Targeted Wet Weather Monitoring Plan for Curlett Stream 2023

Prepared for Christchurch City Council

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Executive summary

The Christchurch City Council (CCC) undertakes monitoring of Christchurch and Banks Peninsula waterways and treatment facilities principally due to the requirements of the Comprehensive Stormwater Network Discharge Consent (CSNDC; CRC2319551) and the associated Environmental Monitoring Programme (EMP). Part of this monitoring covers Curlett Stream for which high contaminant concentrations have been recorded during wet and dry weather (i.e., not associated with stormwater). In order to assist in identifying wet and dry weather sources of contaminant in the catchment, CCC has commissioned NIWA to prepare a Targeted Wet Weather Monitoring Plan (TWWMP) for 2023.

The proposed methodology relies on widespread implementation of monitoring sites dedicated to dry and/or wet weather monitoring. Wet weather monitoring sites (8 sites, "CSAuto" sites) should comprise equipment that allows flow volume calculation and flow weighted composite samples to be collected during a storm event (except at CSAuto3). The objective is to quantify the pollutant loads exported from 6 subcatchments (covering most of the Curlett Stream catchment) to identify those contributing the most to the pollutants load export during wet weather, and to quantify pollutant loads exported to the Heathcote River after treatment by the Curlett wetland.

As dry weather unconsented discharges are suspected in the catchment, water level, temperature and conductivity, in addition to turbidity at selected or all sites (depending on the selected scenario), should be monitored. The objective is to collect continuous data in the stormwater network and in Curlett Stream during dry weather to identify discharges, their flow regime (continuous flow vs pulse), and characteristics (e.g., duration, time of the day/week/year, frequency). This monitoring is proposed for six CSAuto sites (excluding CSAuto3 and CSAuto4b), covering most of the Curlett Stream catchment, and additional 11 "dry weather only sites" located within the CSAuto sites' subcatchment. This extensive coverage will narrow down the location of sources of unconsented dry weather discharges. In a subsequent step (not included in this monitoring plan), grab sampling can be performed at sites of concerns (and in upstream manholes), during expected dry weather discharges, to analyse the water quality for specific pollutants. This would help in narrowing down individual contributing sites in the catchment.

1 Project background and purpose

The Christchurch City Council (CCC) undertakes monitoring of Christchurch and Banks Peninsula waterways and treatment facilities principally due to the requirements of the Comprehensive Stormwater Network Discharge Consent (CSDNC; CRC2319551) and the associated Environmental Monitoring Programme (EMP). This includes targeted wet weather monitoring of surface water in accordance with Schedule 3(k) of the consent and potential further investigations if surface water Attribute Target Levels are not met (as per Condition 59). Monitoring of treatment facilities for TSS, zinc and copper reduction is required by Schedule 3(i).

Previous monitoring performed in Curlett Stream indicated high concentrations of contaminants during wet and dry weather (Borne & Gadd, 2022; Margetts et al., 2022) which warrant additional wet and dry weather monitoring to better identify contributing sources.

CCC therefore wishes to carry out the following activities:

- Wet weather monitoring of Curlett Stream, as part of the Targeted Wet Weather Monitoring Project (TWWMP).
- Dry weather monitoring of Curlett Stream as part of the TWWMP.
- Wet weather monitoring upstream and downstream of Curlett wetland facility.

In order to assist in the completion of these tasks NIWA has been commissioned by CCC to prepare a Targeted Wet Weather Monitoring Plan (TWWMP) for Curlett Stream that covers these three activities.

2 Monitoring plan objectives

The objectives of this round of the TWWMP are:

1. to identify subcatchments contributing the most to stormwater contaminant load exports to Curlett Stream, in accordance with Condition 59 of the CSNDC and the recommendations in the ‘Condition 59 responses to monitoring report 2022 - surface water’,
2. to characterise the presence of dry weather discharges (i.e., not associated with stormwater) to Curlett Stream, and
3. to identify the water quality at the outlet of Curlett wetland facility.

Objectives 1 and 2 will help to identify subcatchments which will later require further investigation to narrow down and/or identify specific contaminant contributing sites.

3 Proposed methodology

3.1 Findings from 2021 wet weather monitoring

Monitoring carried out in 2021 in Curlett Stream indicated high concentrations of metals (copper and zinc), total suspended solids (TSS), Biochemical Oxygen Demand (BOD_5), *Escherichia coli* (*E. coli*) and nutrients (N and P) at multiple locations throughout the catchment. However, some uncertainties persisted regarding the locations with the highest concentrations. This uncertainty was due to the variability between samples and events and/or the possible overestimation of pollutants related to the use of Nalgene bottles. In particular, due to a lack of upstream sampling points it was not possible to identify which upstream subcatchment of the Curlett's eastern branch was the highest contributor of metals. Additionally for some pollutants such as dissolved copper (DCu), no decrease in concentration was observed until after the Curlett wetland suggesting that copper is released in several locations along the upper part of Curlett Stream and precise source identification was therefore not possible.

Comparison of pollutant concentrations solely between sites and /or branches of stream did not allow for hot spot identification. Indeed, as inputs to the stream are diluted to different degrees depending on stream flows, flow measurement appears to be crucial to precisely identify which branch of the Curlett Stream actually receives (and delivers) most of the pollutant loads. Recommended locations for further monitoring were suggested in the 2021 monitoring report as per Figure 3-1.

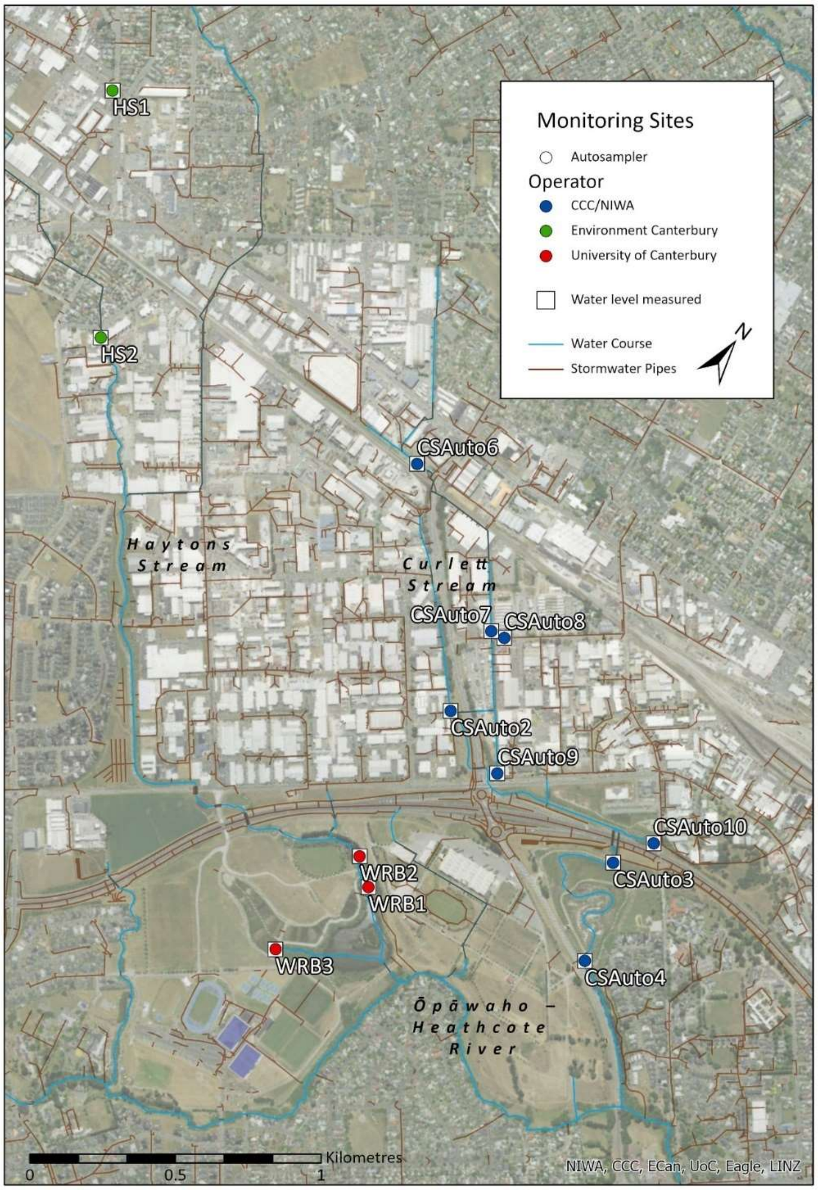

Figure 3-1: Existing and new locations recommended for further sampling in the Curlett Stream catchment (CS sites). From Borne and Gadd (2022).

3.2 Wet weather monitoring

3.2.1 Wet weather monitoring sites criteria

As specified previously, the objective of this year of monitoring is to measure the contaminant loads (rather than solely concentrations) in Curlett Stream during wet weather to be able to identify which subcatchment(s) of the Curlett Stream actually delivers most of the pollutant loads. Pollutant loads are calculated from event mean concentrations and event flow volume which both require flow monitoring.

Sites for wet weather monitoring have been selected:

- to cover most of the Curlett Stream catchment,
- to differentiate as much as possible individual subcatchment pollutant export contributions (e.g. avoiding monitoring sites nested within another monitoring site's subcatchment),
- to include high risk sites identified in the catchment (Lill, 2023),
- to allow for flow monitoring (see 3.2.2),
- to assess the water quality upstream and downstream of the Curlett wetland.

3.2.2 Wet weather sampling sites criteria for flow measurement

Flow monitoring can be performed through three main ways including:

1. water level measurement combined with gauging at various flows to create a rating curve,
2. water level measurement measured close to a rating structure (e.g. weirs), and
3. combination of water level and velocity instrument to provide flow.

Option 1 above is time consuming as a minimum of 3 gaugings (at low, mid and high flow) would be needed at all the sites to provide accurate flow measurement. Furthermore additional gaugings might be necessary depending on the monitoring duration as stream bed and embankment might change over time requiring new measurements. Option 2 is known to provide the best accuracy however requires the installation of a rating structure (such as a weir or flume) in the stream and/or pipe, creating potential fish passage issues and a ponding zone upstream of a weir. In very flat areas, such as in the Curlett catchment, this could create large ponding zones and potentially increase upstream flooding risks. Option 3 relies on a sole instrument (a doppler flow meter), measuring the water depth and velocity to calculate the flow. Implementation is relatively faster than option 1 and 2. It gives best results when installed in a structure with fixed and known dimensions such as culverts or pipes but requires a minimum water depth of 50 mm for accurate measurement and is of lower accuracy for low velocity or in non-laminar flow.

Given the pros and cons exposed above and the necessity to measure the flow mainly during high flow (i.e. during storm event, not during dry weather) option 3 was favoured and specific attention was given to locations where culverts or pipes exists and laminar flow is expected.

3.2.3 Wet weather sampling sites location

Wet weather sampling sites were identified based on criteria presented in 3.2.1 using aerial images of the catchment and location and type of stormwater drainage network. Location of the most suitable monitoring sites were then validated during visits conducted in March 2023 to confirm suitability for instrumentation. The suggested sites for monitoring are presented in Figure 3-2 and listed in Table 3-1.

At the Curlett wetland, stormwater enters via a relatively large channel prone to submersion during high flow (when incoming water ponds in the wetland, raising the water level). This prevents adequate flow measurement at this location. Flow measurement further upstream is not feasible as there are multiple piped inlets. Therefore sampling at this location can only be performed on a time basis to create a time composite sample whose collection would be triggered based on water level measurement. The pollutant concentration of the time composite sample would be indicative of the water quality during most of the storm event but could not be used to assess the event mean concentration (EMC) nor pollutant loads. This means that there can be no assessment of pollutant load exports downstream of CSAuto9 and CSAuto10, including from SH 76. Direct comparison with samples collected downstream of the wetland (CSAuto4) would also not be possible nor would the assessment of the wetland pollutant mass removal efficiency.

Compared to the monitoring performed in 2021, the recommended location of the sampling site at the outlet of wetland has been moved from the upstream to the downstream end of the wetland cell’s exit pipe in order to allow for flow monitoring (new site called “CSAuto4b”). At this location flow can be monitored with water level measurement combined with gauging at various flows to create a rating curve. It is expected that frequent gauging would be required to guarantee a good accuracy of the flow measurement.

CSAuto8 can be installed at Lunns Road within a manhole which was under construction during the site visit performed in March 2023. Construction completion date (initially expected at the latest in May 2023) and instrumentation feasibility will need to be confirmed.

CSAuto7 is accessible via Owens transport yard though this will require access permission from the owner.

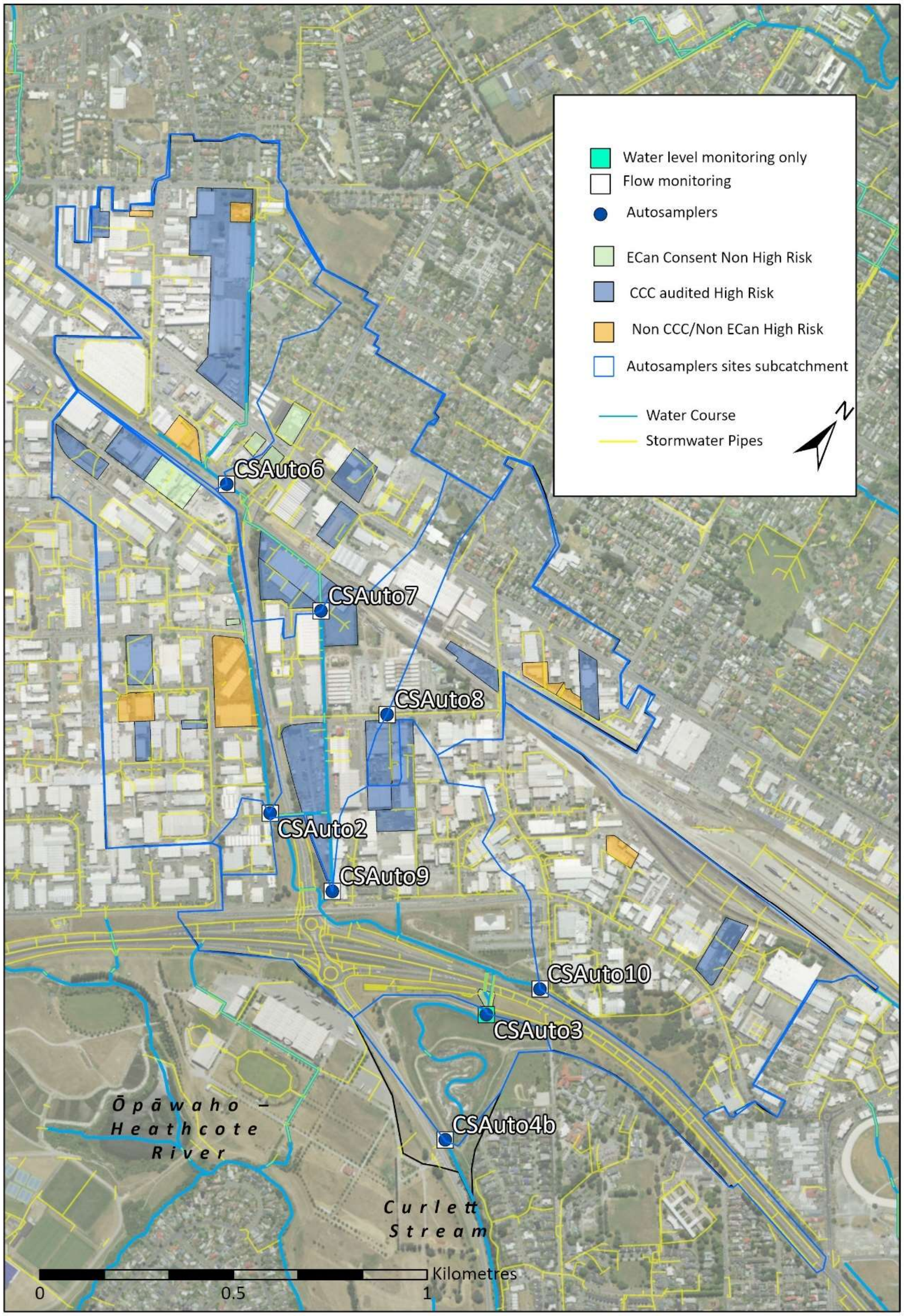

Figure 3-2: Proposed wet weather monitoring sites and associated subcatchments.

Table 3-1: List of wet weather (WW) sites including expected monitoring equipment.

SiteID	Upstream CSAuto sites	WW monitoring	installed in	Monitoring equipement		accessibility
				Flow/water level sensor and sampling	allows for flow measurement	
CSAuto4b	CSAuto3, CSAuto10, CSAuto9, CSAuto2, CSAuto6, CSAuto7, CSAuto8	x	stream	ISCO sampler, logger, water level (PT), telemetry	Yes	ok
CSAuto3	CSAuto10, CSAuto9, CSAuto2, CSAuto6, CSAuto7, CSAuto8	x	wetland inlet chan	ISCO sampler, logger, water level (PT), telemetry	No	ok
CSAuto10	-	x	circular culvert	ISCO sampler, logger, Doppler flow meter, telemetry	Yes	ok
CSAuto9	CSAuto2, CSAuto6, CSAuto7, CSAuto8	x	Stream - boxed section	ISCO sampler, logger, Doppler flow meter, telemetry	Yes	ok
CSAuto2	-	x	Stream- boxed section or circular culvert	ISCO sampler, logger, Doppler flow meter, telemetry	Yes	ok
CSAuto8	-	x	manhole	ISCO sampler, logger, Doppler flow meter, telemetry	Yes	ok but under construction, should be functional end May 2023 at the latest-to be confirmed by CCC
CSAuto7	CSAuto6	x	circular culvert	ISCO sampler, logger, Doppler flow meter, telemetry	Yes	private-access to be confirmed with Owen’s transport
CSAuto6	-	x	circular culvert	ISCO sampler, logger, Doppler flow meter, telemetry	Yes	ok

3.2.4 Wet weather instrumentation

Each wet weather monitoring site should comprise:

- An autosampler (connected to FEP lined polyethylene tubing or PTFE tubing).
- A data logger + telemetry (to log data and drive the sampler remotely).
- A solar panel (+ battery to provide energy to the logger and sampler).
- A Doppler flow meter (water depth and velocity measurement) at all sites but CSAuto3 and CSauto4b– selected for reasons explained in 3.2.2.
- A water level monitoring instrument (e.g. pressure transducer) at CSAuto3 (to drive the sampling) and CSAuto4b (in combination with gauging for flow measurement and to drive the sampler)

At all sites, but CSAuto3 and CSAuto4b, flow rate can be calculated as follow:

$$Q = A\,x\,V$$

Where:

- Q: flow rate (m^3/s),
- A: cross section area (m^2)- derived from water depth and cross section area of the stream/culvert, and
- V: flow velocity (m/s).

At CSauto4b, flow can be calculated from water level measurement and a rating curve derived from gauging at various flows.

There is no method to measure flow at CSAuto3 and hydrometric information for this site is restricted to water level only.

3.2.5 Wet weather sampling and analysis

In accordance with the CSNDC EMP, wet weather samples should be collected when the following criteria are met:

- an antecedent dry period of at least 3 days,
- a total rainfall depth of at least 3 mm, and
- samples can be retrieved and analysed within 48 hours.

Autosamplers should be enabled when forecast storm events meet the above criteria. To set the pacing for sample collection (i.e. flow volume between samples) for a specific storm event depth, a rainfall-runoff volume relationship will need to be developed for each site prior to the start of the sampling. This will require access to rainfall data provided by the closest CCC operated rain gauge (e.g. College of Education). It is anticipated that between 3 to 5 storm events spanning over 3 to 50 mm depth would be required to build this rainfall-runoff relationship prior to the start of the sampling programme.

Individual (discrete) flow (or time for CSAuto3)-based samples should be collected over the duration of the storm hydrograph. A maximum of 24 one litre bottles per storm should be collected at each sampling location. The polypropylene (PP) sampling bottles will have to be acid washed prior to being used in the automatic samplers. Within 24 h of completion of each storm event, the collected samples should be transported to CCC laboratory to make flow-weighted composite samples (or time based composite samples at CSAuto3). As samples will be collected on a flow (or time at CSAuto3) basis, the same amount of sample from each bottle should be mixed into a churn splitter to create a composite sample. In the event of an equipment failure leading to a bottle not being collected then the volume (or time for CSAuto3) proportion that each bottle represents will have to be calculated from the hydrograph.

Each composite sample will then be sub-sampled for analysis for the variables listed in Table 3-2. The analysis of each composite sample will provide the event mean concentrations (EMCs) for each CSAuto site, except CSAuto3 where the composite will provide a time-average concentration.

Table 3-2: Variables for analysis at each site.

Analyte	CSAuto10, CSAuto9, CSAuto2, CSAuto6, CSAuto7, CSAuto8	CSAuto3 and CSAuto4b
TSS; total suspended solids	x	x
Turbidity	x	x
pH	x	
Dissolved copper and zinc	x	x
Total copper and zinc	x	x
Dissolved lead	x	
Total lead	x	
Total ammoniacal-N	x	
Nitrate-N + nitrite-N	x	
Total Nitrogen	x	
DRP, Dissolved reactive phosphorus	x	
Total phosphorus	x	
BOD_5, Biochemical Oxygen Demand	x	
DOC; Dissolved Organic Carbon	x	
E. coli	x	

It is recommended to collect at least 10 storm events (simultaneously at all sites) be able to identify with a certain degree of certainty the subcatchment(s) contributing to most of pollutant exports and overall catchment exports after treatment by the wetland. This is due to the variability in storm event sizes and associated pollutant export. If a fewer storm events are sampled, then only large differences between subcatchment' exports will be identifiable.

3.2.6 Wet weather data analysis

At all sites but CSAuto3, EMCs can be used in combination with the flow volume measured to calculate event pollutant loads as follow:

$$\textit{Event Pollutant load (g)= EMCs (g/m}^3\textit{) x event flow volume (m}^3\textit{)}$$

A statistical summary of pollutant loads should be provided for each site. Pollutant loads measured at each site can then be compared using repeated measures ANOVA, or an equivalent statistical method (only if the number of collected event is large enough, e.g at least 10), to identify significant differences between sites. For easiest comparison between sites and subcatchments, all event load data should also be reported relative to the monitoring site's contributing catchment area (i.e. g/km^2 of contributing catchment).

While a quantitative assessment of the Curlett wetland performance is not feasible (as explained in 3.2.3), a large reduction of the pollutant mass load between CSAuto4b and cumulative pollutant mass measured at upstream sites CSAuto9 and 10 would suggest a treatment effect from the Curlett wetland, the upstream swales and the open channel. Comparison of wetland outlet EMCs to water quality guidelines (e.g. ANZG default guideline value (DGV)(ANZG, 2018)) can be used to indicate unsatisfactory water quality for ecological health.

3.2.7 Strengths and weaknesses of this approach

Issues related to pollutant export assessment for nested sites

The subcatchments monitored at sites CSAuto2, CSAuto6, CSAuto8 and CSAuto10 are independent subcatchments. However, other monitoring sites are nested – i.e., there are multiple sites located within a catchment, with some upstream of the other (e.g., CSAuto6 and CSAuto7).

Pollutant loads for sites whose subcatchment includes other monitoring sites (e.g. CSAuto7 subcatchment) will represent the pollutant exports of the upstream site(s)'s subcatchment (e.g. CSAuto 6, diagonally hatched area in Figure 3-3) but also subsequent potential attenuation in the stormwater network and/or stream as well as additional export in between sites (e.g. between CSAuto6 and 7, cross-hatched area in Figure 3-3). If high pollutant attenuation exists between sites or the additional pollutant export between sites is low compared to upstream pollutant export it will be difficult, if not impossible, to precisely quantify the pollutant export between the two nested sites (e.g. cross hatched area in Figure 3-3).

Only pollutant exports generated by CSAuto2, CSAuto6, CSAuto8 and CSAuto10 subcatchments will be quantified independently with the proposed approach. Pollutant exports from the draining areas between CSAuto9 and 2/7 and/or 8 and CSAuto7 and 6 can only be quantifiable by subtracting downstream to upstream sites' pollutant loads. Therefore, this calculation is only possible if measured pollutant loads increase from upstream to downstream sites.

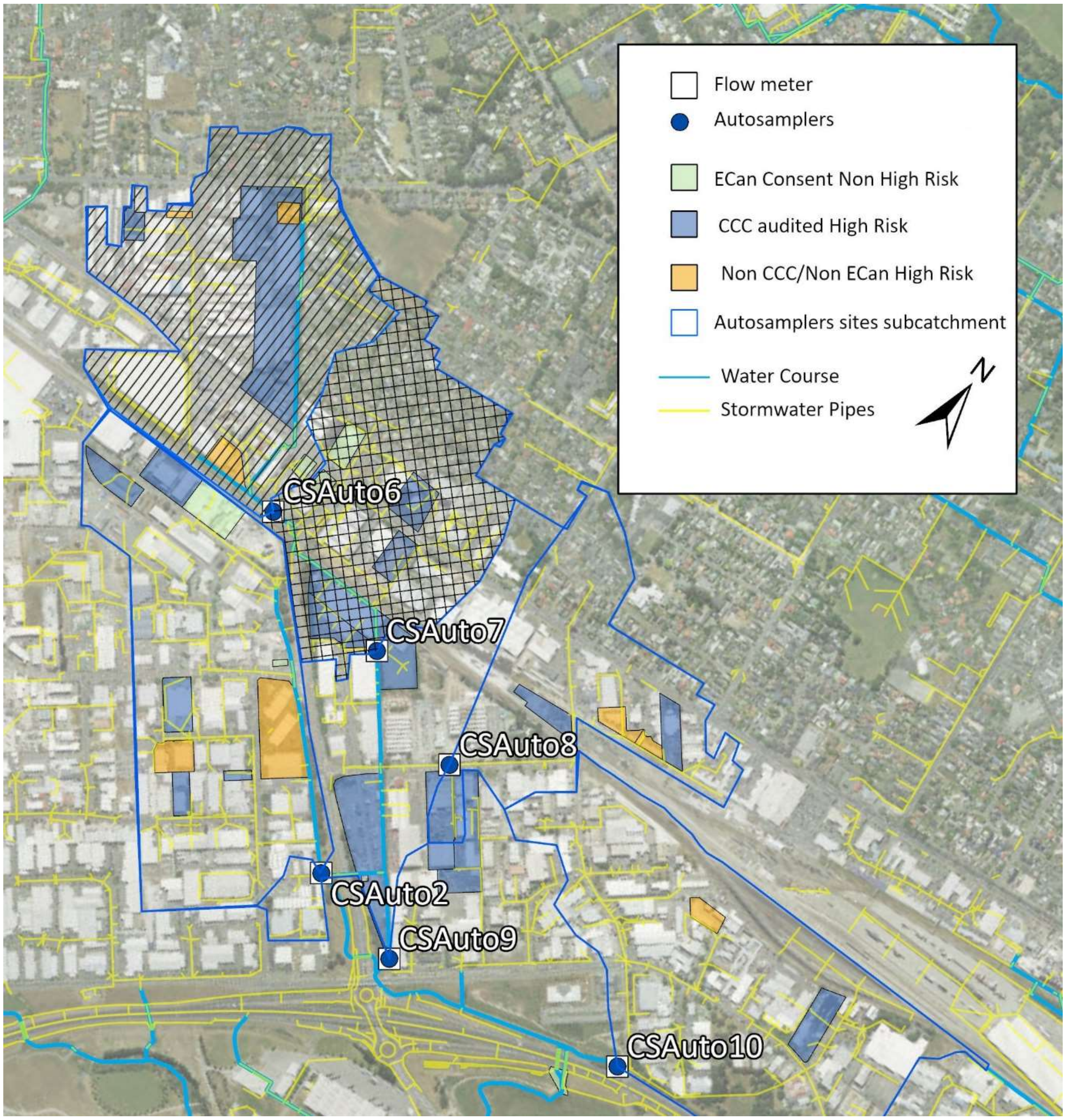

Figure 3-3: Monitoring sites location and associated subcatchments showing an example of nested sites. CSAuto6's subcatchment (diagonally hatched area) is nested in CSAuto7's subcatchment (diagonally hatched + cross hatched areas).

The need to sample storm event simultaneously at all sites

All sites must be sampled simultaneously to identify the subcatchment(s) contributing the most to pollutant exports with any degree of certainty. Indeed this is necessary to account for the pollutant load export variability related to the effect of storm event sizes, antecedent dry period and other external environmental factors. Simultaneously sampling multiple sites using autosamplers is relatively difficult due to inherent logistical issues and possible equipment failure. As an example, only one out of four collected events was simultaneously successfully sampled at the 5 autosamplers sites deployed on Curlett Stream in 2021.

Therefore it is anticipated that the number of storms to be targeted for sampling (and associated field work) would be at least double the amount of required storm event data (e.g. at least 20 attempts to get 10 successful events sampled simultaneously at 8 sites).

The use of passive samplers was investigated as an alternative to autosamplers. For this, accurate continuous flow measurement (both during dry and wet weather) would be needed to assess the total flow volume during the deployment period. Total flow volume would have been needed as a weighting factor to rank the most pollutant contributing sites depending on time proportional contaminant concentration (derived from the passive samplers). However accurate low flow measurement (during dry weather) would have required installation of weirs in the stream which was not appropriate (see 3.2.2).

State highway pollutant contribution not assessed

As flow monitoring is not possible at CSAuto3, potential pollutant exports from SH 76 will not be assessed.

Treatment performance of the Curlett wetland not quantitatively assessed

Most common ways to assess the water quality performance of a treatment system is to:

- Compare the range of outlet and inlet EMCs
- Calculate Mass Removal Efficiencies (which account for the flow volume decrease or increase between inlet and outlet)

Given the large area of the Curlett wetland (promoting water evapotranspiration during long retention time) and possible groundwater interaction, it appears essential to consider the inflow and outflow volume of the wetland to assess its treatment performance. Similar inlet and outlet concentrations could suggest no treatment, however if the flow volume is significantly reduced between inlet and outlet, there could be a significant pollutant mass load reduction (positive Mass Removal Efficiency). In the absence of flow data for both inlet and outlet it will be possible to draw the wrong conclusions regarding the wetland performance. Unfortunately it is not clear how to overcome this as there are no feasible methods for monitoring flow at the inlet so CCC need to be aware of the limitations in the information obtained.

Quantitative data to identify subcatchments contributing the most to pollutant load exports

Provided that:

- sufficient number of storm events (e.g. 10) is collected simultaneously at all sites,
- limited pollutant attenuation exists between nested sites, and
- the additional pollutant export between nested sites is significant compared to upstream pollutant export (i.e. between CSAuto9 and upstream sites and between CSAuto7 and CSAuto6).

the wet weather monitoring methodology will provide a quantitative assessment of the pollutant load exports from different subcatchments covering most of the Curlett Stream catchment. This will help to identify subcatchments which will require further investigation (not included in this methodology) to narrow down and/or identify specific contaminant contributing sites.

3.3 Dry weather monitoring

3.3.1 Monitoring objective

The dry weather monitoring is expected to be a multi-year programme whose first year's objective is to identify which part(s) of CSAuto sites' subcatchments generate dry weather discharges (i.e., not associated with stormwater) and when these occur. In a subsequent step (e.g., in 2024-2025, not included in this monitoring plan), grab sampling can be performed at sites of concern (and in upstream manholes), during expected dry discharges, to analyse the water for specific pollutants. This would help in narrowing down contributing sites in the catchment.

This approach is thought to be the most cost effective to identify unconsented dry weather discharges.

The dry weather monitoring methodology proposed here is based on widespread installation of water level, temperature and conductivity stand-alone sensors in addition to turbidity measurement at selected or all sites (depending on selected scenario, section 3.3.3). This instrumentation will provide continuous data for hydrology and physicochemical parameters that are indicators of discharges. Monitoring of actual contaminants of interest (e.g., metals) is not proposed at this stage.

Continuous data (e.g. at 1 to 5 min intervals) should be collected in the stormwater network and Curlett Stream during dry weather to identify discharges, their types (continuous flow vs pulse), frequency and duration, during one year, similarly to Shi et al. (2022). This will demonstrate which sites have the greatest number of dry discharge events, when (e.g. working days versus week end, morning versus evening…) and for how long.

Dry weather monitoring sites have been selected based on identification of high risks sites (Lill, 2023), favouring manholes in safe locations (not in the middle of the road) and in the public domain, avoiding nested sites where possible.

3.3.2 Dry weather monitoring sites location

Sites for dry weather monitoring include all autosampler sites (CSAuto sites) except CSAuto3 and CSAuto4b, covering most of the Curlett Stream catchment, and additional "dry weather only sites" located within the CSAuto sites' subcatchments to narrow down the areas of potential sources of unconsented dry weather discharges. Sites, and the subcatchments that drain to them, are presented in Figure 3-4 and listed in Table 3-3. Some sites are located on private land and access permission will be required (DW2, 3, 6 and 9).

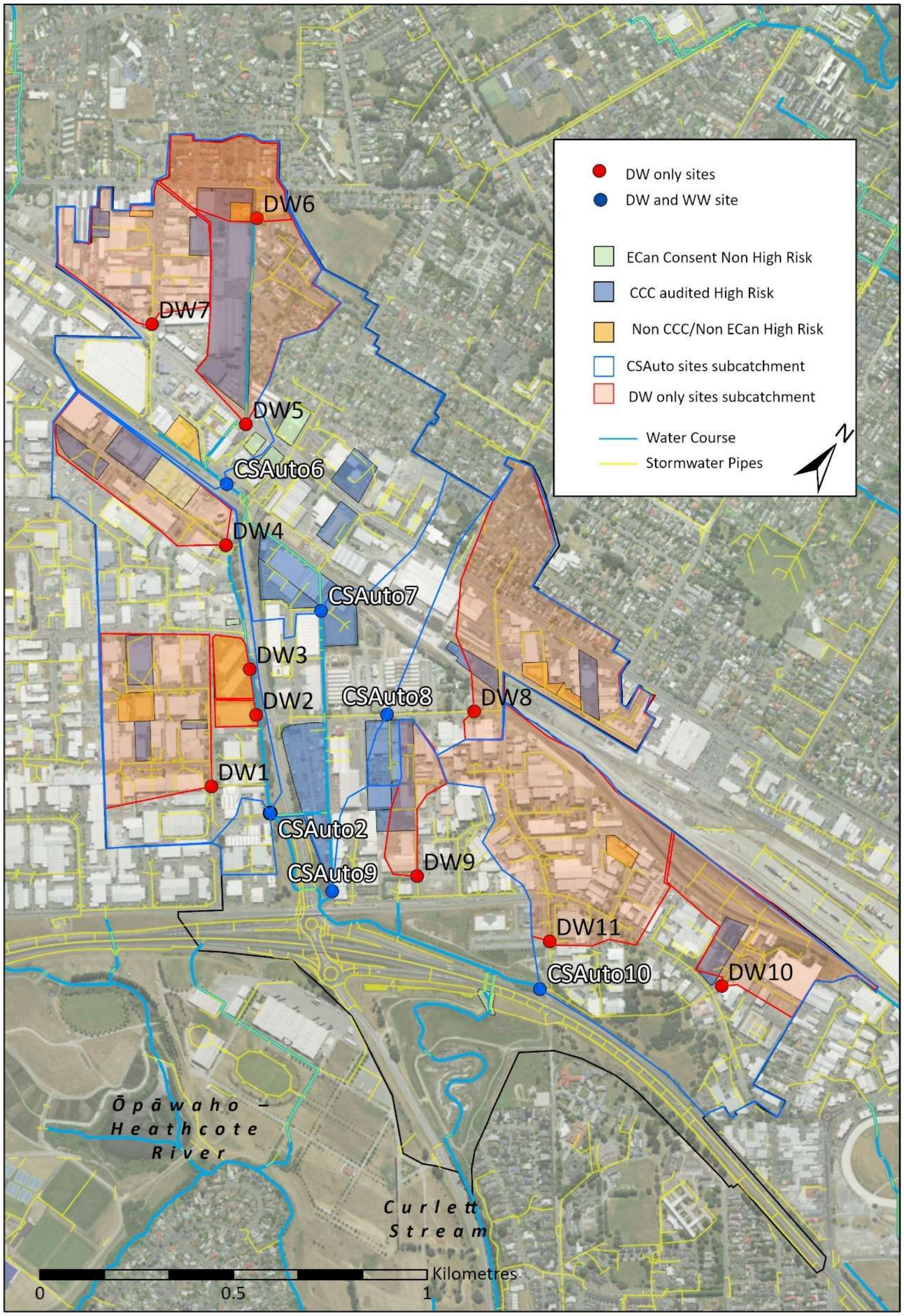

Figure 3-4: Monitoring sites for identification of dry weather discharges. DW = dry weather; WW = wet weather.

Table 3-3: **List of wet weather (WW) and/or dry weather (DW) sites.**

SiteID	Upstream sites	DW monitoring	WW monitoring	installed in	accessibility
DW1	-	x	-	manhole	ok
DW2	-	x	-	manhole	private-access to be confirmed
DW3	-	x	-	manhole	private-access to be confirmed
DW4	-	x	-	manhole	ok
DW5	DW6	x	-	manhole	ok
DW6	-	x	-	manhole	private-access to be confirmed
DW7	-	x	-	manhole	ok
DW8	-	x	-	manhole	ok
DW9	-	x	-	manhole	private-access to be confirmed
DW10	-	x	-	manhole	ok
DW11	-	x	-	manhole	ok
CSAuto10	DW10, DW11	x	x	circular culvert	ok
CSAuto9	CSAuto2, CSAuto6, CSAuto7, CSAuto8 and their upstream DW sites	x	x	Stream - boxed section	ok
CSAuto2	DW1, DW2, DW3, DW4	x	x	Stream- boxed section or circular culvert	ok
CSAuto8	DW8	x	x	manhole	ok but under construction, should be functional end May 2023 at the latest-to be confirmed by CCC
CSAuto7	CSAuto6, ,DW5, DW6,DW7	x	x	circular culvert	private-access to be confirmed with Owen's transport
CSAuto6	DW5, DW6, DW7	x	x	circular culvert	ok

3.3.3 Dry weather instrumentation

To identify dry weather discharges, one common practice is to monitor water level, conductivity and temperature. This approach requires relatively cheap and easy to install instrumentation to allow a widespread implementation (Shi et al., 2022). As sediment discharges during dry weather are suspected to happen in Curlett Stream ('Condition 59 responses to monitoring report 2022 - surface water' report), turbidity measurement is also recommended.

Turbidity sensors can be found as commercial standalone sensors (e.g., YSI EXO-Sondes or *InSitu* multiparameter probes) or individual sensors to be powered and connected to a data logger (commercially available: more expensive or "home-made": cheaper option). All instrumentation options are described further below.

Commercial sensors for temperature, conductivity and water level measurement:

Commercial sensors for combined temperature and conductivity, such as the Hobo U24-001, will allow data recording for subsequent on-site offload. For water level measurement, a telemetered radar sensor (Waterwatch) would be the preferred option where installation in the upper part of the manhole is feasible. Alternatively a Hobo U20-001-04 (stand-alone sensor, not telemetered) can be installed down in the stormwater pipe.

Commercial sensors for combined turbidity, temperature and conductivity measurement:

Conductivity can be monitored by a combined conductivity and temperature sensor (Unidata Model 6536 or similar) and turbidity can be monitored by turbidity sensor NEP5000 (Observator). Both sensors can be directly connected to a data logger, telemetry system and solar panel allowing remote access to the data.

"Home-made" sensors for turbidity, water level, conductivity and temperature measurement:

A research team from the BoSL Water Monitoring and Control laboratory (Monash University) and Queensland University of Technology (QUT) has built and deployed cheap home-made sensors in the past for the purpose of illicit discharges identification (Shi et al., 2022; Shi et al., 2021). As part of a collaboration with NIWA they are willing to provide home-made combined conductivity, temperature, water level and turbidity sensors that would be telemetered. Data would be available through their online platform.

Accuracy and range of these sensors are usually lower than commercially available sensors (Table 3-4). The main identified constraint would be on the water level measurement where the instrument may not provide sufficient accuracy. In large pipes or open channels where water fluctuation might be small during dry weather non-consented discharges, alternative water level measurement systems with greater accuracy and resolution might be needed (e.g. Waterwatch radar sensor or Hobo pressure transducer). This would be identified on a case by case during the early stage of the monitoring.

Other investigated instruments not selected

Installation of other instrumentation, such as EXO-sondes (which CCC have several of), in addition to the above-mentioned sensors, will not bring significant further benefit in terms of identifying the occurrence of unconsented discharges. Indeed, for this purpose, conductivity/temperature and turbidity sensors deployed in several locations are considered to provide more informative data than an EXO-sonde in one location.

The first objective of the dry weather monitoring (covered by the present monitoring methodology) is to identify areas where unconsented discharges occur (and the time of their occurrence) rather than defining the contaminants associated with those discharges. Indeed it appears more cost effective to first identify areas of concern and then carry out further analysis of the water quality at these selected places (and upstream). Therefore using additional water quality sondes such as s::scan spectro::lyser (measuring organic matter) was not included in the present methodology.

Maintenance and calibration
Maintenance and calibration of sensors is highly dependent on the environment in which the sensors are installed. Places subject to algal growth, high sediment loads and debris will require more frequent maintenance and calibration especially for turbidity sensors (e.g. every 2 weeks). Commercial sensors usually require less calibration than “home-made” sensors however it is subject to environmental conditions.

Commercial non-telemetered sensors (Hobo conductivity and water level sensors) would also need to be visited more frequently than telemetered sensors, to download the data and detect any drift or identify malfunctioning.

Maintenance and calibration can thus vary from every 2 weeks to every 4 weeks depending on the type of sensors and deployment environment. These visits will need to include downloading the data (for non-telemetered sensors), cleaning sensors where needed and calibration to guarantee high quality of the collected data. At a minimum, conductivity and turbidity measurements will need to be checked using a reference conductivity/temperature and turbidity meter to identify drift and apply correction (if needed).

3.3.4 Dry weather data analysis

From the data obtained by the proposed monitoring approach, algorithms can be developed in order to:

- Distinguish dry and wet weather period datasets (using rainfall data).
- Identify discharges (and their typology, e.g., pulse or continuous discharges) during dry weather.
- Characterise the discharges (e.g. duration, time of the day/week/year, frequency).

Electrical conductivity will give insight on the ionic strength of the discharges which is representative of the dissolved ion content of the water and potentially indicative of the discharge type. Reported conductivity in the literature was < 600 µS/cm for car and laundry washwater, <1500 µS/cm for sewage and > 2000µS/cm for industrial activities (Brown et al., 2004).

Turbidity (>1000 NTU) can be a supplemental variable that could help to identify industrial dry weather discharges (Brown et al., 2004). When measured at sites located in the Curlett Stream, any discharge would be diluted with the stream water, therefore lowering the turbidity. Direct comparison to a threshold of >1000 NTU might not be possible at these locations. However this will tell us if dry discharges identified in the stormwater network result in increased turbidity at the subcatchment level (i.e. at CSAuto sites just downstream). Feedback from the Monash/QUT universities team suggest that turbidity was more informative than conductivity for the purpose of dry weather discharges identification (personal communication, April 2023).

3.3.5 Cost of *in situ* dry weather monitoring instrumentation

In order to assess the most cost-effective options to identify non-consented discharges during dry weather, several scenarios and approximate instrument costs have been investigated. These scenarios have been built on the basis that the wet weather monitoring will be run independently from the dry weather monitoring to allow CCC to sub-contract these tasks separately if need be.

Scenario 1 relies on the implementation of **commercial sensors** including turbidity sensors at the 6 DW CSAuto sites (all CSAuto sites but CSAuto3 and CSauto4b) and water level, conductivity and temperature sensors at all DW CSAuto sites (6) and DW only sites (11).

Scenario 2 is a reduced version of scenario 1 – the same instruments would be deployed excluding the turbidity sensors.

Scenario 3 is similar to scenario 2 but relies on a **mix of commercial sensors** (for water level measurement at all 17 sites) **and home-made sensors** (for the conductivity and temperature measurement at all 17 sites).

Scenario 4 relies on the implementation of **home-made sensors (for all parameters) at all DW CSAuto sites and DW only sites (17 sites).**

An indicative cost for the instrumentation discussed in section 3.3 is provided in Table 3-4. This costing is only provided for the purposes of comparing the four scenarios. This costing does not include any installation cost (other than the support from QUT/Monash Uni.) nor data interpretation and reporting.

The main difference between scenarios is the extent to which the monitoring relies on commercial or home-made sensors. For the purpose of comparing scenarios, the anticipated sensors maintenance approximate cost has been provided considering maintenance of the sensors every 2 weeks when home-made turbidity sensors are deployed and every 4 weeks for the other scenarios. However, at this stage it is difficult to know the exact maintenance frequency that will be needed.

Table 3-4: Indicative cost, accuracy and range for various scenarios of dry weather *in situ* instrumentation.

		Unit price (excl GST.)	Sensor type	Telemetry	Range	Accuracy	Scenario 1*		Scenario 2*		Scenario 3*		Scenario 4	
							number	total price	number	total price	number	total price	number	total price
Conductivity and temperature measurement														
Hobo	U24-001 Conductivity Logger	$ 1,650	stand-alone sensor	no	Low Range: 0 to 1,000 µS/cm Full Range: 0 to 10,000 µS/cm	Low Range: 3% of reading, or 5 µS/cm, and Full Range: 3% of reading, or 20 µS/cm, whichever is greater	11	$ 18,150	17	$ 28,050				
Hobo	Software and base station to upalod data	$ 450	software	-	-	-	1	$ 450	1	$ 450				
QUT sensor		$ -	stand-alone sensor	yes (data available on QUT platform)	0 and 10,000 µS/cm	17%					17	$ -	17	$ -
Turbidity (with conductivity-temperature) measurement														
Observator & Unidata	NEP5000 and CONDUCTIVITY METER 6536 + data logger and telemetry (12 months)	$ 15,000	connected to baterry and solar panel	yes	**Turbidity:** 0 to 1,000NTU or 0 to 5,000 NTU **Conductivity:** Low range: 0 to 2,000 µS/cm Mid range: 0 to 20,000 µS/cm High range: 0 to 200,000 µS/cm	**Turbidity:** ±1% at 25°C, up to 5,000NTU **Conductivity:** Low range: ±1% Mid range:±0.5% High range:±0.5%	6	$ 90,000						
QUT sensor		$ -	stand-alone sensor	yes (data available on QUT platform)	0 to 1,000 NTU	25% for NTU<25, 5% for higher range of NTU							17	$ -
Water level measurement														
Waterwatch	radar water level sensor	$ 1,600	stand-alone sensor	yes	0.2-7m from the radar	2% (i.e. 6 mm for implementation in a 3m deep manhole)	17	$ 27,200	17	$ 27,200	17	$ 27,200		
Waterwatch	data telemetered for 1 year	$ 120	software	-	-	-	17	$ 2,040	17	$ 2,040	17	$ 2,040		
Hobo	U20-001-04	$ 1,450	stand-alone sensor	no	0-4 m	± 3 mm (± 0.075% FS)								
QUT sensor		$ -	stand-alone sensor	yes (data available on QUT platform)	0-3.5m	±10 mm (accuracy measured for the first generation sensor, new sensors that would be provided would have greater accuracy although not curently assessed)							17	$ -
						Sub total instument cost		$137,840		$ 57,740		$ 29,240		$ -
Installation support from QUT/Monash Uni		$ 10,000										$ 10,000		$ 10,000
5 days QUT staff		$ 5,000												
return flight +accomodation and food		$ 5,000												
Calibration and maintenance indicative cost														
calibration maintenance (once every 4 weeks for 12 months)		$ 60,000					1	$ 60,000	1	$ 60,000	1	$ 60,000		
calibration maintenance (every 2 weeks for 12 months)		$ 110,000											1	$110,000
Indicative total cost for each scenario								**$197,840**		**$117,740**		**$ 99,240**		**$120,000**

* For scenario 1, 2 and 3 where installation of Waterwatch sensors in the upper part of the manhole is not feasible, Hobo U20-001-04 (stand-alone sensor, not telemetered) will be installed down in the stormwater pipe.

The pros and cons of each scenario are summarised in Table 3-5.

Table 3-5: Technical pros and cons of each scenario.

	Pros	Cons
Scenario 1- commercial sensors only	▪ expected lower maintenance cost (if non telemetered conductivity sensors do not drift) ▪ high accuracy of the sensors	▪ Conductivity and temperature data not telemetered at DW only sites ▪ Turbidity measurement only at DW CSAuto sites, not at DW only sites)
Scenario 2- commercial sensors (without turbidity)	▪ expected lower maintenance cost (if non telemetered conductivity sensors do not drift) ▪ high accuracy of the sensors	▪ Conductivity and temperature data not telemetered ▪ No turbidity measurement
Scenario 3- commercial and home- made sensors	▪ expected lower maintenance cost ▪ higher accuracy for water level measurement than scenario 4	▪ No turbidity measurement ▪ Lower accuracy for conductivity and temperature than scenario 1 and 2
Scenario 4- home-made sensors only	▪ all parameters (cond., temp. , turbidity, water level) measured at all sites ▪ all sites and data telemetered	▪ Expected higher maintenance than other scenarios ▪ Possible need to switch to commercial sensors at some sites where accuracy does not allow dry wether discharge identification

Note: For scenario 1, 2 and 3, where installation of Waterwatch sensors in the upper part of the manhole is not feasible, Hobo U20-001-04 would need to be installed down in the stormwater pipe and water level would not be telemetered.

3.3.6 Strengths and weaknesses of this approach

In addition to pros and cons presented in Table 3-5, the dry weather monitoring strategy presents several strength and weaknesses.

The proposed dry weather monitoring methodology is thought to be the most cost effective as it relies on a first step of low-cost monitoring of indicators (water level, conductivity, temperature, turbidity) of discharges that will allow a subsequent more detailed survey (not included in this monitoring plan).

While the present dry weather monitoring methodology will allow CCC to identify where in the CSAuto sites' subcatchments dry weather discharges occur and when, it will not provide any indication on the discharge chemical quality nor pinpoint specific contributing sites. This should be performed during a subsequent step where samples could be collected for specific chemical analyses at selected times and from sites of concern.

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