GEO-SPATIALLY WEB-INTERFACED TELEMETRIC MONITORING SYSTEM TO TRACK CONTAMINANT TRANSPORT

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ABSTRACT

Analyzing contaminant loading from individual storm runoff events is expensive and often insufficient for realistic catchment-modelling predictions. We developed a near real-time telemetric monitoring system that measures base and storm flow and contaminant transport on a campus waterway. The monitoring system was implemented using a mesh network of radio transmitters linked to environmental sensors. This cost-effective system is equipped with in-stream sensors for monitoring discharge, turbidity, temperature, dissolved oxygen, pH and conductivity. A coupled weather station provides complementary data including rainfall intensity, duration, droplet size, temperature, and other climatic parameters. Data are relayed through the wireless network and logged onto an online computer, which is interfaced to Google maps on a dedicated web portal. An automatic sampler can also be added to the system to provide programmed sampling to track event driven contamination. Continuous water quality and discharge monitoring is helping to refine our modelling predictions of contaminant loading to urban waterways and is being extended to trigger an alert system when significant contaminant transport occurs. Supplementary metal analysis of baseflow water and in-stream sediments is revealing insight into contaminant transport and fate in a unique hydro-ecosystem that is actually dependent on contaminated water for flow.

KEYWORDS

Water quality, telemetry, contaminant transport, stormwater, modelling, geo-spatial

PRESENTER PROFILE

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1   INTRODUCTION

The Okeover Stream in Christchurch, New Zealand was originally a spring-fed hydro-ecosystem but now its ephemeral section relies solely on untreated stormwater for flow. The perennial reach primarily receives aquifer discharge used to regulate climatic conditions in neighbouring buildings but it was recently revealed that this source is contaminated from deteriorating copper piping discharging air-conditioning water (O'Sullivan et al., in review). The stream's disconnection with groundwater results from nearby urbanisation. Despite the aesthetically pleasing condition, contaminated inputs are believed to impair the ecological integrity of this ecosystem (Blakely & Harding, 2005).

Internationally, waterways are recognised for providing multi-functional assets to an urban area (e.g. Shaw & Bible, 1996, Tsihrintzis et al. 1995), including acting as a stormwater runoff conduit. Nationally, New Zealand authorities recognise waterways as appreciating assets rather than just a traditional drainage channel (Nolan 2005) while rehabilitation of its urban waterways is an acknowledged priority for urban residents (Boothroyd & Drury, 2006). Local government guidelines in Christchurch afford recognition and protection for six integrated waterways values namely: culture, heritage, ecology, recreation, landscape and drainage (CCC, 2003) considered in urban developments.

Substantial degradation of water quality in urban hydro-ecosystems in New Zealand typically occurs when stormwater runoff from impervious terrain is channelled directly into local streams (Blakely & Harding, 2005; Suren et al., 2005). This is especially common in older suburbs throughout Christchurch where little provision for on-site infiltration-type systems is afforded. Stormwater metal contaminants of greatest concern are Total Suspended Solids (TSS) and heavy metals zinc (Zn), copper (Cu) and lead (Pb), in particulate and dissolved forms (e.g. Gobel et al., 2007; Brown & Peake, 2006; Zanders, 2005). These metals originate mainly from brake linings, vehicle tyres and deteriorating galvanised steel and copper roofs that become washed off during rainfall events into nearby waterways (Pennington & Webster-Brown, 2008; Zanders, 2005; Karlen et al, 2002; Davis et al., 2001). Copper and zinc also originate from corroding copper-zinc alloy piping in reticulation systems (Merkel & Pehkonen, 2006; Rushing & Edwards, 2004; Royuela & Otero, 2003). Studies report that while capturing event-mean concentrations can provide some knowledge of concentrations, the data only represent a "snapshot" of the water quality and may not constitute an accurate representation of the actual contaminant load to the system (Henjum et al., 2010a). The fact that the Okeover stream relies on contaminated water for flow provided impetus to continuously monitor contaminant transport prior to deciding on any treatment mitigation strategies.

Telecommunication systems are employed in many applications for the timely acquisition of hydrologic and water quality data in urban (Henjum et al., 2010a; Henjum et al., 2010b) and remote (Lasorso et al., 2009, Meyer & Huey, 2006) locations. Such systems are believed to benefit urban communities' water utilities and regional water resources managers (Henjum et al., 2010a, Meyer & Huey, 2006) by providing insight into event-driven contaminant transport in a cost-effective manner. A recent effort to provide a coupled alert system that triggers when ecosystem impairment exceeds a threshold (stipulated by the number of fish dying) is reported by Lung (2009). However, there are no reported studies of geo-interfacing near real-time data from telemetric systems into a live web portal. By interfacing near real-time data into a graphical and live format, water managers and other stakeholders can visually yet quantitatively assess the degree of potential contamination and address the situation in a timely manner. This mode of information communication is also more digestible by the general public therefore better engaging them with the importance of urban waterways.

We report on a successful monitoring system that we developed to manage data in our expanding stormwater monitoring and modelling research. The system details a cost-effective telemetric system that provides near real-time hydrologic and water quality data on a more continuous basis that feeds our stormwater modelling efforts. Employing more accurate and increased data in stormwater modelling can help better predict contaminant transport behaviour and consequently helps optimise managerial solutions. Furthermore, empowering communities to understand and help mitigate their impacts on urban water quality can expedite the goal of improving the integrity of urban waterways.

2 MATERIALS AND METHODOLOGY

A telemetric monitoring system comprising parameter-specific instruments, a network of radio transmitters and a computer with logging capabilities was established at the University of Canterbury in Christchurch, New Zealand in 2009. This system monitors near real-time hydrologic flow and water quality and interfaces the information in a geo-referenced format onto a dedicated web portal. More continuous data is helping refine our stormwater modelling predications of the catchment and is a useful cost-effective prototype model for water resource managers of urban catchments.

2.1 TELEMETRIC SYSTEM SET-UP

The geo-spatially web-interfaced telemetric monitoring system established at the University of Canterbury is outlined in Figure 1. This schematic shows the complementary weather station but does not include the automatic (ISCO) sampler, which is activated to collect flow-weighted water samples from the stream channel during storm events and is triggered by a coupled water level-actuator. Theoretically, the automatic sampler could be located anywhere along the stream channel at the sampling point of interest.
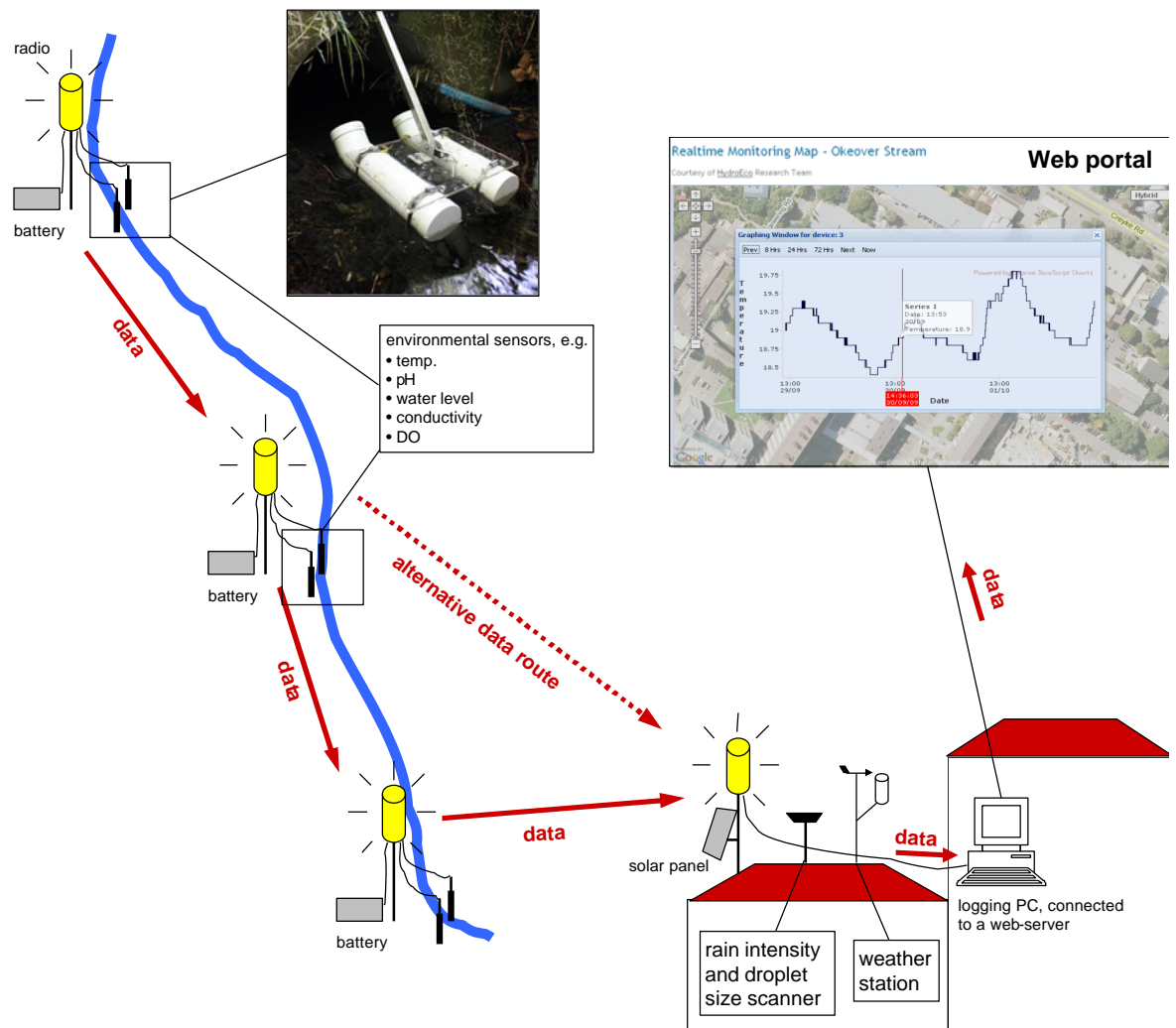

Figure 1. Web-interfaced telemetric monitoring system at the University of Canterbury

The monitoring system components and their model specifications are given in Table 1.

Table 1. Components of the telemetric environmental monitoring system

Component	Model/method specifications	
Water level sensors	Odyssey Capacitance Water Level Probes	
Automatic sampler	ISCO 6712 Full Size Portable Sampler	
Radio transmitters	Indigo Systems IS205 Long range radio	
Weather station	Campbell Scientific	
Laser optical disdrometer (measuring rainfall parameters)	OTT Parsivel	
Parameter-specific environmental sensors		
	Model/method specifications	**Unit**
Turbidity sensors	Greenspan TS 1000	NTU
	Self-developed cost-effective sensor	NTU
Optical Dissolved oxygen (DO) sensor	Zebra-Tech D-Opto	g m^{-3}
Temperature (water) sensor	Indigo IS 1000 robust Temp. sensor	°C
Conductivity sensor	Campbell Scientific CS547A	µS/cm

Overall, these comprise a weather station, water level meters to measure stage height, an automatic sampler programmed to activate during specific events and calibrated parameter-specific environmental sensors that continuously measure water quality and almost instantaneously transfer the data to a dedicated computer for logging. The weather station includes temperature, humidity, solar radiation, wind speed and direction and a laser disdrometer that measures rainfall intensity, volume and rain droplet size. Measurements of stream flow velocity at different stage heights were taken to establish rating curves for the stream, which were then used to quantify flow rates. By logging water level heights at subsequent periods, discharge is calculated using the stage-discharge method.

Radio communication system components were supplied by Indigo Systems (www.indigosystems.net.nz). This includes 14 specifically customized radio transmitters, 12 battery packs and 4 solar panels. The radio transmitters are powered by 12-volt 7 amp-hr gel-type sealed acid batteries that can be connected to a 5-watt solar panel to provide an independent electricity source. If not connected to a solar panel, the batteries require recharging every 3-6 months (with a data packet sent every 5 minutes). The antenna of each radio transmitter is omni-directional so that it can both receive and transmit data.

2.2   DATA RETRIEVAL

The wireless mesh network comprising a series of radio transmitters collects the data at each monitoring point and relays the data onto the subsequent radio transmitter in the line of communication until all data finally reach the base station for logging by the computer. Logging is programmed to measure every 5 minutes but this frequency can be altered by simple changes to the network configuration. Data is stored as ASCII files in specified folders in a database on a PC dedicated for the environmental monitoring programme housed in the environmental engineering laboratory. This data is then transmitted to an off-site web server for displaying near real-time information.

Wireless signals in urban areas are subjected to interferences from vegetation growth (especially in the spring and summer) and buildings with reductions in the effective radio transmission ranges to between 150 m to 1,000 m, depending on the attenuation in the radio frequency path. Therefore, additional relay stations were mounted on the tallest (8-storey) campus building to minimize impedances in data transfer.

The network operates a polling scheme in which each of the radios is queried once every five-minute interval for new data. The radios "sleep" the rest of the time thus saving battery power. Typically, the network will generate a 10-15 kb of stored data per hour and has relatively low latency from any given radio.

2.3   COSTING

The capital outlay of establishing this model telemetric geo-interfaced system is outlined in Table 2. Inherent labour costs are not included as this constituted core business of the University researchers and technicians. Additionally, there are no costs for radio signalling to the logging station, which is a distinct advantage over telephone/modem systems that require phone line installation and supporting services (Meyer & Huey, 2006). Analytical costs from episodic sampling with the automatic sampler are not included as these can vary depending on required frequency of sampling.

Overall, our capital costs amounted to (NZ) $54,866 in 2009 of which $28,466 (52%) was attributed to 18 environmental sensors and $ 4,200 (8%) to the radio transmitters. The automatic sampler ($7,000), laser disdrometer ($7,000) and the weather station were established in advance of the telemetric function and are complementary to the overall telemetric monitoring system but not essential components. The overall cost of establishing a telemetric monitoring system of this nature can vary depending on the number of sensors deployed, which are the greatest cost. We reduced the cost of the turbidity sensors by developing in-house optical sensors that are less than one tenth of the cost of the propriety (e.g. Greenspan) ones currently available on the market.

Despite initial capital costs of telemetric monitoring systems, operational costs are typically minimal. Other studies report that after two years, a radio telemetric system is competitive with the telephone system and that some vegetation clearing around the antennae is the only maintenance required other than continuing operation (Meyer & Huey, 2006). We expect to maintain our environmental sensors on a frequent basis to ensure calibration accuracy. Additionally, as the system develops with more sensors being added (financially permitting), we expect to incur some on-going maintenance with new installations and calibrations. Also, server space for data housing will incur an annual charge. There is on-going trouble-shooting with interfacing the data to the web-portal and so this maintenance aspect is likely to present the greatest operational time demand until the system becomes fully functional. Nonetheless, a telemetric near real-time monitoring system of this type is undoubtedly more cost-effective than periodic or episodic in-stream monitoring and sampling efforts that may not truly reflect accurate water quality of the waterway.

Table 2. Cost of the wireless telemetric environmental monitoring system

Component	Cost ($NZ in 2009)
Automatic sampler	7,000
Weather station including Laser disdrometer	Weather station refurbished Laser Disdrometer ~ 7,000
Water level meters, n= 6	200 (each)
Radio transmitters, n=14	300 (each)
Professional web design	4,000
Annual server space for data visualization	600
Environmental sensors (•, n = 18)	• 28,466
- dissolved oxygen, n= 4	4,050 (each)
- turbidity (self-developed), n= 6	300 (each)
- turbidity (Greenspan), n=1	3666
- conductivity, n= 4	950 (each)
- pH, n=3	1,000 (each)
Dedicated Computer with logging capabilities	1,000
Mounting equipment, battery packs, and other miscellaneous installation consumables, n=14	100 for each sensor node
Total cost for all components	54,866

3   DISCUSSION OF ONGOING AND FUTURE DEVELOPMENTS

3.1   MONITORING

The coupled base station (radio connected to online computer), radio relay points and monitoring stations are shown in Figure 2 using Google Earth™. Most of the monitoring locations (including the base station) are positioned along the Okeover stream but stage two of our environmental monitoring programme has initiated installation of some monitoring instruments in the Avon River. It is envisaged that we will further develop

our sampling regime along the Avon in order to increase our knowledge of hydrological flow and water quality on both campus waterways.

Figure 2. Locations of the telemetric web-interfaced components

A summary of the functional details for each system component, along with their respective grid reference, is given in Table 3. The base station serves as the main receiver and directly logs data received from the sequence of other relaying radios onto the dedicated computer housed in the environmental engineering laboratory. The turbidity sensor is expected to serve as a continuous surrogate measurement of total suspended solids since a site-specific correlation between these two parameters can be developed (e.g. Henjum et al., 2010b). Conductivity will be instrumental in understanding contamination from storm runoff (and perhaps air-conditioning discharge in the perennial reach) since rainfall has a very low conductivity compared with in-stream conductivity measurements reflecting all water inputs. Dissolved oxygen and temperature provide complementary knowledge of the water quality and are also employed to standardise some measurements (i.e. conductivity to specific conductance) for comparison across temporal and spatial zones. Specifically, these two parameters are frequently measured in rivers and streams to ascertain the ecological integrity of hydro-ecosystems (e.g. Blakely & Harding, 2005).

Stage height recorded in the lower perennial and upper ephemeral reaches of the Okeover stream was used to estimate flow, which can be seen in Figure 3. In the upper ephemeral section of the stream (Figure 3a), the flow represents storm events and hence provides a continuous knowledge of stormwater runoff entry time and duration in the stream exemplified by the peak intensity correlating to rainfall on the 24/07/2009 in the timeframe shown. Flow data in the perennial reach (Figure 3b) showing a different timeframe, highlights the diurnal fluctuations resulting from operational management of the air-conditioning discharging providing the flow during baseflow conditions. This data has been critical in the calculation of base flow in the perennial reach and subsequently in quantifying contaminant load transport from the corroding copper piping conveying

air-conditioning discharge. Rainfall inputs (e.g. 23/01/2010) are also recorded in the lower perennial reach. Tracking diffuse runoff from storm events helps identify potential contamination transport in this urban system and better inform catchment managers of how to strategically mitigate against such contaminants.

Table 3. Components of the radio communication system

| Name	Function	Latitude (S)	Longitude (E)
Base station	Main receiver	43.5217389	172.5832833
Relaying radios			
Environmental Lab balcony	Data relay	43.5217917	172.5830722
Central Library roof	Data relay	43.5239389	172.5826417
Arts carpark	Data relay	43.5253778	172.5857361
Ilam field sports building	Data relay	43.5214806	172.5748194
Radios with environmental sensors			
Engineering Bridge	Water level, Temp., pH, Turbidity, Conductivity, dissolved oxygen	43.5219139	172.5832389
Engineering Road	Water level, Temp., Turbidity	43.5219139	172.5832389
Geology Carpark	Water level, Temp., Turbidity	43.5225306	172.5848278
Health Centre Bridge at Avon river	Water level, Temp., Turbidity	43.5248389	172.5815806
Downstream of storm inputs on Avon river	Water level, Temp., Conductivity, Turbidity, pH	43.5265861	172.5861361
Corner of Ilam fields	Water level, Temp., Turbidity, Conductivity, pH	43.5203861	172.5736222
Bridge at Ilam stream	Conductivity, Temp., Water level, Turbidity	43.5229667	172.5746972
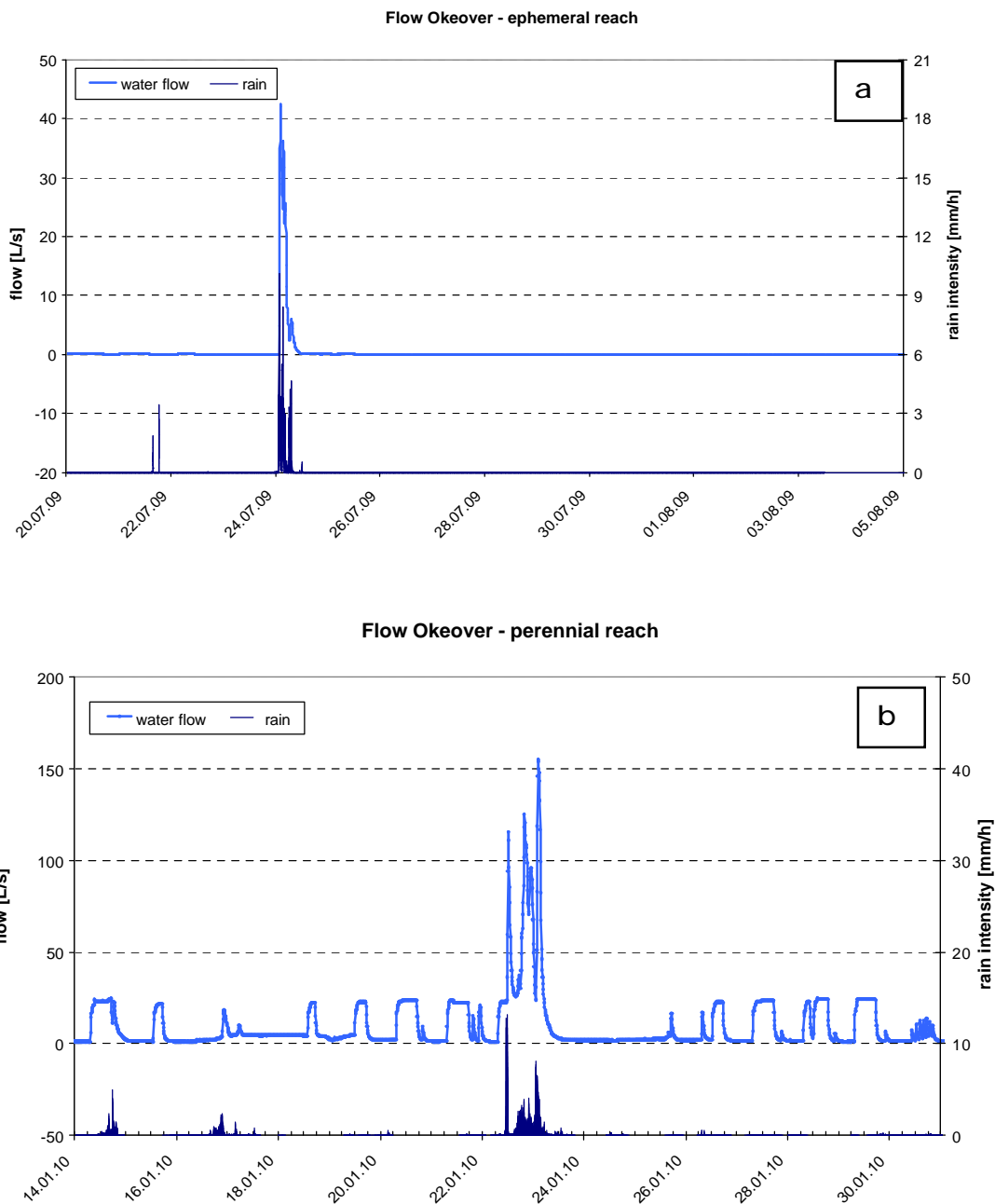
Figure 3. Flow and precipitation data logged in the upper ephemeral (a) and lower perennial (b) reaches of the Okeover stream.

Overall, the increased water quality and hydrologic flow data retrievable from continuous monitoring can provide more accurate knowledge of the stream's dynamics during base and storm flow events than is typically afforded in standard periodic sampling regimes. Henjum et al. (2010a) found that periodic sampling underestimated pollutant loads and compared with near real-time sampling, errors of between 19-200% were calculated. Furthermore, data is typically presented from archived logging – a situation not conducive to assessing and responding to potential contamination in a timely manner (Meyer & Huey, 2006). These discrepancies with ad-hoc periodic sampling do not provide for accurate or adequate modelling inputs in estimating contaminant load and transport. We anticipate that the additional data derived from the near-real time continuous monitoring will more accurately predict urban contamination in local catchments.

3.2   ONLINE DATA INTEGRATION

The dedicated web portal (www.urbanwaterways.info) was initially developed for showcasing the Okeover and upper-Avon waterways and disseminating information to the wider public about healthy urban waterways. As we procured more monitoring equipment and other resources to increase our databank of hydrologic and water quality information, we developed links to this portal to provide an interface for the near real-time data.

3.2.1 Climatic Data

The catchment weather station currently provides climatic data in 5-minute intervals interfaced on the publicly accessible web site. The parameters temperature, humidity, solar radiation, rainfall intensity, wind speed, wind vector and wind direction are currently provided on a time basis as well as retrievable for archive information (Figure 4).
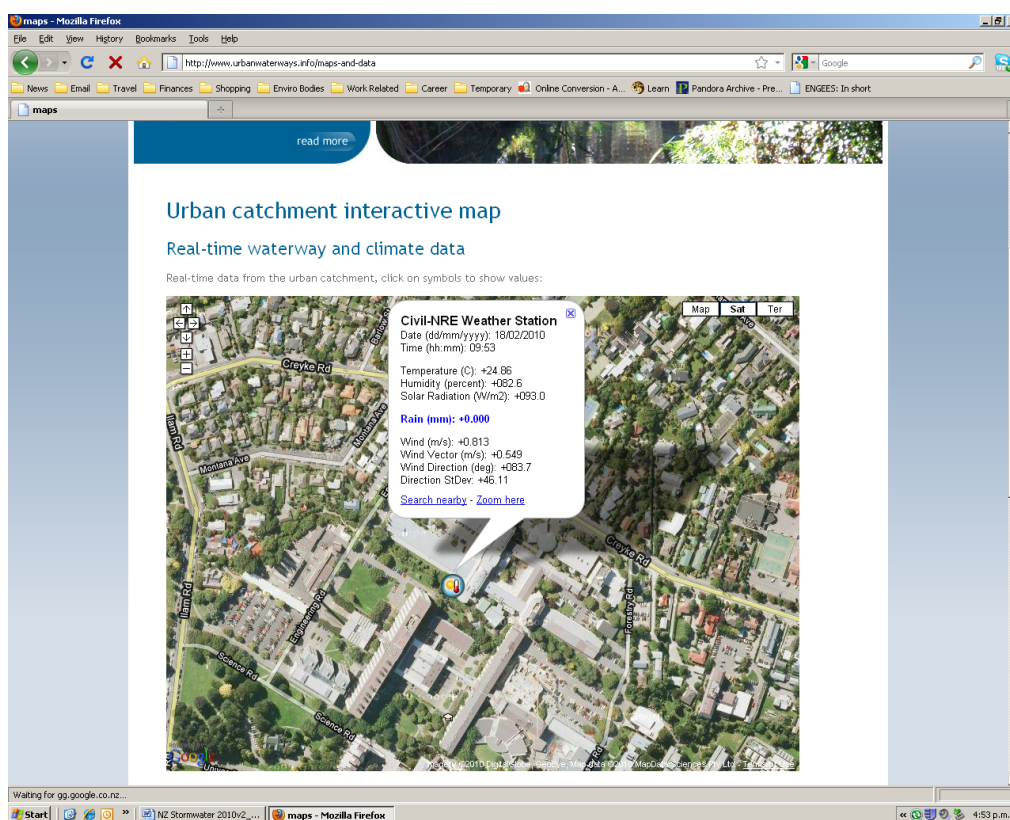

Figure 4. Near real-time climatic data interfaced on the dedicated web portal

3.2.2 Hydrologic and Water Quality Data

The hydrologic and water quality data that are currently recorded in the Okeover stream have not been released to the public yet. The live-interface with the web portal is being upgraded as new radio software and sensors are currently being installed. However, it is anticipated that these challenges will be overcome very soon and that the upgrade software provided by Indigo Systems will have the capacity to manage larger integrated data sets. Presently, water levels have been logged independently through coupled data loggers but once the web integration is complete, water level will also be logged directly to the computer without requiring the need for coupled dataloggers for any instrument.

Although the dedicated website is currently being upgraded and the live water quality monitoring-interface is not yet complete, this portal will provide public access to

environmental data in the University waterways. Data is instantly uploaded to the web portal and displayed on an interactive map where users will be able to visually retrieve quantitative measurements along the monitoring points. Google Earth™ is currently employed for the spatial interfacing and we also plan to make the data downloadable for end users.

By interfacing near real-time data into a graphical and live format, water managers and other stakeholders can visually yet quantitatively assess the degree of potential contamination and address the situation in a timely manner. This mode of information communication is also more digestible by the general public therefore better engaging them with the importance of urban waterways.

3.3   ECO-HYDROLOGICAL MODELLING

The modelling aspects of our stormwater research provide complementary value to the online telemetric system. We initially developed a rainfall-contaminant relationship model for Christchurch urban catchments that ascertained specific associations for each metal contaminant of concern and for suspended solids with particular rainfall parameters (Wicke et al., 2009). We are subsequently investigating contaminant build-up and runoff from various road surface materials (concrete and asphalt) as well as wind-driven effects, as reported elsewhere (Egodawatta et al., 2009). Functions for these behaviours are being developed and the data from our concomitant experiments are being applied to the US EPA's stormwater management model (SWMM). Furthermore, we are deciphering contaminant loads from various roof surfaces as distinct from pavements to better understand urban contaminant origins and their mobility in storm events.

The Eco-hydrologic alert system will serve as a warning that triggers once a specific contaminant concentration (or load, which will be computed from concentration and flow) is reached in the waterway. This function could provide a valuable communication means for tracking potential contaminant plumes and responding accordingly in a shorter time frame than is normally afforded. It may also provide an effective pedagogical tool for local communities to then appreciate impacts on the local waterway from specific events.

4   CONCLUSIONS

Recent surveys of our communities revealed few were knowledgeable about water quality challenges in their local waterways. These deficiencies provided a strong impetus for our research group to (i) collect continuous water quality data; (ii) improve our understanding of contaminant fate and transport in the local hydro-ecosystems; (iii) advance our modelling efforts that better predict stormwater contaminant loads and; (iv) develop a publicly accessible user-friendly tool (web portal) that increases community awareness. A geo-referenced web-interfaced telemetric monitoring system was designed to meet these goals by employing a mesh network of radio transmitters linked to environmental sensors. This data is almost instantly uploaded to the web portal, displayed on a map, and is currently being integrated into a model showing contaminant loads and their risk in local waterways. This prototype system will provide a community focused solution for quantifying and mitigating key contaminants in urban catchments and is applicable and transferable across Christchurch and other cities with similar urban water quality issues. Concurrently, it serves as a pedagogical tool featuring a near real-time system that monitors contaminant loads in local urban waterways. Additionally, this portal provides resources including scientific reports, guidelines for best practice (mitigation) as well as a forum tab. Most of the website is publicly available but the water-quality interfacing and eco-hydrologic modelling components have not yet been

released until the work is completed (2010). We continue to advance complementary aspects of local and regional councils' strategy for improving New Zealand's waterways by providing a near real-time modelling system validated with actual contextual data.

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