ g m}^{-3}$ ).

The 1080 baits collected during the experiment were stored in individual storage bags and kept frozen at  $-80^\circ \text{C}$  until sent for analysis. The baits were analysed by Animal Control

Products (Wanganui) to quantify residual 1080 using the gas chromatography technique based on Method 8B of the Denver Wildlife Center. This method has a 1080 detection limit of  $1 \text{ mg kg}^{-1}$  (Hall, Animal Control Products, 2010; pers comm). Based on the original 1080 concentration (0.15%), the amount of 1080 leached from the baits was calculated. Owing to stringent manufacturing process, 1080 concentrations in the baits were not tested for their concentrations and were assumed

## 2.3 Statistical analyses

Two analyses were done on the data. Firstly, we examined whether leaching of 1080 from cereal baits differed with rainfall intensity. This analysis used a mixture of data from previous studies (Table 2-1), and from the rainfall simulator study (Section 2 of this report). Each of these studies had different rainfall intensities, ranging from a low intensity of  $3 \text{ mm h}^{-1}$  (Srinivasan et al., 2010 & 2012a) to baits being fully submerged (Suren, 2006). Separate analyses were performed on data for each bait type. All statistical analysis were conducted to a significance level of  $p = 0.05$ .

Analysis of covariance (ANCOVA) was used to determine whether there was a difference in the rate of 1080 leaching from baits under different intensity of rainfall. ANCOVA allows for comparisons to be made of one variable (in this case 1080 concentration in baits) in 2 or more groups (in this case the different rainfall intensities) taking into account (or correcting for) variability caused by other variables, called covariates (in this case time). The ANCOVA test tells us whether there was a difference in 1080 concentrations in baits between the different rainfall intensities, whether there was an effect of time on 1080 concentration in baits, and whether there was an interaction between the rate of 1080 loss over time and the different rainfall intensity. The magnitude of these differences is determined by the F-ratio, with the probability value (P) of rejecting the null hypothesis (e.g., that there is no effect of rainfall intensity on bait loss) being set to 0.05. ANCOVA analysis requires normally distributed data. This was best achieved by fourth-root transformation of the time series, and the bait concentration data from both bait types. ANCOVA was also used to determine whether there was a difference in leaching rates between 1080, nitrate and chloride from the RS5 over time, and from the Wanganui No. 7 baits over time. For ANCOVA analysis, data from the two baits types were treated separately.

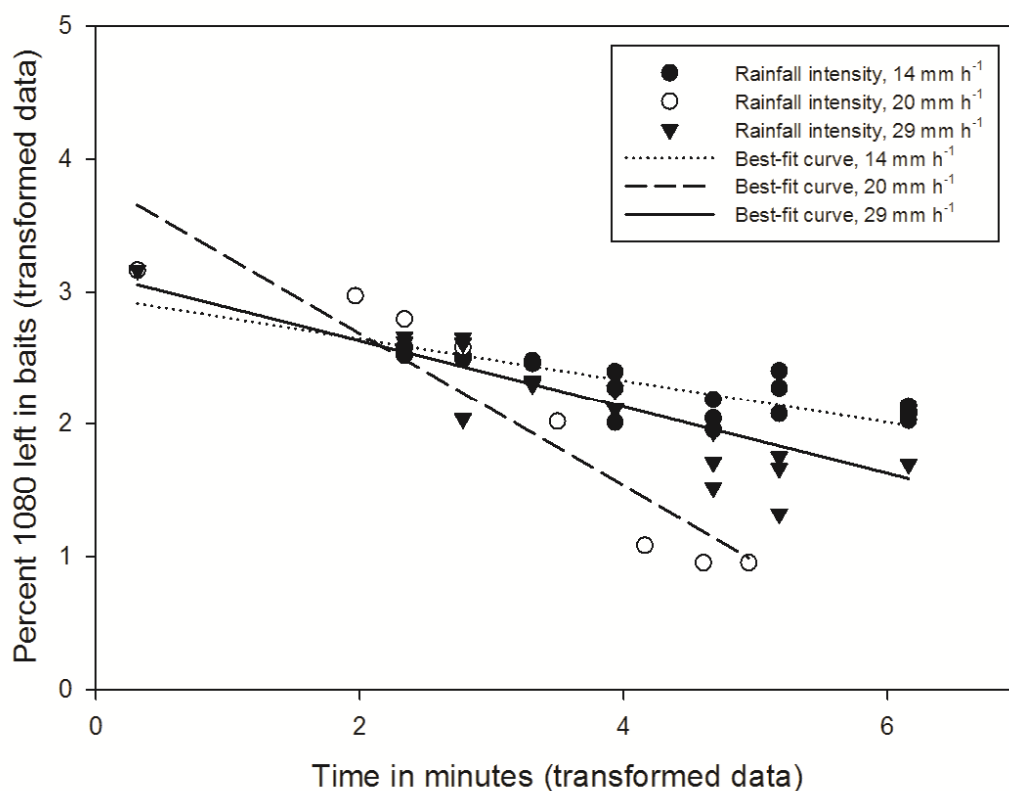
## 2.4 Results

### 2.4.1 Effect of rainfall intensity on 1080 leaching

During our laboratory experiments, we used a high rainfall intensity ( $> 14 \text{ mm h}^{-1}$ ). Rainfall simulators when used to simulate low intensities ( $< 10 \text{ mm h}^{-1}$ ) seldom result in uniform and consistent distribution. Thus, we used intensities greater than  $10 \text{ mm h}^{-1}$ .

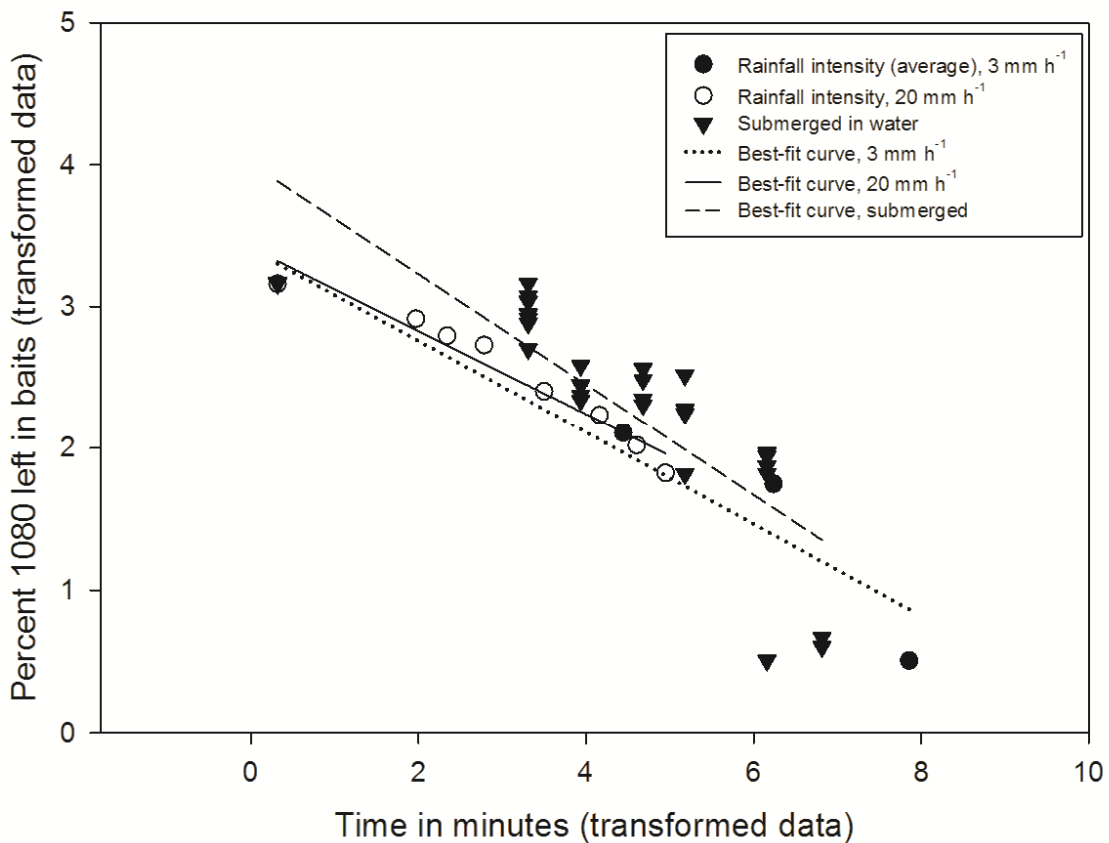
For RS5 baits, a significant relationship between 1080 concentrations and time was found for each rainfall intensity. The slope of the relationships were not the same, and could not be explained by the rainfall intensity magnitude. Examination of the data showed that the rate of loss appeared higher from the study by Bowen (at  $20 \text{ mm h}^{-1}$ ), intermediate for the rainfall simulation study at  $29 \text{ mmh}^{-1}$ , and lowest of the rainfall intensity at  $14 \text{ mm h}^{-1}$  (Figure 2-2). We expected that the rate of 1080 loss would be quicker under higher rainfall, yet we found that this was not the case (Figure 2-2). This suggests that the loss of 1080 from RS5 baits was independent of rainfall intensity (based on intensities we tested), despite being different

between the three studies. Another explanation for the increased loss at 20 mm h<sup>-1</sup> study could be due to small baits (6 g) used in that study (Bowen et al., 1995), while we used 12 g baits. The influence of bait size on 1080 release may need further investigation.



**Figure 2-2: 1080 concentrations (in percentage w/w) in RS5 baits exposed to different rainfall conditions.** Data sources: 20 mm per hour from Bowen et al. (1995); and 14 and 29 mm per hour from current study. Note that the axes represent fourth-root transformed data.

For Wanganui No. 7 baits, a significant relationship between 1080 concentrations and time was found for each rainfall intensity (Figure 2-3). The slopes of the relationships were the same. These results suggested that for Wanganui No. 7, we could compare 1080 leaching rates using data from all studies, irrespective of rainfall intensity.



**Figure 2-3: 1080 concentrations (in percentage w/w) in Wanganui No. 7 baits exposed to different rainfall conditions.** Data sources: 3 mm per hour came from Srinivasan et al. (2012a); 20 mm per hour from Bowen et al. (1995); and submerged in water from Suren (2006). Refer Table 2-1 for details on rainfall conditions. Note that the axes represent fourth-root transformed data.

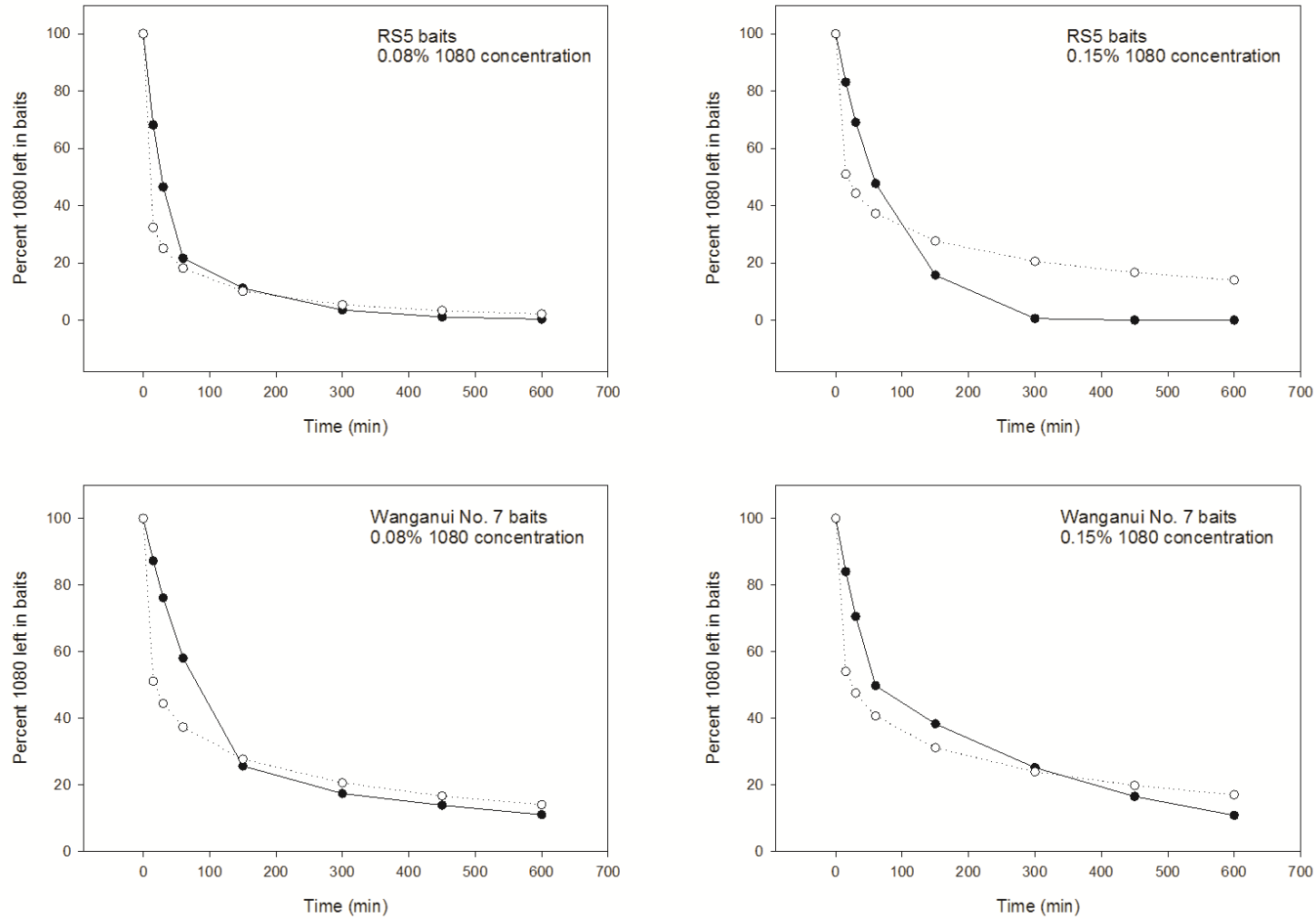


Even though we found rainfall intensity had no effect of Wanganui No.7, we could not confirm the same with RS5. The differences in 1080 loss over time could more likely be due to the bait weight as suggested by Thomas et al. (2004). Hence, we did not combine the 1080 release data from both types into one. With the Wanganui No. 7 baits, the differences in bait weights between our study (12 g) and that of Bowen et al. (1995) (6 g) did not appear to have an influence on release rates.

In the original 1080 model, Srinivasan et al. (2009 & 2012a) developed two different 1080 release rate equations for each bait type (RS5 and Wanganui No. 7). These included a large, quick initial release of 1080 in the first 1 to 2.5 h of rainfall, followed by a much smaller and slower release. These equations were originally derived from the data of Bowen et al. (1995). Results from our current study suggest a single 1080 release rate equation could be used for each bait type. These equations are listed in Table 2-2, and were used in the 1080-hydrology transport model, Pesticide Runoff Simulation model described in Srinivasan et al. (2012b). No published data are available describing 1080 release rates from baits with 0.08% w/w 1080, with the exception of data available in Bowen et al. (1995) that was not used in our analyses. We thus assumed similar 1080 release characteristics for these lower concentration baits. Figure 2-4 presents a comparison of old (from Srinivasan et al., 2012a) and revised (Table 2-2) for RS5 and Wanganui No. 7 baits.

**Table 2-2: Best fit 1080 release equations for Wanganui No. 7 and RS5 cereal baits.** Equations are valid for time greater than zero. For Wanganui No. 7 and RS5 baits with 1080 concentration 0.15% w/w, data from studies listed in Table 2-1 and current study were used. For Wanganui No. 7 and RS5 baits with 0.08% 1080 concentration w/w, data from Bowen et al. (1995) were used.

Bait type	Percent 1080 remaining in bait
Wanganui No.7 (0.08% 1080)	$[(-0.2472 \times (\text{time in minutes})^{0.25}) + 3.1600]^4$
Wanganui No. 7 (0.15% 1080)	$[(-0.2279 \times (\text{time in minutes})^{0.25}) + 3.1600]^4$
RS05 (0.08% 1080)	$[(-0.3939 \times (\text{time in minutes})^{0.25}) + 3.1600]^4$
RS05 (0.15% 1080)	$[(-0.2478 \times (\text{time in minutes})^{0.25}) + 3.1600]^4$

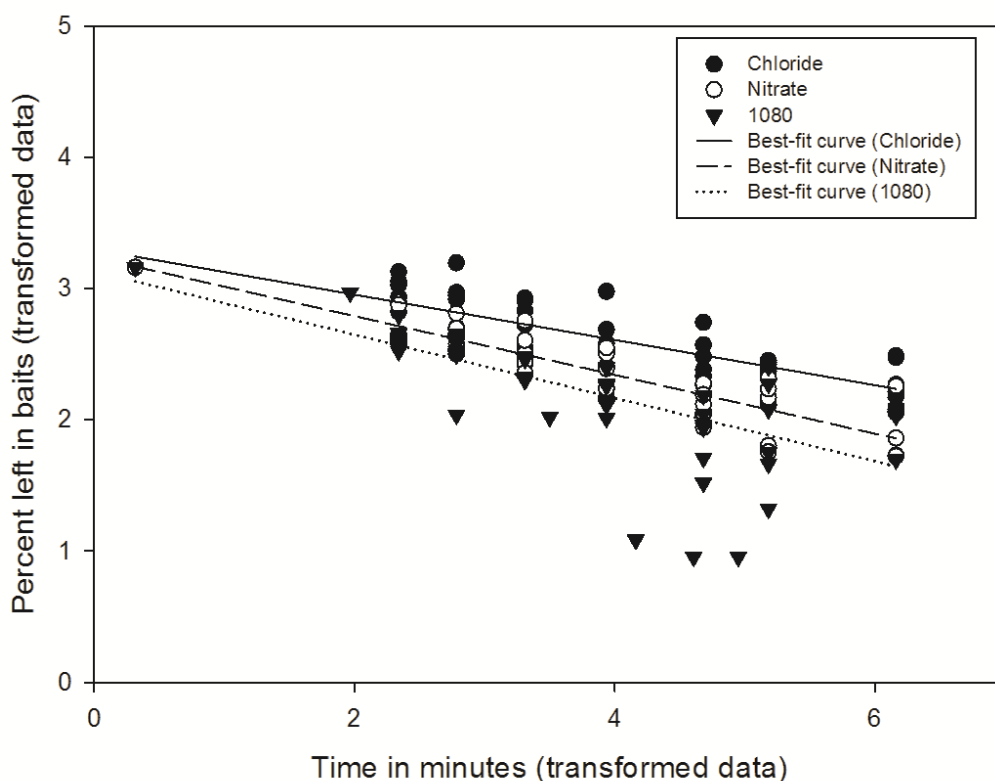


**Figure 2-4: Comparison of 1080 release rate equations from published and current studies.** Data source: Solid circles, data from Bowen et al. (1995) and Srinivasan et al., (2012a); and hollow circles, current study and studies listed in Table 2-1.

## 2.4.2 Differences between 1080, chloride and nitrate

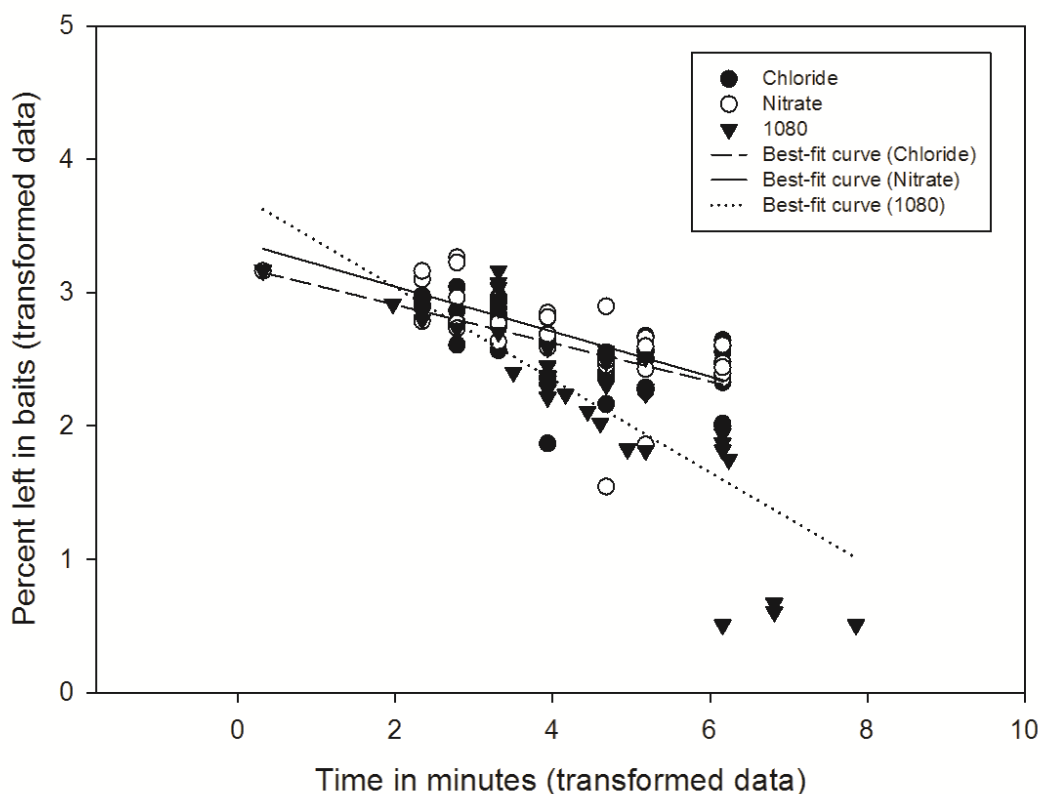
The leaching of 1080, chloride, and nitrate from RS5 and Wanganui No. 7 was compared to see whether these anions could be used as surrogates for 1080 tracing studies. As with the previous analysis, we used fourth-root transformed data, as this transformation achieved data that was normally distributed. We also converted all concentrations into percentages of the original concentration, reflecting the different starting concentrations in each bait type: 0.15% w/w for 1080, and 5% w/w each for chloride and nitrate.

ANCOVA showed no differences in the percentage loss of either 1080, chloride or nitrate from RS5 baits ( $F = 0.918$ ,  $P > 0.05$ ), and no significant chemical  $\times$  time interaction between 1080 and the 2 anions ( $F = 2.78$ ,  $P > 0.05$ ). This suggested that the loss of 1080 and each anion was consistent over time in RS5 baits. However, examination of the data showed that the initial losses of chloride and nitrate were similar to 1080, but after approximately 2 h, more 1080 was lost over time than chloride or nitrate (Figure 2-5).



**Figure 2-5: Comparison of percentage loss of 1080, chloride and nitrate from RS5 baits over time.** All anions had a similar pattern of loss over time, although more 1080 was lost after two hours than the anions. Note that the axes represent fourth-root transformed data.

ANCOVA showed significant differences in the rate of loss of 1080, chloride and nitrate from Wanganui No. 7, and a significant chemical  $\times$  time interaction effect. Examination of scatter plots showed that the rate of 1080 loss was higher than the loss of either nitrate or chloride (Figure 2-6).



**Figure 2-6: Comparison of percentage loss of 1080, chloride and nitrate from Wanganui No. 7 baits over time.** 1080 was leached from Wanganui No. 7 baits at a faster rate than either chloride or nitrate. Note that the axes represent fourth-root transformed data.

## 2.5 Conclusions

During the rainfall simulation study, we used rainfall intensities of 14 and 29 mm h<sup>-1</sup>. Earlier rainfall simulation studies by Bowen et al. (1995) and Thomas et al. (2004) reported rainfall intensity of 20 mm h<sup>-1</sup>. For rainfall intensities of less than 10 mm h<sup>-1</sup>, as rainfall simulators do not produce consistent and uniform rainfall distribution, we have to rely on natural rainfall, though the duration and continuity of natural events are beyond our control. Srinivasan et al. (2009 & 2012a) reported 1080 release rates under natural rainfall conditions where they recorded rainfall intensity varying from 0.8 to 9.6 mm h<sup>-1</sup> (average 3.3 mm h<sup>-1</sup>), and the event was intermittent.

Bowen et al. (1995) had indicated that rainfall intensity might influence 1080 release rate from baits. A priori we had assumed that 1080 release rates from baits would be higher at higher rainfall intensity. However, we did not observe this for both bait types. For the RS5 baits, we found a significant interaction, but 1080 release rate bore no relationship to rainfall intensity. For the three rainfall intensities tested, there was no consistent effect on the loss of 1080. For the Wanganui No. 7, the rate of 1080 release was similar, irrespective of rainfall intensity. For Wanganui No. 7, release data were available for a wide rainfall intensity range, while the intensity range was very narrow (14 to 29 mm h<sup>-1</sup>) for RS5 data. Additional 1080 release data collected at low rainfall intensities (< 5 mm h<sup>-1</sup>), might allow us to further explore the influence of rainfall intensity on 1080 release from RS5 baits.

Analysis of Wanganui No. 7 baits indicated no significant rainfall intensity effect. This indicates that all baits that are applied in a catchment and that land either in a stream, or are exposed to rainfall of different intensities appear to release 1080 at a similar rate. This greatly simplified the equations in the 1080 runoff simulation model.

The use of chloride and nitrate as a surrogate for future experimental work remains equivocal. For RS5 baits, observed release rates of 1080, and of the two anions were similar during application of simulated rainfall (up to 2 h). We observed generally high release of anions during this period (as high as 50 per cent). This indicates that, for RS5, nitrate or chloride may have use as a surrogate for 1080 in future field trials. However, we observed far quicker leaching of 1080 from Wanganui No 7 baits than we did for either chloride or nitrate. Thus, the use of these two anions as surrogates of 1080 may be complicated by the fact that the leaching characteristics differ. Differences in the behaviour of these two anions and 1080 as they move through the soil are investigated in the next section.

### 3 Site selection for field studies

Sites for the plot-scale rainfall simulator study (section 4) and the hillslope-scale natural rainfall study (section 5) were selected based on the criteria listed in Table 3-1 (factors listed in decreasing order of importance). During the initial reconnaissance survey in May 2011, a total of 36 potential sites were visited around the Greymouth region, including Nelson Creek, Red Jacks Creek and the Arnold Valley. An additional inspection was undertaken in June 2011 to select the final study site.

**Table 3-1: Factors considered for the selection of sites for plot- and hillslope-scale field studies.**

Factors	Preference/remarks
Proximity of study site to a stream	Required to enable tracking of 1080 from study hillslope to stream via surface and subsurface pathways
Size of stream	First or second order stream where flows can be gauged safely during large flows and a reliable rating curve can be developed based on stage measurements
Slope	A steep slope that would enhance the generation of overland flow and transport of 1080 to stream
Vegetation	Vegetation similar to catchments where 1080 applications occur
Scale of hillslope	Hillslope large enough to accommodate both rainfall simulator and natural rainfall studies
Accessibility	Easy access to transfer instruments to the study site Low traffic to safeguard the instruments when left unattended between plot- and hillslope-scale studies Driving distance from the nearest accommodation so that water samples can be stored in a freezer immediately after collection as well as allow sampling after hours

The final site, adjacent to Wallaby Creek, was located in the Mawhera State forest (Figure 3-1). Figure 3-2 shows a photograph of the study site. Figure 3-3 illustrates the location of the rainfall simulator and natural rainfall study site with respect to the stream. The site was accessed via a forested road, where very little traffic was observed over the entire study period. Wallaby Creek generally had small flows ( $< 500 \text{ L s}^{-1}$ ), with a peak flow of  $6,044 \text{ L s}^{-1}$  recorded following a period of heavy rain during the hillslope-scale experiment (January 2012).

According to Landcare soil classification map (<http://gisportal/landcareresearch.co.nz/>), soils in this region belong to Arahura/Blackball soil series. These are well drained soils, with depth to the confining layer greater than 1.5 m. These soils are neutral (pH, 6.4-7.5). They are poorly permeable. Following the field experiments, a few test pits were dug (60 cm deep) to describe the soils within the study site hillslope. These are described later in this report (section 5.3.3).

The average drop in elevation across the hillslope ranged from 0.6 (at the natural rainfall site) to 1.1 (at the rainfall simulator site) metre per metre. The hillslope was covered by Douglas Fir trees. The soil surface was covered with litter, whose thickness varied from few mm to up to 5 cm. The hillslope ended in a small flood plain, whose width varied between 0.4 and 2 m, before draining into the creek. Upslope of the study sites, the hillslope extended over a

distance of 10-15 m and then flattened off. Presence of erosional features such as rills across the hillslope indicated that concentrated flows could be occurring during large rainfall events. A small pool of water at the bottom end of the hillslope within the floodplain indicated the emergence of subsurface flow from the hillslope.

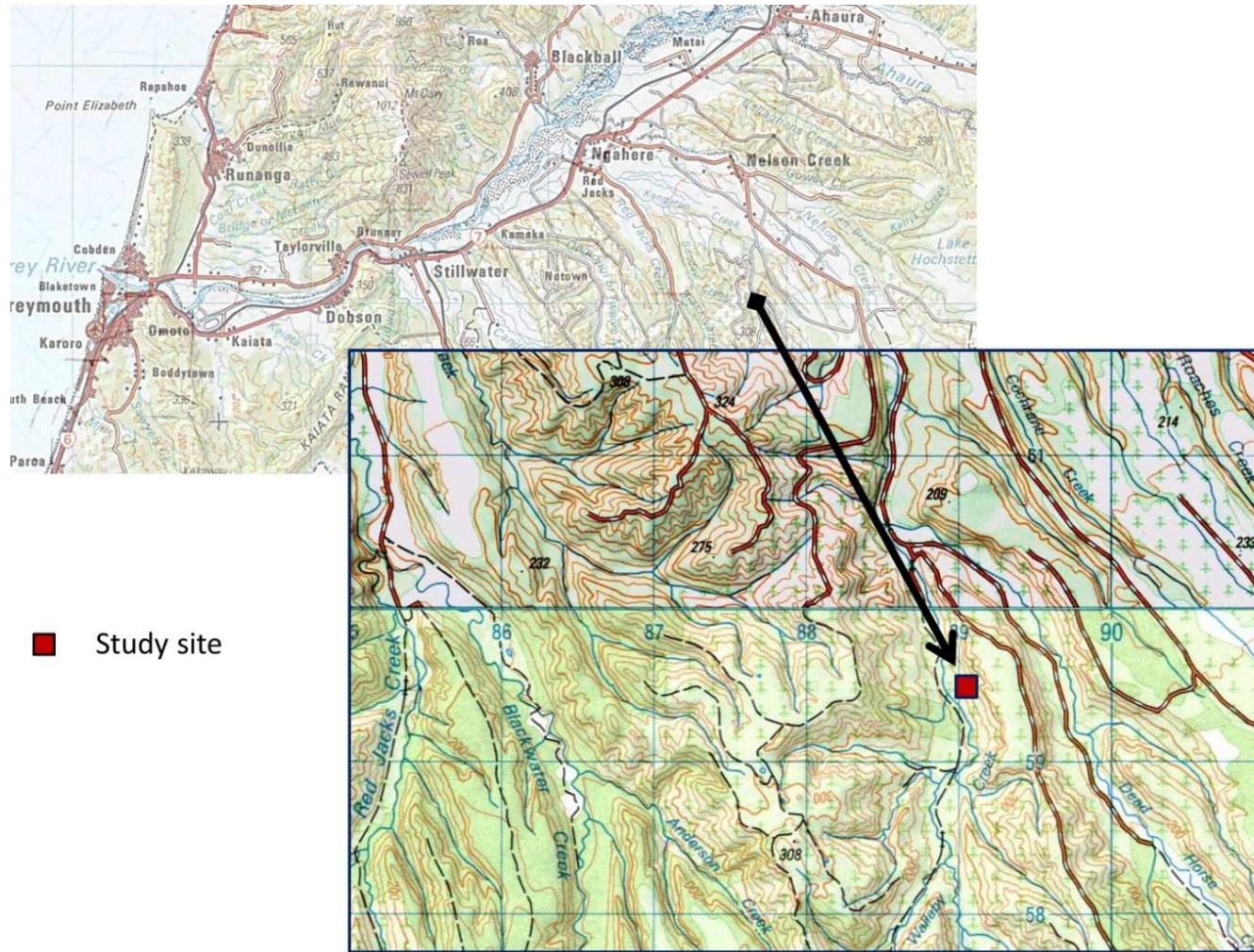
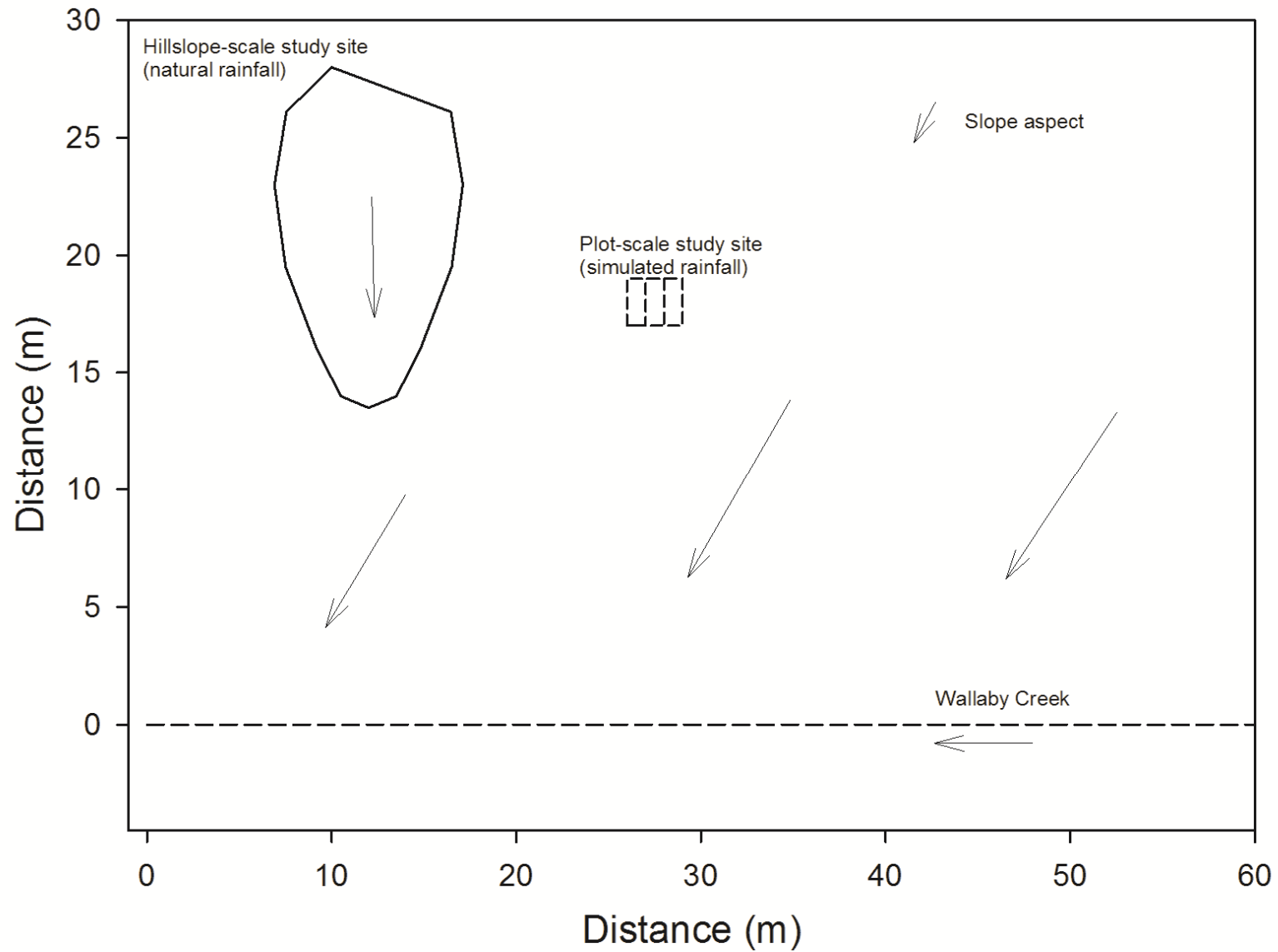


Figure 3-1: Location of field study site.





**Figure 3-2: Field site hillslope - Wallaby Creek in the background.** (Photo: E Hreinsson, NIWA).



**Figure 3-3: Location of stream and plot and hillslope study sites.** Additional instrumentation associated with these studies is shown elsewhere.

## 4 Plot-scale transport of 1080 under simulated rainfall

### 4.1 Study objectives and experimental set up

The objectives of this plot-scale study were threefold:

1. Quantify 1080 transport via overland flow and infiltration under simulated rainfall conditions;
2. Quantify 1080 movement within the soil profile, with particular emphasis on investigating lateral movement downslope, versus vertical movement into the soil; and
3. Compare the movement of 1080 with that of chloride and nitrate to see whether they behaved in a similar manner to 1080.

Three runoff plots (2 m long and 0.8 m wide) were placed adjacent to each other (see Figure 4-1 for a photograph of the runoff plots and Figure 4-2 for a schematic of the runoff plot and instrumentation). Stainless steel frames were inserted into the ground to a depth of 5 cm, and the gap between the frames and soil sealed with silicon to prevent the entry of overland flow into the soil. During the experiment, baits were placed at the top end of the plot. Overland flow from each plot was collected individually at the bottom end of the plot. Within each plot, suction lysimeters were installed close to and far from the baits. These lysimeters were arranged to sample both vertically infiltrating rainfall (shallow and deep lysimeters) and lateral subsurface movement of infiltrated rainfall (upper and lower locations).

Before each experiment, plots were pre-wetted for 30 min with a rainfall intensity of 12 to 15 mm h<sup>-1</sup>. Experiments were conducted for six consecutive days (August 7 to 12, 2011). In order to ensure uniform antecedent conditions, the pre-wetting was conducted on all six days. RS5 baits (1080, nitrate and chloride) were used on days 1 to 3, and Wanganui No. 7 baits (1080, nitrate and chloride) on days 4 to 6. Baits (2 kg on day 1 and 1 kg on all other days) were applied over an area of 0.8 by 0.2 m. These application rates are equivalent to 50,000 and 25,000 times that of the typical application rate of 2.5 kg of baits per ha, respectively. A large application rate was used to ensure a solute (1080/chloride/nitrate) signal was generated, as in many earlier reported studies 1080 concentrations in water samples were below detection limits.

None of the RS5 or Wanganui No. 7 bait types were applied more than once to each plot. For example, on day 1, plot 1 received RS5 1080 baits, plot 2, RS5 chloride baits, and plot 3, RS5 nitrate baits. On day 2, plot 1 received RS5 nitrate baits, plot 2, RS5 1080 baits and plot 3, RS5 chloride baits. On day 3, plot 1 received RS5 chloride baits, plot 2, RS5 nitrate baits, and plot 3, RS5, 1080 baits. The same procedure was used with Wanganui No. 7 baits. This procedure served three purposes (1) each plot received all bait types, and thus, any small scale variability associated with micro-topography and surface cover influencing overland flow and soil properties affecting infiltration and leaching was controlled; (2) cross-contamination of samples from traces of chemicals from the previous day was eliminated. By the time the same bait type was applied to any one of the plots, in excess of 250 mm of rainfall would have been applied, and any traces would have been washed away; and (3) there was no cross contamination of suction lysimeter samples between plots on any given day.

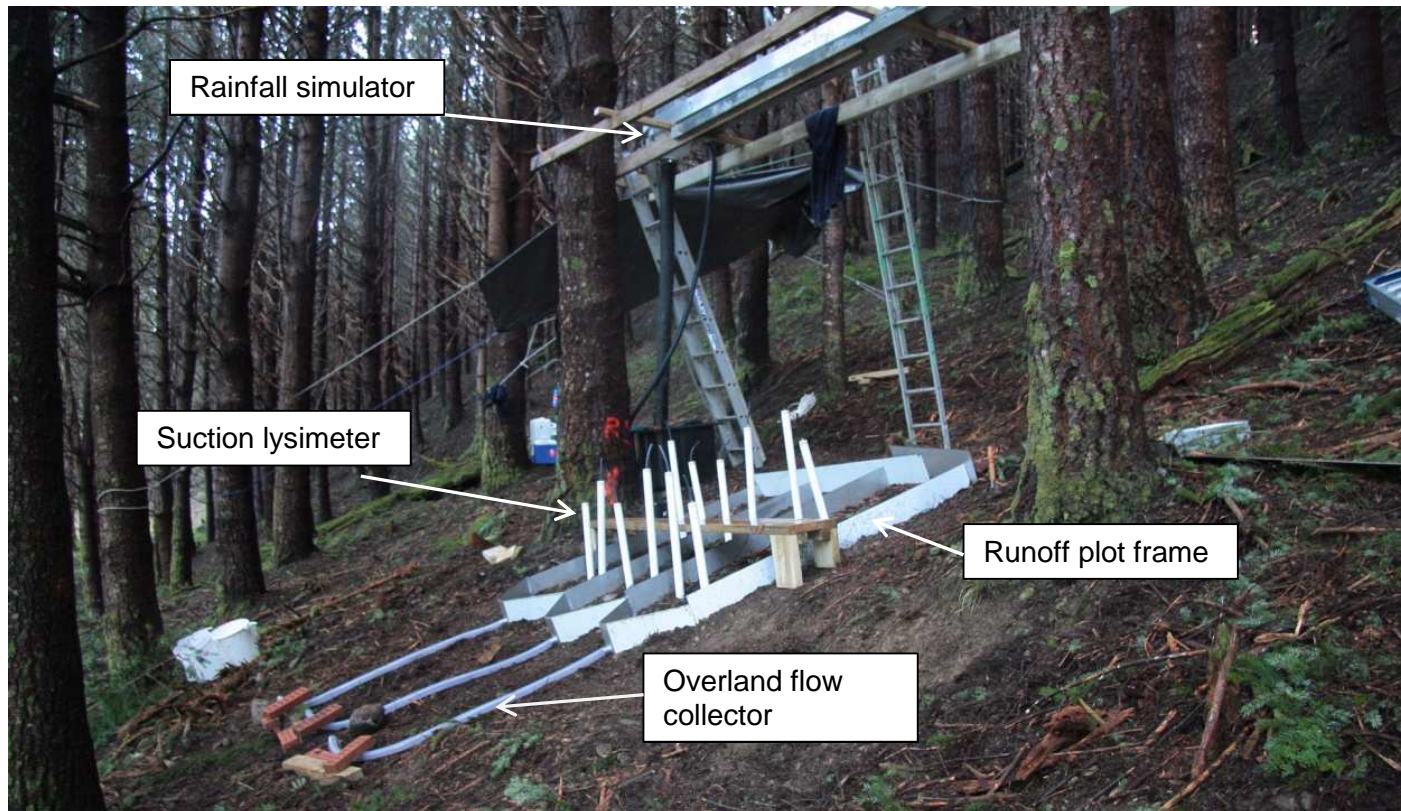
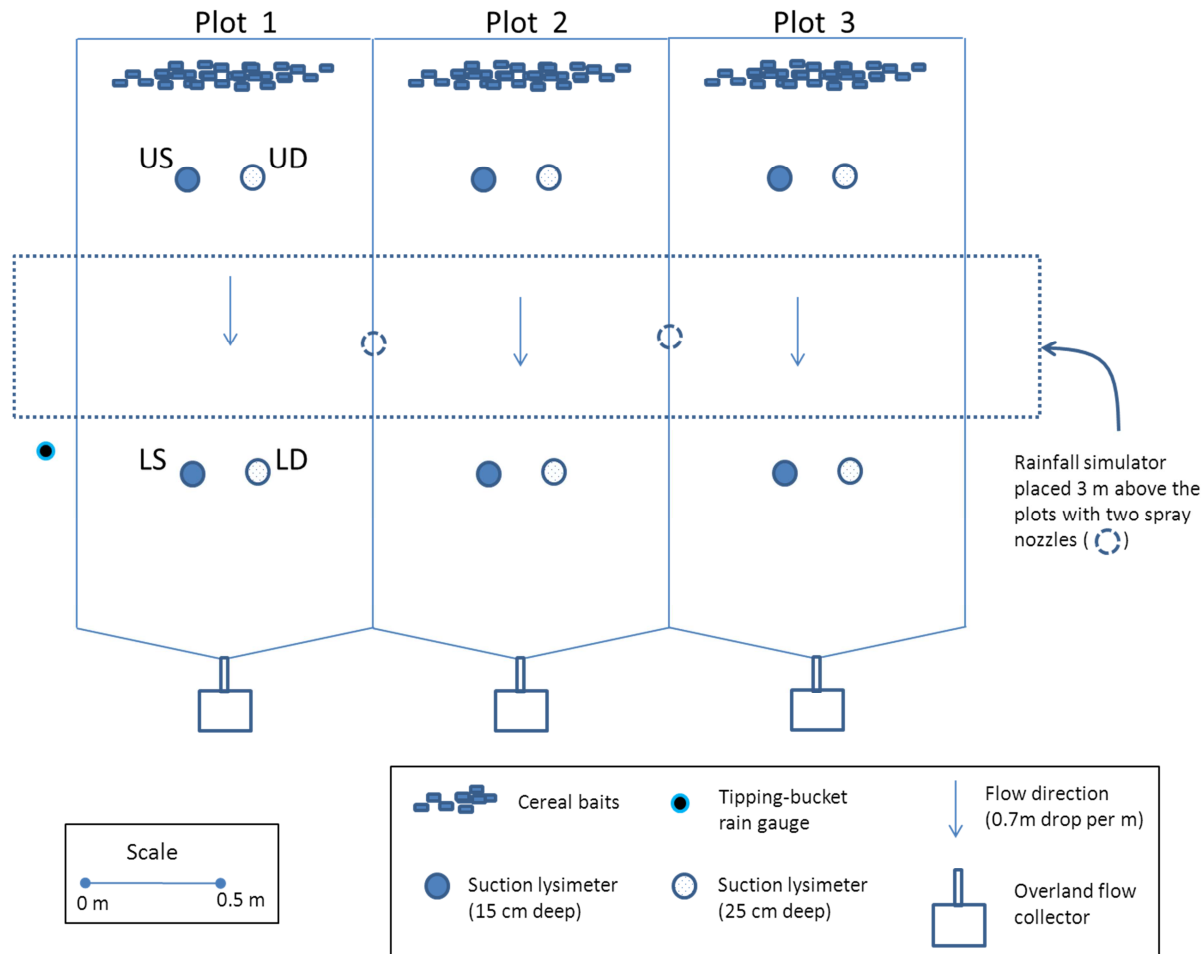


Figure 4-1: Rainfall simulator and runoff plot arrangement - plot-scale study. (Photo: A Suren, NIWA).



(US – Upper Shallow Lysimeter; UD – Upper Deep Lysimeter; LS – Lower Shallow Lysimeter; LD – Lower Deep Lysimeter)

**Figure 4-2: Schematic of plot and instrumentation arrangement - plot-scale study.**

During the plot-scale experiment, rain was applied at an intensity of 12 to 15 mm h<sup>-1</sup>, continuously for 8 h. A tipping-bucket rain gauge placed immediately outside the plot, below the rainfall simulator recorded the rainfall (0.2 mm per tip). Soilwater and overland flow samples were collected at 2, 4 and 8 h from the start of rain simulation and 4 and 16 h after the cessation of rain application. Baits were removed 24 h after the start of rainfall application.

Suction lysimeters were primed two hours before each sample collection using a hand pump so that water samples could enter the sampling tube via a porous ceramic cup. The volume of overland flow collected at the bottom was measured and a sub-sample collected for analysis. All water samples collected were stored at -80° C before being sent for laboratory analysis. All chloride and nitrate water samples were sent to Hills Laboratory (Hamilton) for analysis, and 1080 samples were analysed at Landcare (Lincoln). Chloride and nitrate samples were filtered (0.45 µm membrane filter) by Hills Laboratory. The filtered chloride samples were analysed using a Ferric thiocyanate colorimetry test (method detection limit, 0.5 g m<sup>-3</sup>). Filtered nitrate samples were analysed using ion Chromatography (method detection limit, 0.05 g m<sup>-3</sup>). 1080 samples were analysed using a gas chromatography method (Ozawa & Tsukioka 1987) with a method detection limit of 0.1 µg L<sup>-1</sup>.

#### **4.1.1 Statistical analyses**

All data summarising the volumes of overland flow and soil water collected, as well as the concentrations of 1080 in overland flow and soilwater were fourth-root transformed prior to analysis to achieve a normal distribution.

We first quantified the relative proportion of applied rainfall that left the experimental plots either as overland flow, or as infiltration. Secondly, we used a t-test to compare the concentration of 1080 found in overland flow to that found in soilwater (irrespective of whether it was from the upper or lower, or shallow or deep lysimeters).

Finally, we compared and contrasted movement of 1080 through the soil profile. For this analysis, we tested whether the concentration of 1080 differed between the upper and lower lysimeters, and between the deep and shallow lysimeters. We used a repeated measures 2-WAY ANOVA for this analysis, where we were able to determine whether there was a significant difference between 1080 concentration in the upper and lower lysimeters (location effect), and whether there was a difference in 1080 concentration in the deep and shallow lysimeters (depth effect). The 2-WAY ANOVA also allows us to determine whether movement of 1080 from shallow to deep areas in the soil was the same in the upper and lower locations.

## **4.2 Results**

### **4.2.1 Comparison of overland flow to subsurface flow**

During the plot-scale experiment, the simulated rainfall intensity ranged from 12-15 mm h<sup>-1</sup>. Less than 0.5 per cent of total applied rainfall became overland flow, indicating a high infiltration capacity of soils in the experimental area. This was despite applying a moderately-high intensity rainfall for 8 h, and on a steep slope. Overland flow was found to be limited to the rainfall application period (0 to 8 h of the experiment). Results from overland flow samples are shown in Table 4-1.

The average volume of overland flow collected was 48 mL, with a median of 7 mL. A maximum of 224 mL was recorded during a 4 h collection period. During this same period, a total of as high as 96 L of rainfall was applied to each plot. The overland flow accounted for between 0.03 and 0.25 per cent of the total rainfall applied.

The average 1080 concentration in overland flow during the RS5 trial was highly variable (mean  $\pm$  std error,  $2.7 \pm 5.6 \mu\text{g L}^{-1}$ ), and was not significantly different (t-test  $P > 0.05$ ) to the 1080 concentration collected in the soilwater ( $0.88 \pm 1.39 \mu\text{g L}^{-1}$ ). A similar result was found for Wanganui No. 7 baits, where the mean soil 1080 concentration ( $9.18 \pm 22.9 \mu\text{g L}^{-1}$ ) was not statistically different to the mean overland flow 1080 concentration ( $0.6 \pm 1.5 \mu\text{g L}^{-1}$ ).

**Table 4-1: Overland flow volumes and 1080 concentrations from plot-scale study.** Rainfall was simulated between 0 and 8 h.

Day	Time interval (h)	Overland flow volume collected (mL)	1080 concentration ( $\mu\text{g L}^{-1}$ )
RS5 baits (concentration, 0.15% w/w)			
Day 1	0-4	224	10.18
	4-8	50	17.20
Day 2	0-2	2	1.79
	2-4	5	0.32
	4-8	5	0.20
Day 3	0-2	5	0.05
	2-4	3	0.68
	4-8	7	0.14
Wanganui baits (concentration, 0.15% w/w)			
Day 1	0-2	102	0.76
	2-4	178	0.55
	4-8	92	0.20
Day 2	0-2	0	No sample
	2-4	0	No sample
	4-8	4	5.36
Day 3	0-2	87	0.05
	2-4	30	0.11
	4-8	19	0.05

#### 4.2.2 Characterisation of 1080 movement through the soil

Data from soilwater samples are shown in Table 4-2. Analysis of soilwater sample data using 2-WAY ANOVA from the RS5 experiment showed that 1080 concentrations were significantly higher in the lysimeters closer to the baits ( $1.58 \pm 1.69 \mu\text{g L}^{-1}$ ), than those lower down the slope ( $0.18 \pm 0.21 \mu\text{g L}^{-1}$ ) (Figure 4-3). There was no difference in 1080 concentrations between deep ( $0.87 \pm 1.3 \mu\text{g L}^{-1}$ ) and shallow ( $0.89 \pm 1.5 \mu\text{g L}^{-1}$ ) lysimeters, and no depth  $\times$  location interaction effect. This suggests that any 1080 that leached from RS5 baits moved mainly into the upper layers of the soil close to where the baits were, and from there did not appear to move to deeper areas downhill to be intercepted by the lower lysimeters. A similar result was found in the trial of the Wanganui No. 7 baits (Figure 4-4). Here, 1080 concentrations were much higher in soilwater collected from lysimeters closer to the baits ( $17.85 \pm 30.3 \mu\text{g L}^{-1}$ ) than those on the downhill slope ( $0.55 \pm 1.2 \mu\text{g L}^{-1}$ ), and were similar in the shallow and deep lysimeters ( $9.1 \pm 21.7 \mu\text{g L}^{-1}$ ). This result again emphasise the fact that any 1080 leaching from baits moves into fairly shallow depths of the soil (within top 25 cm), but does not appear to move from here into deep areas, or move to any great degree down the hill slope.

### **4.2.3 Comparison of 1080, chloride and nitrate movement**

The majority of water samples recorded chloride and nitrate concentrations below detection limits (0.5 and 0.05 g m<sup>-3</sup>, respectively). Unfortunately, further enquiries revealed that the laboratory had run wrong tests on the samples. Therefore, we were unable to present any results characterising the movement of chloride and nitrate in overland flow and through the soilwater. Thus, the possibility of using one of these two anions as surrogate to 1080 during field experiments remains unanswered.

## **4.3 Conclusions**

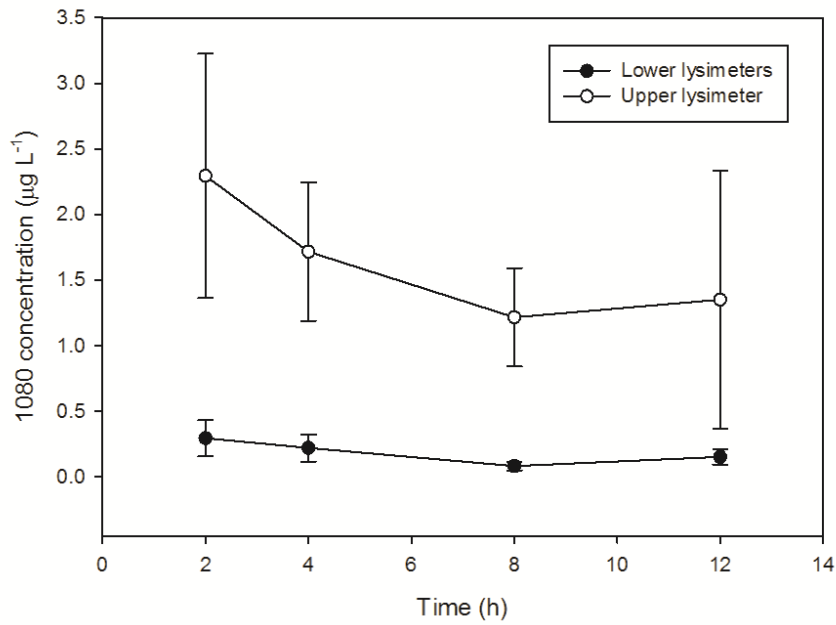
The plot-scale rainfall simulator study was conducted on a steep hillslope and at moderately-high intensity and continuous (8 h) rainfall conditions. Less than 0.5 per cent of rainfall became overland flow. As much as 99.5 per cent of the rainfall infiltrated into the soil, carrying with it most of the 1080 released from baits. Higher 1080 concentrations were found in the lysimeters closer to the baits than those farther. 1080 could have reached the lower lysimeters via lateral subsurface flow or infiltrating 1080-laden overland flow. Whichever be the transport mechanism, 1080 concentrations in soilwater (within the top 25-30 cm) appear to be diminishing with distance from the source (baits).



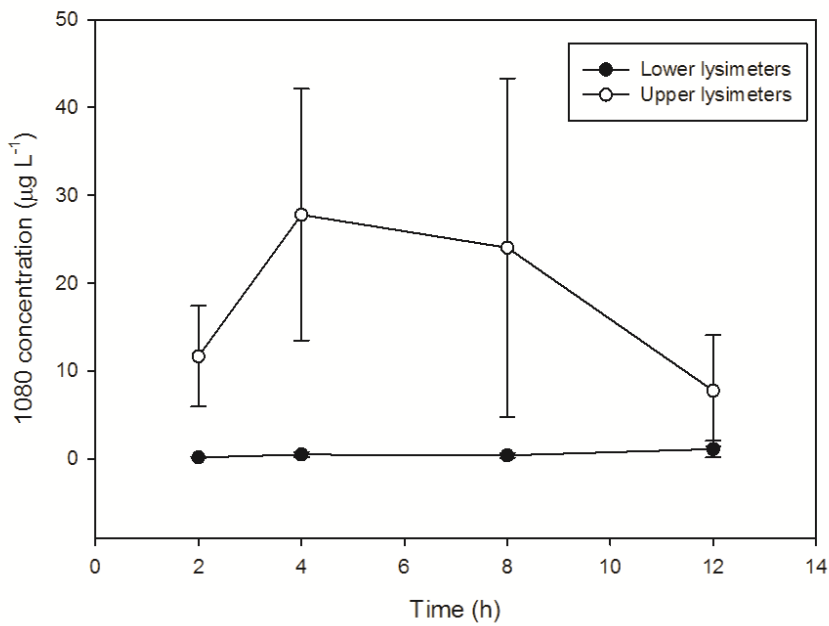
**Table 4-2: Soilwater 1080 concentrations for Wanganui No. 7 and RS5 baits.** Rainfall simulated from 0 to 8 h.

Day	Duration of sample collection (h)	Measured 1080 concentration ( $\mu\text{g L}^{-1}$ )							
		Wanganui No. 7 baits				RS5 baits			
		Upper shallow	Upper deep	Lower shallow	Lower deep	Upper shallow	Upper deep	Lower shallow	Lower deep
Day 1	0-2	0.35	0.63	0.05	0.05				
	2-4	0.23	2.15	0.12	0.05	0.83 <sup>1</sup>	1.23	0.70	0.05
	4-8	0.16	2.69	0.05	0.05	0.62	0.80	0.24	0.05
	8-12	0.05	0.21	0.05	0.05	0.23	1.25	0.05	0.05
Day 2	0-2	11.30	25.50	0.27	0.42	3.66	4.78	0.76	0.32
	2-4	83.60	56.99	0.53	1.95	1.49	3.98	0.26	0.21
	4-8	119.80	12.95	0.30	1.78	0.39	1.48	0.05	0.05
	8-12	39.10	2.11	0.69	5.80	0.05	0.22	0.41	0.14
Day 3	0-2	0.29	32.00	0.15	0.05	0.10	0.63	0.05	0.05
	2-4	0.44	23.30	0.18	0.15	0.41	2.37	0.05	0.05
	4-8	0.05	8.85	0.15	0.10	2.92	1.09	0.05	0.05
	8-12	0.19	4.93	0.05	0.05	6.18	0.17	0.21	0.05

<sup>1</sup> Sample collected from 0 to 4 h.



**Figure 4-3: Observed 1080 concentrations in soilwater from lysimeters placed on the upper slope close to RS5 baits, and the lower slope (mean + 1 se).**



**Figure 4-4: Observed 1080 concentrations in lysimeters placed on the upper slope close to Wanganui No. 7 baits, and the lower slope (mean + 1 se).**

## 5 Hillslope-scale transport of 1080 under natural rainfall

### 5.1 Study objectives and experimental set up

The goal of this final study was four-fold:

1. to better quantify 1080 transport in overland flow during a natural rainfall event
2. to better understand movement of 1080 into the soil under natural rainfall conditions
3. to examine the transport of 1080 to shallow groundwater, and
4. to monitor 1080 concentrations in a stream under natural rainfall conditions following a large 1080 application

The major difference between this hillslope-scale study (natural rainfall) and the plot-scale study (simulated rainfall) was that in the former the entire catchment was wet. In addition, unlike the plot-scale study, this study tracked 1080 transport under a varying intensity, intermittent rainfall conditions.

The hillslope-scale study site was adjacent to the rainfall simulator study (Figure 3-3). A schematic of plot and instrument arrangement are shown in Figure 5-1. Within the hillslope, a small area was bounded by metal frames dug into the ground (sealed with bentonite clay) to a depth of 5 cm to delineate and collect overland flow over a defined area. The area within the frames represented our experimental area (103 m<sup>2</sup>), and this was 64 times greater than used in the plot-scale study. All overland flow was collected at the bottom end of the plot, measured and sampled. Subsurface flows entering, leaving, or passing through the plot were not impeded.

Suction lysimeters were installed at three locations along the hillslope – two pairs at the top of the hillslope, 2-m downslope of baits, two pairs at the mid-section, 10 m downslope of baits, and two pairs at the base of the hillslope 18 m downslope of baits. Each pair consisted of one shallow (30 cm) and one deep (45 cm) lysimeter. At each landscape location, the lysimeter pairs were separated by 1.5 to 2 m from each other. Samples collected at each location and at each depth were pooled. This enabled us to collect sufficient sample volume (minimum 50 mL needed) for laboratory analysis.

A shallow (1 m) groundwater well was hand-dug at the base of the study hillslope, 3.5 m away from the stream. While installing, the water table in this well was observed at a depth of 80 cm, indicating a link between the hillslope and the stream. Water levels in this well were monitored at 5-minute intervals during the rainfall event. This well was also used for sampling groundwater. Before each sampling round, three volumes of water (three times the amount of water stored in the well at the time of sampling) were pumped out of the well (or pumped dry once) to avoid sampling the pooled water. 50 mL of water sample was collected for analysis.

Wallaby Creek was sampled for 1080, just downstream of the study site. A pressure transducer was installed to record the stream stage. Stream stage was recorded at 5-minute intervals. During the natural rainfall experiment, flows were manually gauged several times to develop a stage-discharge curve. A tipping-bucket rain gauge (0.2 mm per tip) was located adjacent to the runoff plot to record rainfall.

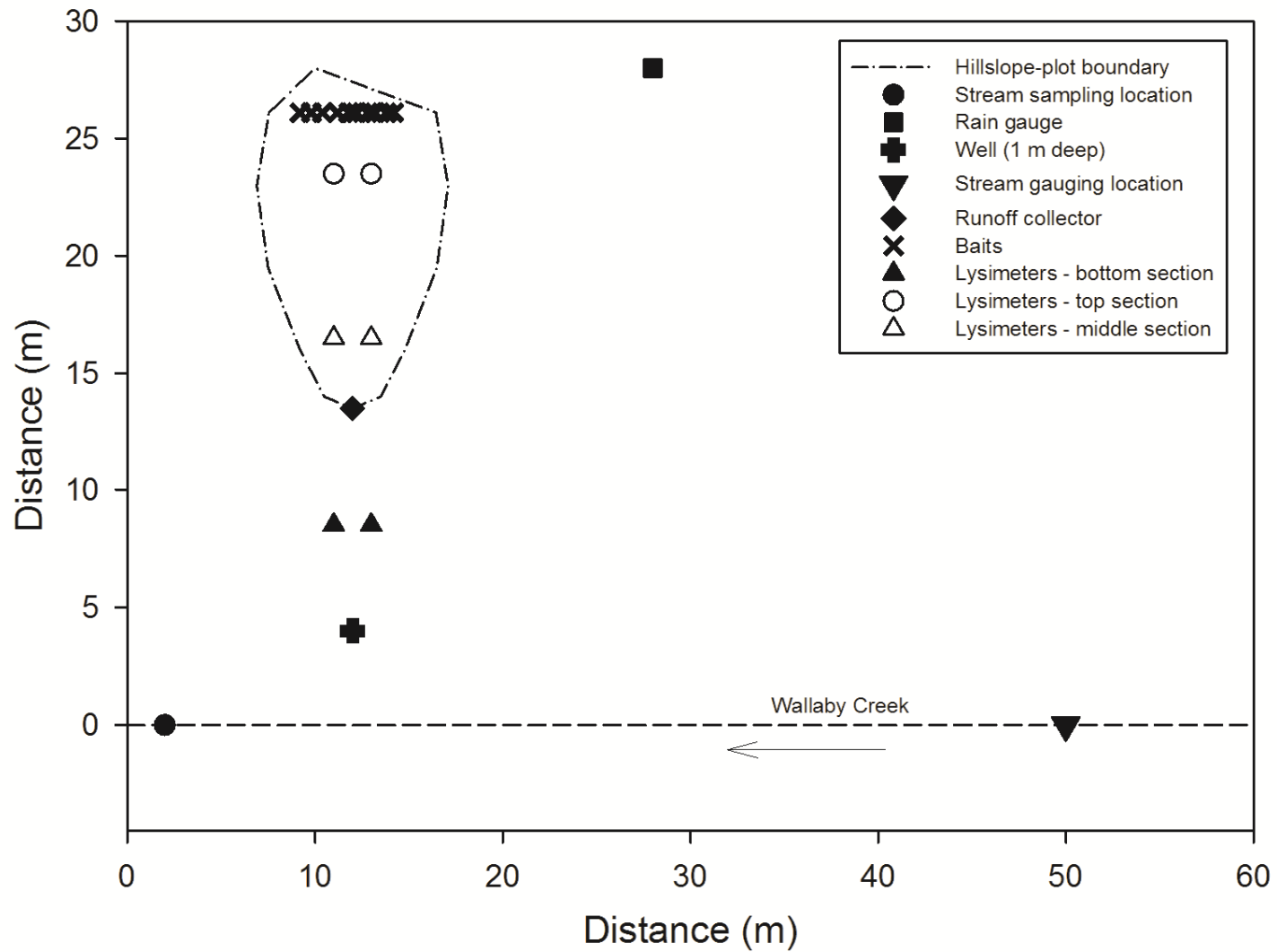


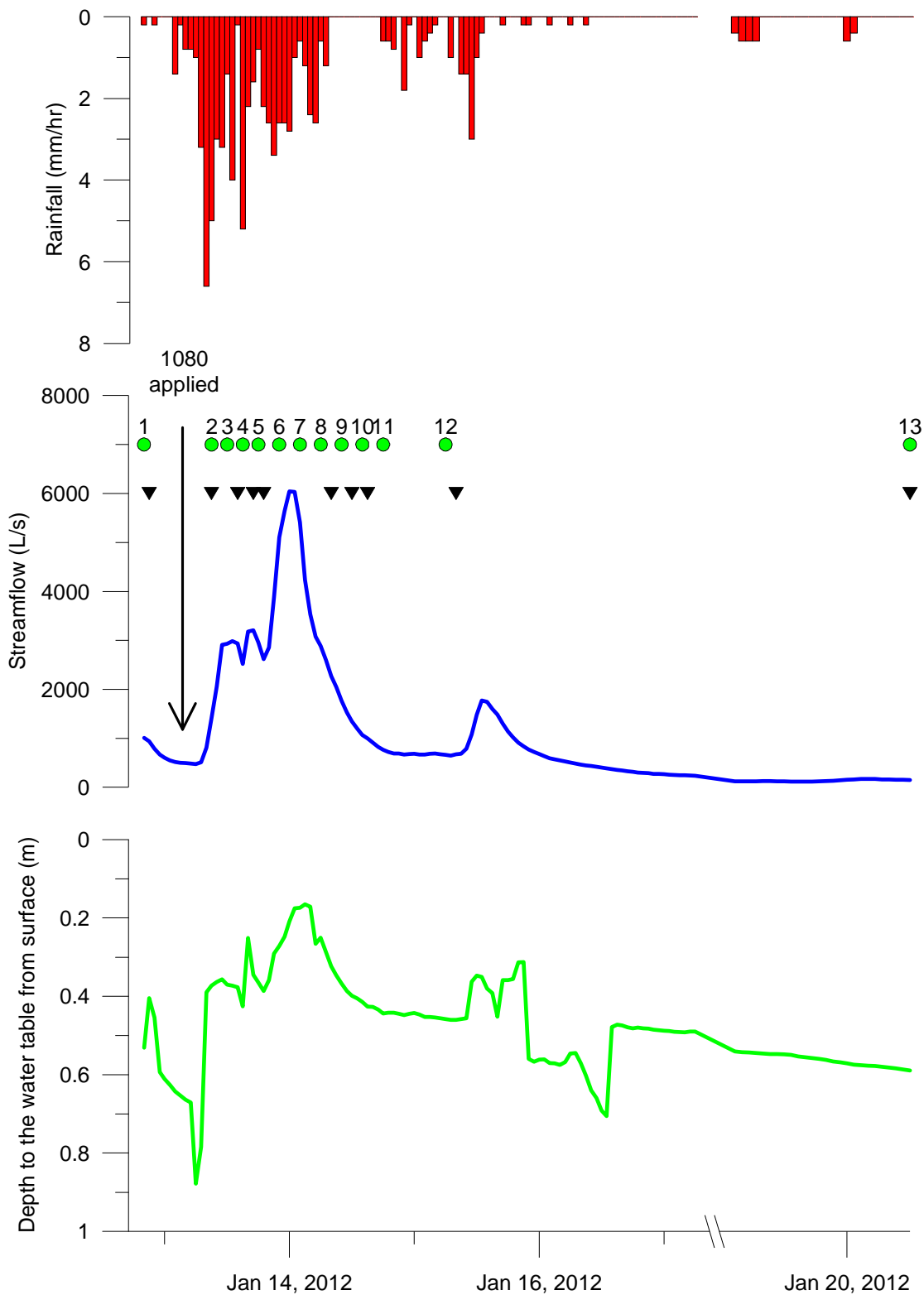
Figure 5-1: Schematic of hillslope-scale study site.

## 5.2 Results

During the rainfall event (Jan 13-15, 2012), a total of 74.4 mm of rainfall fell within the catchment, with rainfall intensity varying from 0.2 to 6.6 mm h<sup>-1</sup> (Figure 5-2). Streamflow ranged from 497 to 6044 L s<sup>-1</sup>. Both sampling and manual flow gauging events covered the rising and falling limbs of the hydrograph. Because of varying rainfall intensities, the flows showed a few small peaks and one significant peak (6044 L s<sup>-1</sup>). At the start of the storm event, the water table was measured at a depth of 90 cm from the surface. During the rainfall event, the water table rose as close to 20 cm from the surface, reflecting rainfall infiltrations and subsurface contributions from the hillslope.

For this study, a total of 2 kg of RS5 1080 (concentration 0.15% w/w) baits was applied, 50,000 times that of typical application rate (2.5 kg of baits per ha). Samples from pre-bait sampling time and samples collected at 168h after the application of baits were analysed to ensure no traces of 1080 was left in the groundwater and stream. Less than 1% of rainfall was recorded as overland flow. Many lysimeters did not always yield samples, indicating little soil moisture in these locations, despite the relatively heavy rainfall.

A total of 95 samples were collected of which 59 were sent for analysis (see Table 5-1 for samples collected and analysed). All samples were frozen soon after collection, and sent to Landcare for analysis. Of the 59 samples analysed, only seven samples returned positive (see Table 5-2), four of which were just at the limit of detection (0.1 µg L<sup>-1</sup>). The highest 1080 concentration observed was only 1.4 µg L<sup>-1</sup>, less than half the Ministry of Health standard for drinking water (3.5 µg L<sup>-1</sup>). No 1080 was detected in any of the groundwater, overland flow or stream samples.



**Figure 5-2: Rainfall, flow and depth to the water table recorded during the natural rainfall study.** Also, shown are times of 1080 application, sampling (solid green circles) and stream gauging (inverted solid triangles) times. Numbers above solid green circles refer to sampling round (refer Table 5-1).

**Table 5-1: Details of water samples collected and analysed for 1080 during the hillslope-scale study.**

Sampling round	Sample time since rainfall (hours)	Soilwater sample						Overland flow sample	Ground water sample	Stream sample
		Lower-Shallow	Lower-Deep	Middle-Shallow	Middle-Deep	Upper-Shallow	Upper-Deep			
1	0	One soilwater sample taken - sample pooled from the four lower lysimeters - sample analysed							Y	Y
2	3	N	N	N					N	N
3	6	Y	Y			Y	Y	Y	Y	Y
4	9	N	N	N		N	N	N	N	N
5	12	Y	Y	N	N	Y	Y	Y	Y	Y
6	16	YP	N	N		N	N	Y	Y	Y
7	20	Y	Y	N		Y	Y	Y	Y	Y
8	24	N	N				N	N	N	N
9	28	Y	Y	N	N	Y	YP	Y	Y	Y
10	32	Y	Y	N	N	YP			Y	Y
11	36	Y	Y	N	N	Y	Y		Y	Y
12	48	YP	Y	N	N	YP	Y	Y	Y	Y
13	168	YP	YP	N	N	Y	Y	Y	Y	Y

<sup>1</sup> Baits deployed at 0600 h on 13 January, 2012 and first sample drawn 3 h later at 0900 h. Sample round 1 refers to pre-bait application sampling.

<sup>2</sup> Y – sample taken, analysed and returned negative for 1080 (below method detection limit) ; YP – Sample taken, analysed and returned positive for 1080; N – sample taken but not analysed; blank cells indicate no sample available and hence not analysed. See Table 5-2 for 1080 concentrations in positive samples.

**Table 5-2: 1080 concentration in water samples returned positive during the hillslope-scale study.** For sampling round, refer Figure 5-2.

Sampling round	Location	1080 concentration ( $\mu\text{g L}^{-1}$ )
6	Lower shallow soilwater	0.1
9	Upper deep soilwater	0.4
10	Upper shallow soilwater	1.4
12	Lower shallow soilwater	0.1
12	Upper shallow soilwater	0.1
13	Lower shallow soilwater	0.3
13	Lower deep soilwater	0.1

## 5.3 Discussion

### 5.3.1 1080 contamination of surface and ground waters

During the hillslope-scale study, a large 1080 load (2 kg of RS5, 0.15% baits) was applied within 25 m from the stream. This application rate translates to 50,000 times more than what is applied during normal 1080 operations. Water table depth recorded at the shallow well during the rainfall event indicated a dynamic contribution from the hillslope. However, neither groundwater nor stream water recorded 1080 concentrations above the detection limit ( $0.1 \mu\text{g L}^{-1}$ ). This demonstrates that 1080 contamination of surface water and shallow groundwater is almost negligible under typical application conditions. Despite applying 50,000 times the typical 1080 application rate, the absence of detectable 1080 in the majority of samples demonstrates the importance of dilution during rainfall events. Even under conditions where more than 99% of the rainfall infiltrated into the soil, and where the soilwater was monitored continuously for 48 h, we found evidence of only slight 1080 contamination.

### 5.3.2 Overland flow and 1080 concentration differences between plot- and hillslope-scale studies

Our results indicated that in both studies, overland flow was only a minor component of rainfall. The hillslope-scale study yielded marginally more overland flow (0.7% of rainfall) than the plot-scale study (<0.5% rainfall). While the differences in overland flow conversions were very small, more overland flow was expected from the plot-scale study because of moderately-high intensity ( $12\text{-}15 \text{ mm h}^{-1}$ ), continuous rainfall (8 h). This intensity was twice the maximum intensity recorded during the hillslope-scale study. Visual observations during the hillslope-study indicated pooling of water near the plot outlet though there were no observable surface flows upslope of this location. This indicated that the recorded overland flow might have been very local.

Overland flow samples from the plot-scale study returned positive samples, while 1080 was below detection limits in all hillslope-scale study overland flow samples analysed. The longest overland flow path connecting the runoff collector to the bait was approximately 1.8 m in case of plot-scale study, while it was about 12 m in the hillslope-scale study. The longer



overland flow path in the latter case might have resulted in the infiltration of overland flow and 1080 between the bait location and sampling point.

### **5.3.3 Soilwater 1080 concentration differences between plot- and hillslope-scale studies**

In the hillslope-scale study the highest 1080 concentrations were measured in the upper, shallow lysimeters (consistent with the plot-scale study), but much less than in the plot scale study. This could be due to a combination of reasons: (1) in the plot-scale study, the lysimeter closer to the baits was less than 40 cm from the baits, while it was at a distance of 2 m in the hillslope-scale study. 1080 transport and hence concentrations might have been attenuated by this distance. This distance was also evident when near- and far-lysimeter 1080 samples from plot-scale study were compared; (2) While the rainfall was greater in the case of plot-scale study, as this rainfall was locally applied, it could have resulted in less dilution. In case of hillslope-scale study, the catchment-wide rainfall would have resulted in more subsurface connectivity to the hillslope than during the plot-scale study. Thus, this additional water could have resulted in more dilution. The amount of rainfall applied to the baits was higher in the plot-scale study than in the natural rainfall study, so that would have diluted 1080 locally; (3) in both field studies, more 1080 was detected at shallower depths than at deeper depths. This indicated that 1080 entering the soil might not be moving quickly through the subsoil. In case of plot-scale study, a high rainfall intensity could have resulted in a greater transport than the hillslope-scale study. This could have resulted in more 1080 reaching the depths during the plot-scale study where the shallow lysimeters were sampling; and (4) there could be small-scale sub-soil differences between sites.

Both plot- and hillslope-scale studies were conducted on the same hillslope, separated by a distance of 25 m (see Figure 3-3). In both cases, based on very small quantities of overland flow recorded, it is clear that almost all rainfall infiltrated into the soil. Similarly, the soilwater 1080 concentrations recorded during the plot-scale study were far greater than those during the hillslope scale. To further investigate this variability in soilwater response, we dug 60 cm deep soil pits at both sites, to describe the subsoil differences (Figures 5-3 and 5-4). Soils at both sites were characterised by rocks and stones, however the rainfall simulator site was dominated more by sandy and silty soils whereas the natural rainfall site was dominated by clayey soils. Both sites had very similar land cover as well as upslope areas. This difference in soil texture could have resulted in differences in soilwater response. The presence of more root hairs within the soil profile at the plot-scale study site indicated that that site might have better infiltration capacities than the hillslope-scale study site. The plot-scale study site had a thicker surface organic layer than the hillslope-scale study site, allowing medium to high intensity rainfall events to infiltrate, thereby resulting in less overland flow.



(a)



(b)

**Figure 5-3: Soil profile at the plot-scale study site.** (a) top 35 cm of soil profile; (b) soil profile between 40 and 60 cm depth. Note the high density of root hairs and a thick organic layer. The colour contrast between photos was due to ambient lighting. (Photo: M Srinivasan, NIWA).



**Figure 5-4: Soil profile at the hillslope-scale study site.** Note, the poor density of root hairs and a thinner organic layer compared to plot-scale soil profile. The sandy patches indicate locations of lysimeters. (Photo: M Srinivasan, NIWA).

## 6 Refinement of 1080-hydrology model

The primary goal of the studies described in sections 2, 4 and 5 was to improve the 1080-hydrology model developed by Srinivasan et al. (2009 & 2012a). Based on the results from these studies, the following changes were made to the model:

1. Currently 1080 release in the 1080-hydrology model is altered based on rainfall intensity. Since the analysis described here shows no useable relationship between 1080 release rates and rainfall intensity or duration, a single equation is to be applied for each bait and concentration type.
2. Hillslope- and plot-scale studies indicated that overland flow represents a small portion of runoff. This also impacts the potential of 1080 transport via the quickest flow pathway. Our new revised model has set the amount of 1080 available for transport via overland flow to only 1% of the total rainfall applied to a catchment. Although this is considerably higher than the runoff to rainfall ratios observed in this study, it builds a degree of conservatism to the model.
3. While soilwater samples recorded 1080, considering the long time it takes for 1080 to reach the stream via subsurface pathways, we have not included that transport pathway in the revised model. Processes such as dilution and degradation may also reduce soilwater 1080 concentrations to below detection limits.

Use of this revised model (as outlined in Srinivasan et al. 2012b) will provide more robust information to resource managers and the public as to the likelihood that surface waters will be contaminated by 1080 following aerial applications.

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