Water Science & Technology | 63.2 | 2011

Developing a public information and engagement portal of urban waterways with real-time monitoring and modeling

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ABSTRACT

Waterways can contribute to the beauty and livelihood of urban areas, but maintaining their hydro-ecosystem health is challenging because they are often recipients of contaminated water from stormwater runoff and other discharges. Public awareness of local waterways' health and community impacts to these waterways is usually poor due to of lack of easily available information. To improve community awareness of water quality in urban waterways in New Zealand, a web portal was developed featuring a real-time waterways monitoring system, a public forum, historical data, interactive maps, contaminant modelling scenarios, mitigation recommendations, and a prototype contamination alert system. The monitoring system featured in the web portal is unique in the use of wireless mesh network technology, direct integration with online modelling, and a clear target of public engagement. The modelling aims to show the origin of contaminants within the local catchment and to help the community prioritize mitigation efforts to improve water quality in local waterways. The contamination alert system aims to keep managers and community members better informed and to provide a more timely response opportunity to avert any unplanned or accidental contamination of the waterways. Preliminary feedback has been positive and is being supported by local and regional authorities. The system was developed in a cost-effective manner providing a community focussed solution for quantifying and mitigating key contaminants in urban catchments and is applicable and transferable to other cities with similar stormwater challenges.

Key words | urban waterways, water quality, monitoring, modelling stormwater quality, web portal

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INTRODUCTION

Substantial degradation of water quality in urban ecosystems typically occurs as stormwater runoff from impervious surfaces is channelled directly into local waterways (Blakely & Harding 2005). Total suspended solids (TSS) and metals (zinc (Zn), copper (Cu) and lead (Pb)), originating from wear of vehicle tyres and brake linings, as well as from metal roofs (Davis *et al.* 2001; Zanders 2005; Gobel *et al.* 2007), are of particular concern. Poor management practices from disposing of household paints and ad-hoc chemicals as well as construction activities, also substantially impair local waterways.

Telecommunication systems are employed in many applications for the timely acquisition of hydrologic and water quality data in urban (Henjum *et al.* 2010a, 2010b) and remote (Meyer & Huey 2006; Lasorso *et al.* 2009) locations. Such systems are believed to benefit urban communities' water utilities and regional water resources managers (Meyer & Huey 2006; Henjum *et al.* 2010a) by providing insight into event-driven contaminant transport in a cost-effective manner. 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.

doi: 10.2166/wst.2011.043

Since 2006, our research group has quantified background signatures and urban stormwater loadings in two campus waterways at the University of Canterbury (Christchurch, New Zealand) through direct sampling. Despite the aesthetically attractive condition of these waterways, our data reveals very poor water quality resulting from campus vehicular traffic and additionally from stormwater runoff originating further up-stream within the catchment. The metals Zn and Cu were measured at consistently elevated concentrations for the protection of 80% of aquatic species as defined in the contextual eco-toxicological effects-based guidelines (ANZECC 2000). These diffuse contaminants are believed to impair the ecological integrity of these hydro-ecosystems (Beasley & Kneale 2002; Blakely & Harding 2005), which constitute a valued asset for the community. In response to our preliminary findings, local and regional authorities responsible for the management of our natural resources including these waterways expressed a strong desire to attain a robust dataset with which they can devise effective stormwater contaminant mitigation strategies. Furthermore, they wish to develop and implement appropriate mitigation and treatment responses including public awareness programmes and integrated treatment infrastructure. Community awareness (and engagement) about the water quality of Christchurch local waterways is weak, and recent surveys revealed few were knowledgeable about the direct impact of their activities on their local streams. Inadequate robust water quality data and ineffective community engagement provided a strong impetus for our research group to (i) collect continuous stormwater monitoring data in a cost-effective manner; (ii) ascertain catchment spatial and temporal variability in the long-term data; (iii) improve our knowledge of contaminant fate and transport in the local hydro-ecosystems; (iv) advance our modelling efforts that better predict stormwater contaminant loads and; (v) develop a publicly accessible user-friendly tool that increases community awareness and empowers them about effective stormwater mitigation.

PUBLIC ENGAGEMENT WEB PORTAL AND MONITORING SYSTEM

Web portal development

A web portal (Figure 1(a)) was designed to translate our research outcomes (data, knowledge and resources) in a meaningful manner that is digestible by the local public. It effectively serves as a pedagogical tool featuring a real-time system that monitors and models contaminant loads in local urban waterways. Other key features of the portal include a public forum, historical waterways data, interactive maps and modelling scenarios, mitigation recommendations, and a prototype alert system (i.e. that triggers when contaminant levels reach an upper threshold). Therefore, impacts of communities on the water quality of their local waterways can be better appreciated due to its context and interactive potential. This prototype system was developed in a cost-effective manner for quantifying and helping to mitigate key contaminants in urban catchments and is applicable and transferable to other cities experiencing similar stormwater challenges.

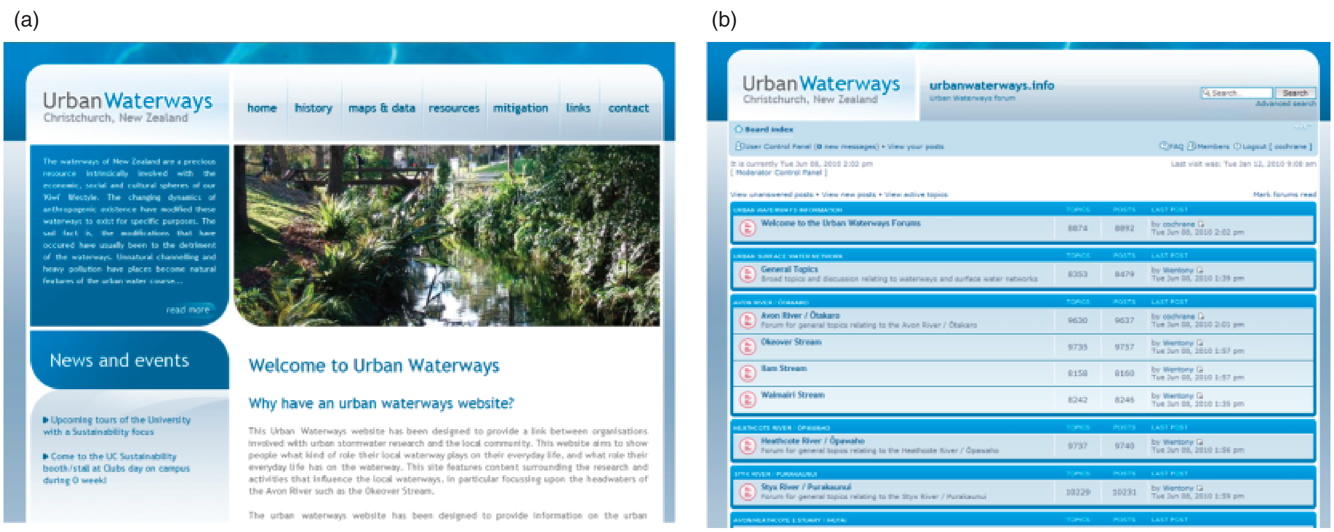

Figure 1 | Sample view of (a) urban waterways web portal and (b) public discussion forum.

The forum enables public participation in addressing concerns related to specific waterways contamination (Figure 1(b)). Initial trials with an "open management" forum unfortunately resulted in undesirable posting of unsolicited advertising and spamming by random users not part of the urban waterways catchment. This situation was resolved by tightening the management of the forum through increased security during forum registration. Although the forum is still accessible for all public perusal, interactive users are now required to register and obtain approval from the forum manager(s). Once successfully registered, users can post messages on the forum and communicate directly with other legitimately registered members. The web portal is also linked on 'facebook', which enables community members to share positive and negative experiences concerning specific urban waterway activities or water quality status.

An information pamphlet was produced to introduce this portal to the local community and inform them about the negative impacts of diffuse urban runoff on their local waterways. The pamphlet provides an initial source of information on local urban waterways, encouraging visits to the web portal. The web portal is also being promoted by local (Christchurch City Council) and regional (Environment Canterbury) authorities responsible for the health of local water bodies who are leading similar community engagement initiatives across Christchurch city. Dedicated links to our website are highlighted in their mitigation and public campaign efforts.

Real-time monitoring

A prototype real-time monitoring system is a key feature of the web portal. This system provides information to the public on water quality at selected points along the University of Canterbury campus waterways. The unique, cost-effective monitoring system was developed using a mesh network of radio transmitters linked to turbidity, pH, conductivity, water level, and other sensors as listed in Table 1 and shown in Figure 2 a for seven locations around the campus. Sensor readings are taken every 5 minutes and are relayed through the network until data reaches a base node connected to an online computer. The data is instantly uploaded to the web portal where it is processed, and displayed on Google based

Table 1 | Radio nodes and sensor types located at different waterways around the University of Canterbury providing real-time data through the wireless network and web portal

Location (Figure 2)	Sensor types
Engineering Bridge	Water level, Temp., pH, Turbidity, Conductivity, dissolved oxygen
Engineering Road	Water level, Temp., Turbidity
Geology Carpark	Water level, Temp., Turbidity
Health Centre Bridge at Avon river	Water level, Temp., Turbidity
Downstream of storm inputs on Avon river	Water level, Temp., Conductivity, Turbidity, pH
Corner of Ilam fields	Water level, Temp., Turbidity, Conductivity, pH
Bridge at Ilam stream	Conductivity, Temp., Water level, Turbidity

Figure 2 | (a) Location of monitoring nodes and (b) web portal showing real-time monitoring nodes from the Okeover stream at the University of Canterbury campus overlaid on Google maps.

interactive maps (Figure 2b). The public is able to view current and historical data presented as interactive charts for each node and sensor on the map. To be of greater interest and service to the general public, real-time weather information (rainfall, wind speed/direction, temperature, humidity, and radiation) is also provided from a dedicated climate station located near the Okeover waterway.

The real-time monitoring system was designed to be easily deployable, cost-effective, and independent of external power requirements. The wireless radio system (developed by Indigo Systems) functions by transmitting data from one radio to another in a mesh type network. Radios are required to be within a 150 to 1000 m range (depending on vegetation and building interferences) of each other in order to facilitate an expanded network across many waterways within an urban area. Up to eight sensors can be attached to each radio node. The overall cost of establishing a telemetric monitoring system of this nature can vary depending on the number and type of sensors deployed, the number of radios in the system, installation costs, and accessories such as cables and batteries. The cost of each radio is about NZ$300 and costs for sensors vary significantly. Overall, our capital costs to-date amounted to (NZ) $54,866 of which $28,466 (52%) was attributed to 18 environmental sensors and $4,200 (8%) to the radio transmitters (O'Sullivan *et al.* 2010). 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 (or cell phone charges) and supporting services (Meyer & Huey 2006). 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). Both the radios and monitoring sensors can run off batteries or from solar power cells. Power consumption and battery life for two typical monitoring nodes with 5 and 3 different environmental sensors connected is clearly dependent on the number of sensors used and on the monitoring time interval of these sensors (Table 2). Measurements from 3 environmental sensors can be recorded at 5 minute intervals for an average of 100 days using a 12Ah battery compared to 50 days when 5 sensors are used. A solar power panel, however, can be used to re-charge the batteries, extending the system operation indefinitely. The combination of a mesh radio network system, independent power supply, and the ability to link up to eight sensors per radio node make the system easily extendable and deployable to other (urban) catchments.

Sample data from a monitoring node at the Okeover stream on campus is shown in Figure 3. This data was collected through the wireless system at 5 minute intervals using a specially designed sensor "boat" concealed beneath a small bridge over the waterway (Figure 4). Changes in water level, turbidity, temperature and pH can readily be observed and analysed over short time intervals. This level of hydro-ecosystem response and potential impact on waterways health would otherwise be missed if continuous monitoring was not conducted. Additionally, continuous quantitative monitoring of this nature provides visual near real-time information for the local community and has helped refine our stormwater and contaminant modelling objectives.

Table 2 | Power consumption (mAh/d) and stand alone battery life for telemetric monitoring system sampling at a 5 minute interval under two typical sensor node configurations

Sensors operating in node	sensors [mAh/d]	output signal [mAh/d]	standby radio [mAh/d]	interface boards [mAh/d]	Total Consumption [mAh/d]	9 A Battery Life [d]	12 A Battery Life [d]
5 sensors:							
• temp. • depth • turb. • pH • cond.	23 to 60	16	23	163	225 to 262	**40 to 34**	**53 to 46**
3 sensors:							
• temp. • depth • cond.	6 to 14	6	23	82	117 to 125	**77 to 72**	**102 to 96**

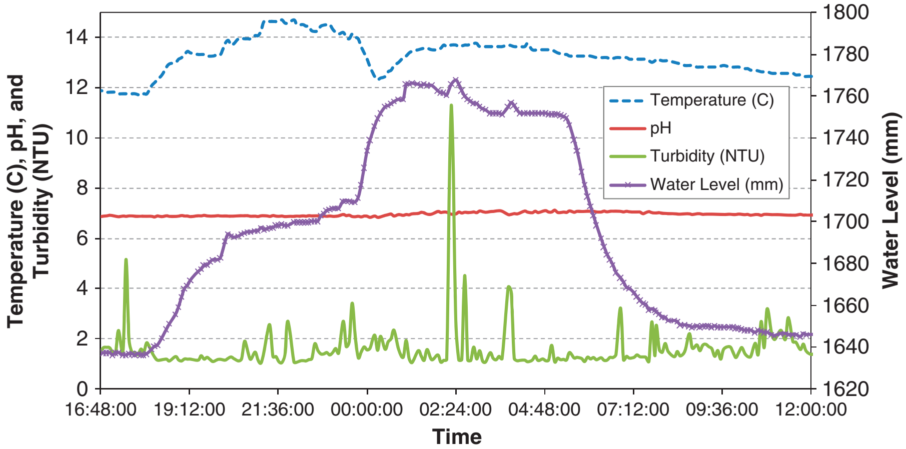

Figure 3 | Sample data from a monitoring node on the Okeover stream at the University of Canterbury collected at 5 minute intervals.

Model integration and alert system

The real-time monitoring data is being integrated into a model showing related contaminant loads and their transport risk to local waterways through an interactive web-based GIS map interface. 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 subsequently investigated 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 were 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. A GIS interface is currently being employed to model contaminant contributions to local waterways from these different impermeable surfaces (e.g. Figure 5). Each impermeable surface directly contributing contaminated run-off to the waterway is categorized by having a build-up and wash-off contaminant function, which is triggered by rainfall. The web portal will demonstrate the level of contamination originating from each surface after a given storm event. Overall, these models will be employed to show the origin of contaminants within the local catchment and effects of contaminant source mitigation. The information will enable

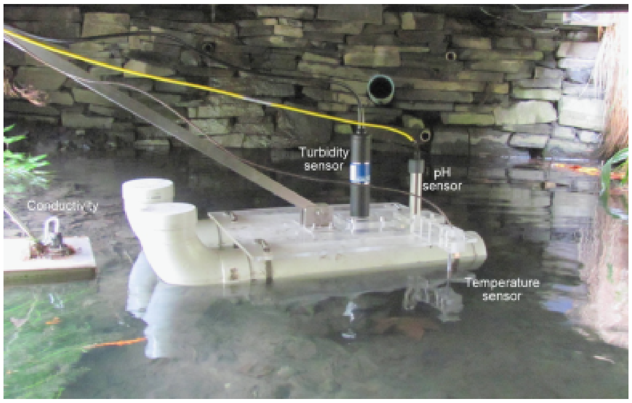

Figure 4 | Sensor "boat" under bridge linked to the wireless real-time monitoring system.

Figure 5 | Impermeable surfaces directly feeding runoff to the urban waterway used for modelling purposes and for demonstrating contaminants origins.

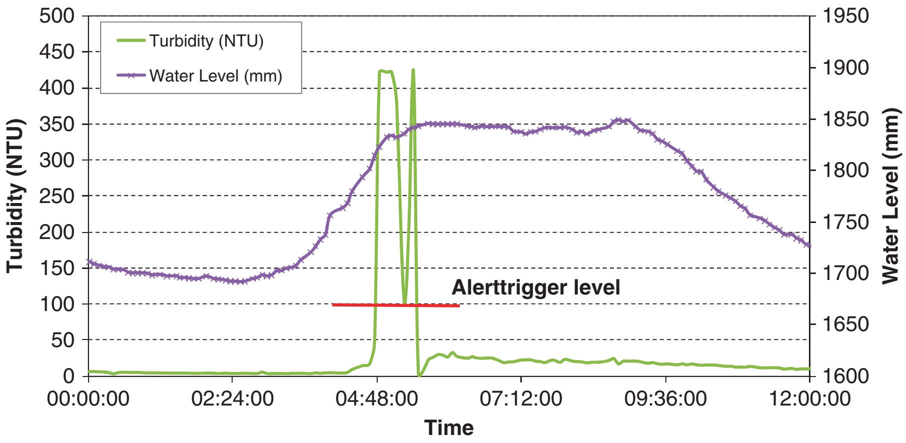

Figure 6 | Alert triggered due to disturbance of the stream caused by a waterways maintenance team commencing work at 4:30 pm.

the community to help prioritize mitigation efforts to improve water quality in local waterways.

A recent effort to provide an alert system that triggers when ecosystem impairment exceeds a threshold (stipulated by the number of fish dying) is reported by Lung (2009). We developed an eco-hydrologic alert system to serve as a warning that triggers once a specific key 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. For example, when turbidity (suspended sediment) at a node in a certain waterway exceeds a specified trigger level, an alert is displayed on the website. A record of this alert is maintained showing when and for how long the contaminant (or combination of contaminants) exceeded the trigger level. In Figure 6, turbidity from one of our monitoring nodes exceeded the established alert trigger level for about 30 minutes. The trigger level was set at 100 NTU based on historical observations of acceptable NTU levels in the stream following storm events. Values above 100 NTU therefore warrant an alert warning. In this particular case, the alert was caused by a waterways maintenance crew working near that specific location in the stream which disturbed streambed sediments resulting in elevated turbidity levels. The eco-hydrologic alert trigger is displayed on the web portal and subsequently posted on the forum for future discussion. Additionally, a text message "trigger alert" can be immediately sent to waterway managers and key community representatives. With this system in place, planners, managers, and concerned citizens would be better informed and afforded a more timely response opportunity to avert any unplanned or accidental contamination of the waterways.

CONCLUSIONS

Preliminary feedback on the portal has been very positive. The local city and regional authorities have been supportive of this initiative and plans are under way to extend the system to other waterways. The automated monitoring and data organisation system are providing a wealth of information, which will exponentially increase our knowledge of stormwater contaminant processes. The system is cost-effective and unique in the use of mesh network technology, direct integration with online modelling, and a clear target of public engagement. We anticipate this tool will serve as a key instrument for adequately quantifying contaminant signatures in urban waterways and hence in recommending appropriate stormwater runoff mitigation technologies. It may also be adopted as a user-friendly pedagogical resource and influence urban planning and practice to some extent. Overall, this web portal aims to empower the community to enhance their waterways health.

ACKNOWLEDGEMENTS

The authors wish to thank Dave Rankin and Jeremy Corbert from Indigo Systems, Shaun Cosgrove, Alan Stokes, Peter McGuigan and Peter Coursey (Dept. technicians), Matt Mabley (web designer), and the Brian Mason Scientific and Technical Trust for funding some of this work.

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