Integration of Roadway Flood Information into an ITS Traffic Management System – an Example from Queensland, Australia

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Abstract

In the State of Queensland, Australia, flooding, rather than snow and ice, is the most prominent weather related hazard to impact road users, and figures show that more than half of flood-related deaths in Queensland are a result of driving through floodwater (Department of Transport and Main Roads, 2016a). Following the tragic Queensland flood events of 2010/2011, the Queensland Floods Commission of Inquiry recommended that the Department of Transport and Main Roads, in its capacity as primary provider of information about road conditions to the public, should continue to improve the accuracy of road condition information and the timeliness of its distribution to the public and other agencies (Queensland Government, 2012).

Following the release of a new Technical Specification for Roadway Flood Monitoring Systems by the Department of Transport and Main Roads, there is now a concerted effort underway in Queensland to integrate existing and new Roadway Flood Monitoring Stations into the STREAMS Intelligent Transportation System (ITS) Traffic Management System used by the Queensland Government Road Agency. Using a case study Roadway Flood Monitoring System located in the city of Townsville, North Queensland, this paper explores the system architecture behind a STREAMS integrated Roadway Flood Monitoring System, and examines the operational benefits of having real-time roadway flood information available to Traffic Management Centers (TMCs) through an integrated Traffic Management System.

Background

Whilst over 80% of the Australian continent has an annual rainfall of less than 600 mm, parts of the North Queensland coast annually average over 3,000 mm (Figure 1). Rainfall patterns over Australia are highly seasonal however, with the majority of rainfall in the State of Queensland occurring during the months of October to April, commonly referred to as the Northern wet season (Figure 2).

Interannual variability in this rainfall is heavily influenced by the strength of the atmosphere-ocean coupling on the interannual timescale which is observed in association with the El Niño Southern Oscillation (ENSO). El Niño refers to the recurrent pattern of positive sea-surface temperature anomalies in the equatorial Pacific, whilst the Southern Oscillation refers to the atmospheric component of El Niño where sea-level pressure oscillates between the tropical eastern and western Pacific Ocean (Wallace & Hobbs, 2006). The strength of the Southern Oscillation is measured by the Southern Oscillation Index (SOI), and a positive SOI indicates the onset of a La Niña event (Bureau of Meteorology, 2016a).

La Niña refers to the extensive cooling of the central and eastern Pacific Ocean and warmer than average sea surface temperatures in the western Pacific and to the north of Australia. La Niña events are typically associated with increased probability of wetter conditions over much of Australia, and have been correlated with higher numbers of tropical cyclones during the Northern wet season (Bureau of Meteorology, 2016a).

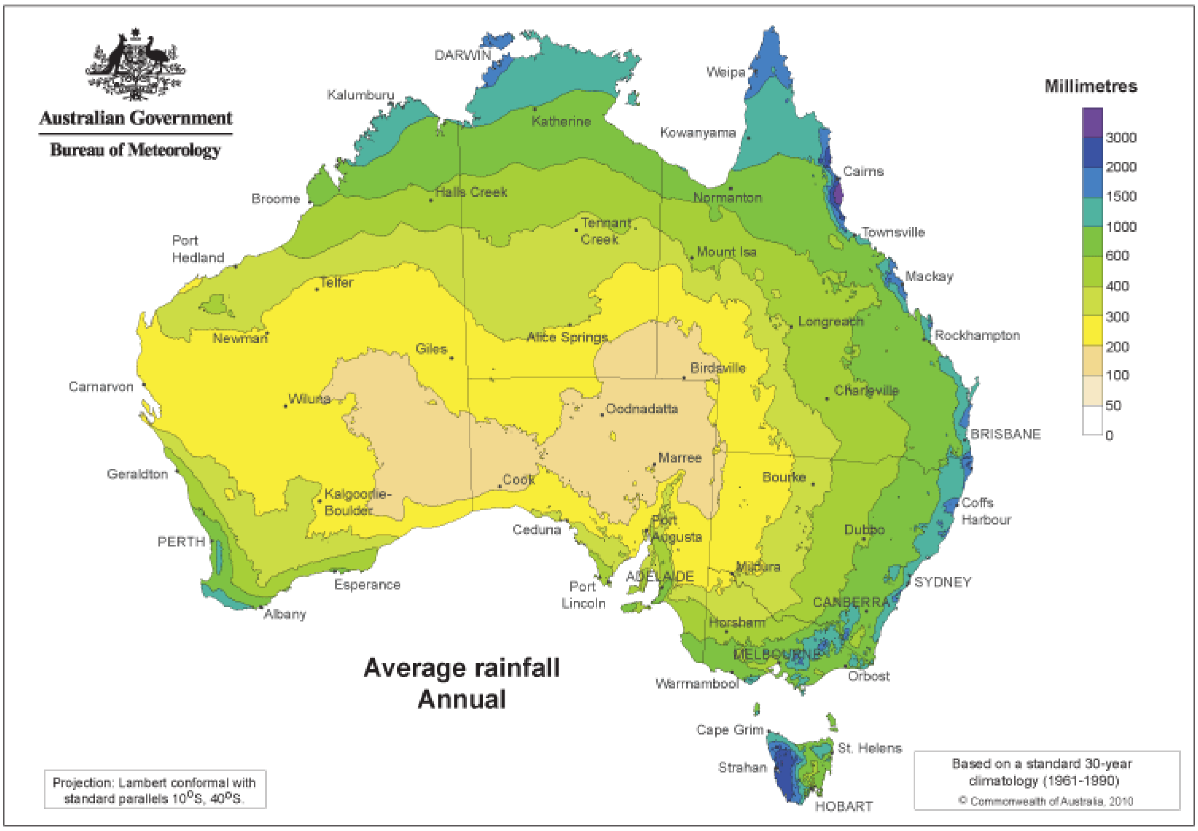

Figure 1: Average annual rainfall, Australia. (Bureau of Meteorology, 2016b).

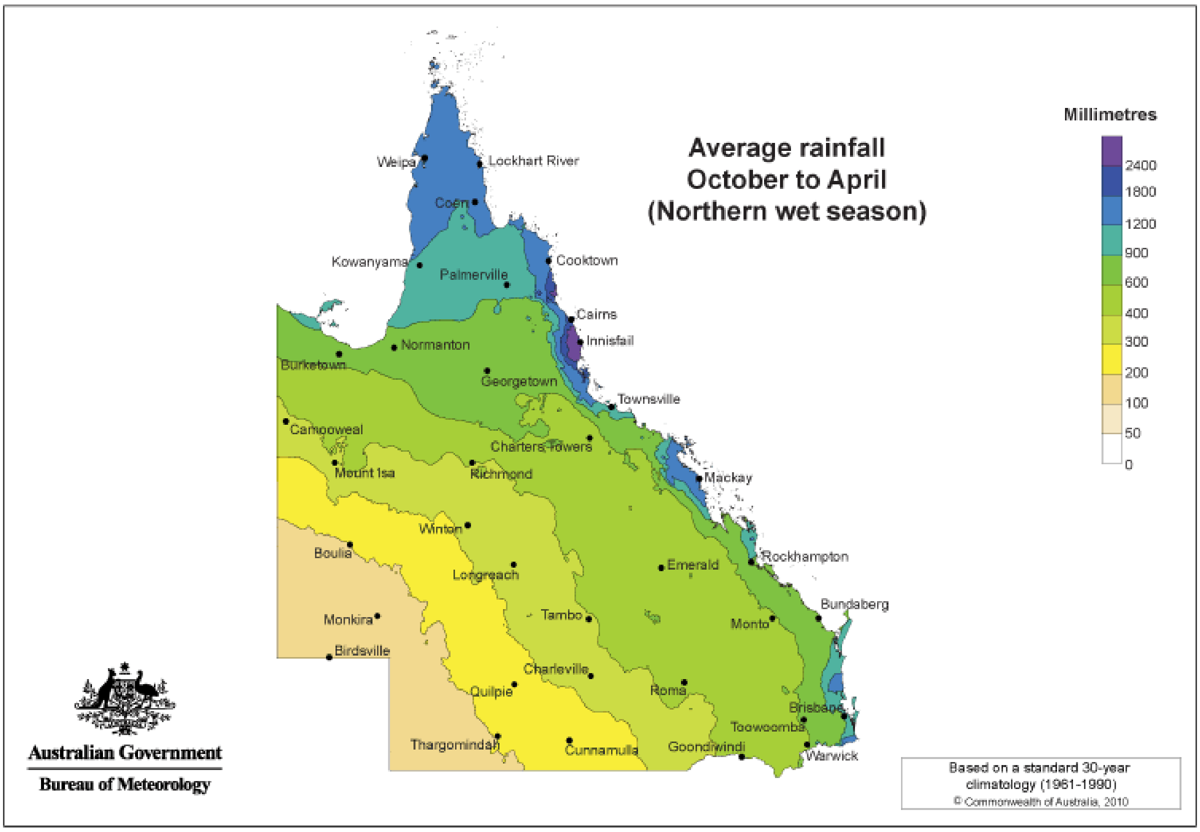

Figure 2: Average rainfall October to April, Queensland. (Bureau of Meteorology, 2016b).

In October and December 2010, and February and March 2011, the SOI values were the highest recorded for each month since records commenced in 1876. This La Niña event brought with it record breaking rainfall and widespread flooding to many parts of Australia, and severe flooding to southeast Queensland with 33 flood-related deaths (Bureau of Meteorology, 2016a). The Queensland Floods Commission of Inquiry reported that almost a quarter of the deaths in Queensland during the 2010/2011 floods occurred while people were trying to drive through floodwaters on roads or causeways. In some of these instances, the Inquiry concluded that the lack of information about road conditions ahead may have been a contributing factor in the decision to attempt to drive through floodwaters (Queensland Government, 2012).

Queensland has over 33,000 kilometres of state-controlled roads which are managed by the Department of Transport and Main Roads. During the 2010/2011 floods many roads became inundated and had to be closed. Based on Department of Transport and Main Roads Guidelines at the time, the road closure process involved the following steps (Queensland Government, 2012):

- the road is assessed by transport department officers or police officers
- after consulting others including the department's website operators, local police and affected residents, the officer closes the road or imposes conditions on access
- road access information is submitted to the transport department and, following and approval process, the road condition is published on the transport department's website.

The same process is also used when roads are reopened.

Following the tragic flood events of 2010/2011, the Queensland Floods Commission of Inquiry recommended that the Department of Transport and Main Roads, in its capacity as primary provider of information about road conditions to the public, should continue to improve the accuracy of road condition information and the timeliness of its distribution to the public and other agencies.

Automated Road Flood Monitoring Systems

Automated Roadway Flood Monitoring Systems have existed in Queensland for a number of years, but a lack of central governance regarding the specification of such systems has resulted in a range of ad-hoc systems being deployed by hardware integrators, each with their own hardware, communications and software solutions. Many of these systems provide roadway flood data and alarming to local councils via third party data hosting solutions, providing the information necessary to enable informed decisions to be made and actions to be taken accordingly regarding local road closures. In remote areas with no telecommunications coverage, Roadway Flood Monitoring Systems are often autonomous systems which locally activate Variable Message Signs (VMS) or Wig Wags (flashing lights) when roadway water levels exceed a pre-determined threshold, often referenced to the height of a river at a certain gauge in terms of Australian Height Datum (AHD).

Whilst these existing in-situ monitoring systems undoubtedly provide valuable information to road authorities and the general public, they typically use proprietary software and communications protocols which have prevented the integration of roadway flood data into an ITS Traffic Management System. Hence, the Department of Transport and Main Roads State-wide TMCs have no visibility of these systems within their ITS software platform, and local councils are typically left having to fund costly ongoing third party software and data hosting fees to maintain such systems at a time of huge cuts to public finance. As such, these existing in-situ Roadway Flood Monitoring Systems are increasingly being seen as inefficient from an asset management perspective, and incapable (in their current form) of providing data into the STREAMS Traffic Management System.

In an effort to address such issues, local councils together with the Department of Transport and Main Roads are now making a concerted effort to integrate new and existing Roadway Flood Monitoring Systems into the STREAMS ITS software platform used by the Queensland Government Road Agency. In 2015 the Department of Transport and Main Roads published a new Technical Specification for Roadway Flood Monitoring Systems (MRTS 233), within which the operational requirements for a Roadway Flood Monitoring System specify that the monitoring system shall support remote TMC head end flood height backhaul data within Transport and Main Road's Traffic

Management System (STREAMS) to enable departmental operators to centrally monitor Road Flood Monitoring System sites directly via the STREAMS User Interface (Queensland Government, 2015).

STREAMS Intelligent Transportation System

The Department of Transport and Main Roads Queensland uses the STREAMS ITS Traffic Management System, developed by Transmax Pty Ltd, to integrate multiple traffic management functions into one system. Most ITS software platforms run on an inter-operability model, where multiple ITS systems work in parallel, each performing a discrete function. As an integration platform, STREAMS provides the ability to integrate both discrete ITS field devices and third party ITS sub-systems together into a single coherent system with a unified User Interface, operational workflow and cross-functional coordination and control capability.

STREAMS' approach to ITS integration utilises a distributed computing architecture (Figure 3) with the following components:

- **Client Workstations** – Rich client UI deployed in the TMC and Engineers offices
- **Application Server(s) –** Central monitoring and control services that coordinate the operations of the system, deployed centrally
- **STREAMS Connect** – Distributed computing layer that provides device abstraction and distributed communications & processing for ITS field devices, deployable both centrally and in the field
- **BI Server** – Data Analytics and warehousing platform, deployed centrally

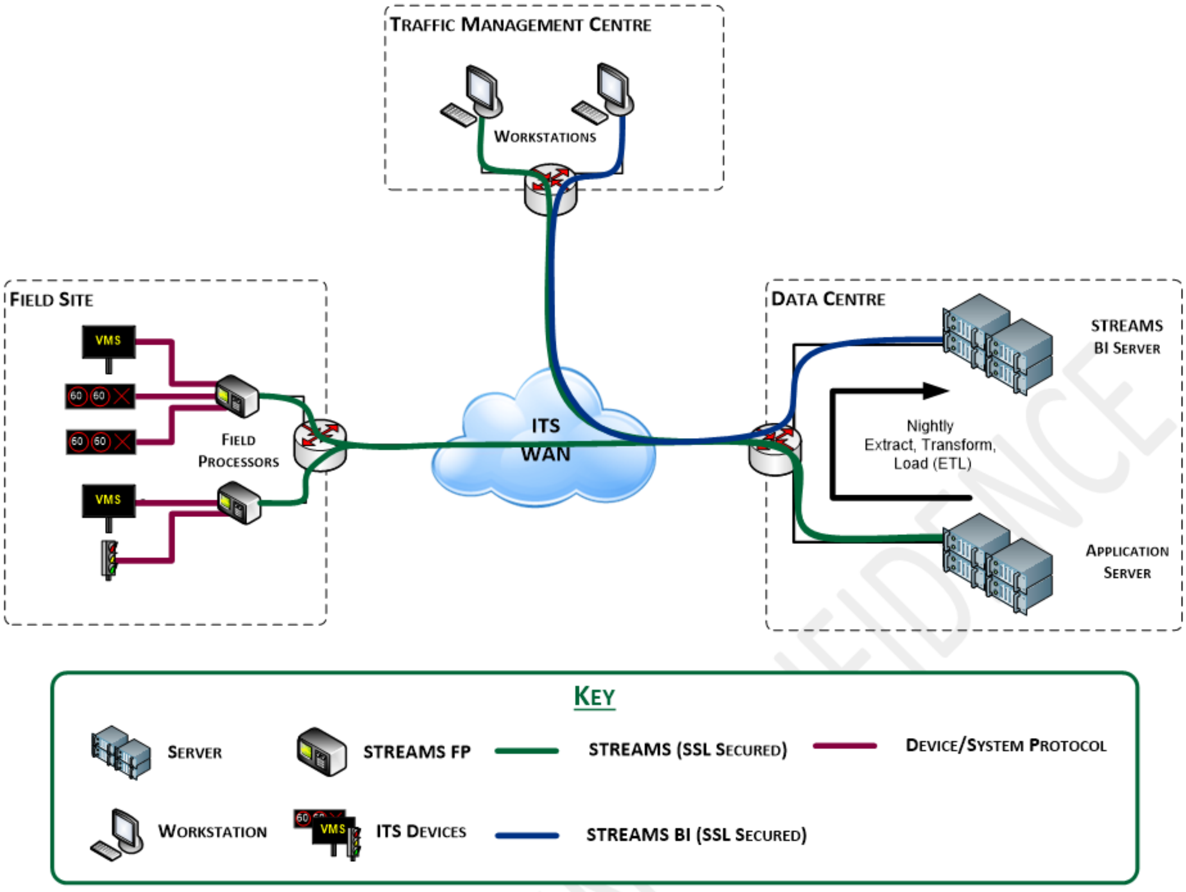

Figure 3: STREAMS distributed computing architecture.

The STREAMS Connect layer is key to the flexibility of STREAMS for integration of ITS field devices. It supports multiple vendors for devices of a specific type (e.g. weather stations or vehicle detectors) through the use of a device driver model. Vendor specific implementations of a device type are handled in a STREAMS Connect driver and abstracted to a generic device type model for communication back to the Application Server which consumes the generic model's data homogeneously in its various higher-level functional services.

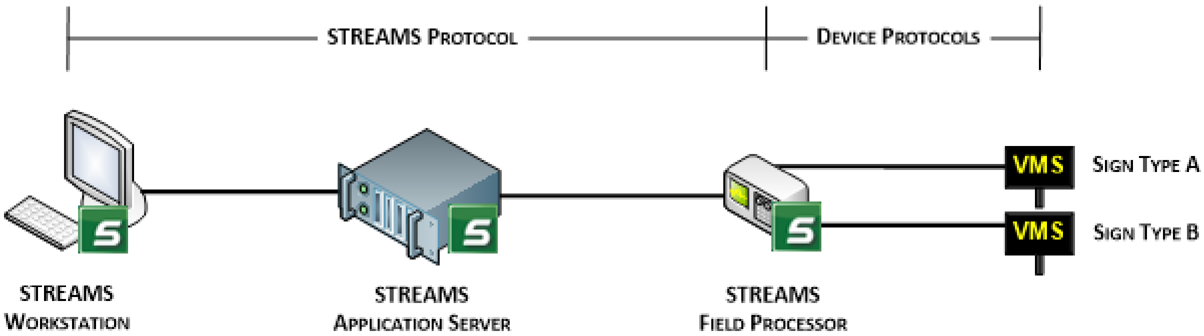

Figure 4: STREAMS Connect Layer

The STREAMS Connect software supports two deployment configurations that are applicable in different scenarios:

- **Field Processor (FP)** – these are deployed at the Field Site and allow native rapid communication to the field devices, local processing and field intelligence and secured SSL communications from the FP. This configuration provides the most responsive control and monitoring capability for the devices, best communications loss failure modes and reduces network bandwidth and latency issues that can be problematic when trying to tunnel other communications protocols (e.g. serial) over IP.

- **Communications Processor (CP)** – these are deployed centrally alongside the Application Server and allow communication to network enabled field devices (e.g. Modbus TCP) or those with legacy communications arrangements such as dial-up modems. This configuration requires less hardware to deploy and is suitable where responsive local control is not required and the Field IP network is well managed & configured to handle the required bandwidth and lower latency requirements of effective ITS device communications.

By integrating functions such as traffic signal management, motorway management, road weather information, incident and event management, vehicle priority systems, traveller information, network video management and parking guidance systems into one integrated system, STREAMS offers road authorities a total solution to their ITS needs. It provides significant benefits including:

- synergy between existing systems and equipment – no vendor lock-in
- secure, flexible data communications
- reduced training and resourcing costs associated with a single ITS platform
- optimised road network performance through a single user interface
- cost savings through easy to enter policies and third party interfaces
- modular, scalable architecture facilitating streamlined migrations and system upgrades
- efficient data management

Case Study – Glendale Drive Roadway Flood Monitoring System

Campbell Scientific Australia were approached by Townsville City Council to provide a non-invasive Roadway Flood Monitoring System with full data integration into the Department of Transport and Main Roads (Northern Region) STREAMS ITS Traffic Management System. The floodway, located in the residential Townsville suburb of Annandale, is a constant flooding hotspot during the Northern wet season when rain waters from the surrounding mountains rapidly fill the tributaries and flood mitigation channels that feed into the Ross River. A risk of flash flooding to motorists exists where roads intersect these channels, and council determined an automated Road Flood Monitoring System integrated into the city's ITS Traffic Management System was required for the Glendale Drive floodway in Annandale.

Figure 5: Location of the Glendale Drive floodway in the suburb of Annandale, Townsville, North Queensland. (Google Maps, 2016).

The Roadway Flood Monitoring System (Figure 6) consists of a 20 Watt solar powered Campbell Scientific CR1000 datalogging system with 12V, 24Ahr power supply, measuring a Campbell Scientific CS475 radar water level sensor mounted 7.934 metres above the road surface using an 8m ITS traffic pole with radar mounting bracket. The CS475 radar sensor emits short microwave pulses and measures the elapsed time between the emission and return of pulses to calculate the distance between the sensor face and the target surface. The distance value calculated is then compared to a baseline road surface distance measurement, recorded at the time of system installation, to determine water depth. The CR1000 datalogger interrogates the radar sensor for water depth readings every 10 seconds, and passes the measured data through traffic filtering algorithms within the datalogger to prevent false alarming due to vehicles passing under the radar sensor.

Figure 6: Radar Roadway Flood Monitoring System installed at the Glendale Drive floodway in Townsville.

This monitoring system communicates via RF411 radio (922 MHz) to a nearby (< 100m) mains powered Campbell Scientific CR800 datalogger with IP connection into the Department of Transport and Main Roads Private IP network via a Telstra UC-372SP3GE modem. The STREAMS ITS Traffic Management Software communicates with the Campbell Scientific CR800 datalogger via a Communications Processor located within the TMC using the Modbus TCP protocol over port 502. Modbus is a simple and robust openly published and royalty-free protocol which has become a de facto standard communication protocol for connecting industrial electronic devices.

Within the Communications Processor (CP), the STREAMS Connect driver handles the Modbus communication to the CR800 datalogger, polling for water depth and other parameters (e.g. system battery voltage) on a configurable interval. This data is sent in an event driven manner from the CP to the Application Server (AS) and presented to the system as a Simple Device value.

Simple Devices are STREAMS' generic representation of Modbus or PLC style devices where each 'device' has the ability to Read or Read/Write a configurable register and raise alarms. By abstracting to this generic representation, any semantically similar device can be consumed in a consistent manner within STREAMS' response engines, presented on a geographic Map or custom Schematic in the User Interface and monitored for faults in Alarm Manager.

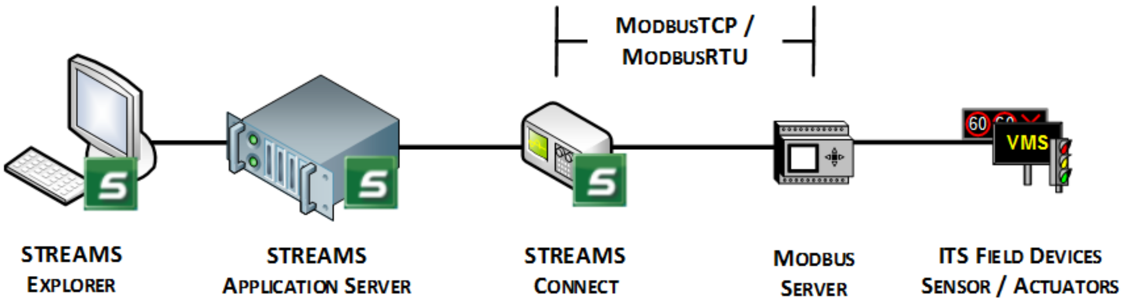

Figure 7: Communications schematic for the Glendale Drive Floodway in Townsville

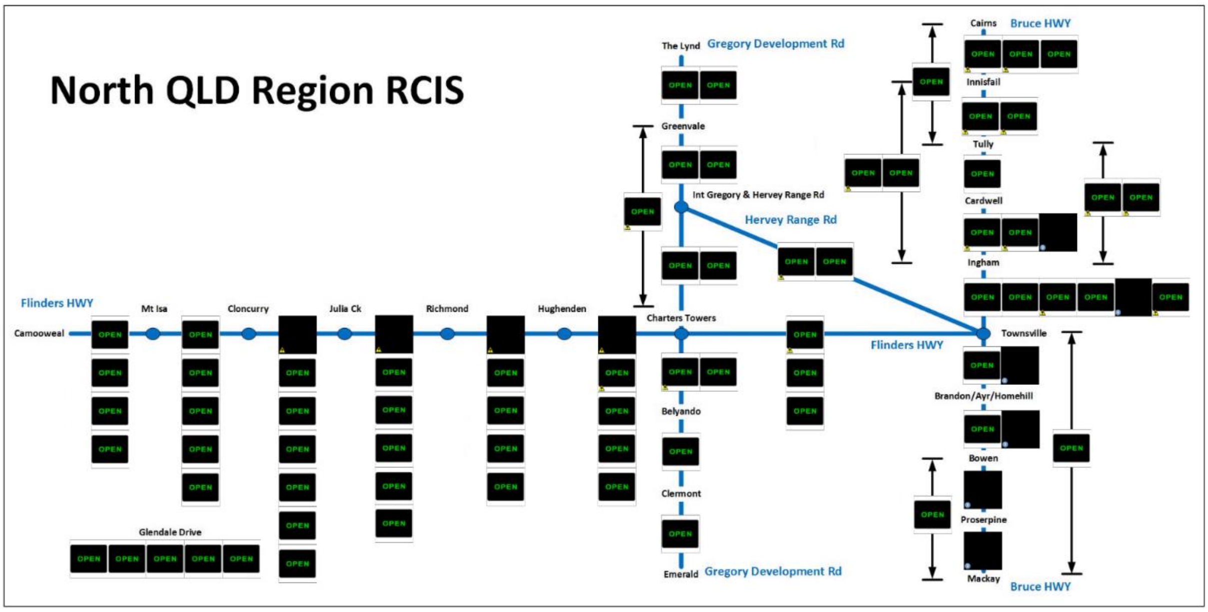

Figure 8: Example STREAMS user interface for a Roadway Flood Monitoring System.

Figure 8 shows a schematic view of the flood monitoring and response deployment used in the Queensland Northern Region TMC. It provides a concise overview all the relevant ITS equipment including roadway flood sensors, IP video cameras and Road Condition Information Signs (RCIS) providing operational awareness of the entire situation. Operators may view video feeds, manually set messages on the signs and initiate automated Response Plans from the schematic. The schematic background and visual representation of the sensor devices are user configurable, with options such as map overlays that provide geolocation of ITS equipment with colour coded road conditions to assist with traffic management operations.

STREAMS provides a number of mechanisms for automating the response to such Simple Device value changes:

- **Stimulus/Response engine** – this provides a simple, configurable mechanism to automate responses to any sensor device in STREAMS. ITS Engineers may pick a device and value (e.g. water level on a Simple Device) and configure a condition or threshold that when matched will automatically set a response on any actuator device (e.g. a Message Sign). Multiple device conditions can be combined together and multiple actuator devices used for response.

- **Response Plan engine** – this provides the ability to script a series of steps to be run by the system. The script engine allows for branch conditions to be employed within the script (e.g. IF/GOTO) based on sensor input and/or operator responses. It can also take actions on actuator devices and interact with TMC operators to prompt them to perform manual actions or confirm steps that should be run. These response plans can be executed automatically from the Stimulus/Response engine but are often associated with sensors on a schematic so that they may be manually launched by an Operator to open or close a road following a manual video surveillance to confirm a flood sensor reading provided by the system.

- **Custom service/algorithm** – where neither of the in-built generic engines above are sufficient, flood sensor data may also be consumed by custom services written to support bespoke or specific algorithms.

These flexible options allow the TMC to monitor the road floodway sites consistently with their other ITS assets and define the workflow that is appropriate to their operational protocols and use-case. The Glendale Drive floodway consists of a network of five RCIS strategically located to forewarn commuters of the road condition at the floodway site. The RCIS use a tri-colour (Red, Green and

Amber) full graphic 7 character LED display remotely controlled through STREAMS' stimulus/response engine. For this particular floodway, when the water level measured is less than 0.03 metres, the RCIS LEDs are set to display "Open" in Green text. When the water level rises above 0.03m, the LEDs are changed to display "Caution" in Amber text. Finally, when the water level rises above 0.09m, the LEDs are changed to display "Closed" in Red text.

Example Flood Event – 16th March 2016

On the 15th March 2016 a tropical low located over the Gulf of Carpentaria tracked rapidly east and crossed the western Peninsula coast of North Queensland just below cyclone strength around 4pm local time. The tropical low was attached to a strong upper level trough which funnelled moisture from the main monsoon trough located over North Queensland through to the North East Queensland coast. In 24 hours that followed, the North East Queensland coast experienced widespread monsoonal rainfall which led to localised flooding in many towns and cities including Townsville where over 120 mm of rainfall was recorded within a 24-hour period (Figure 9).

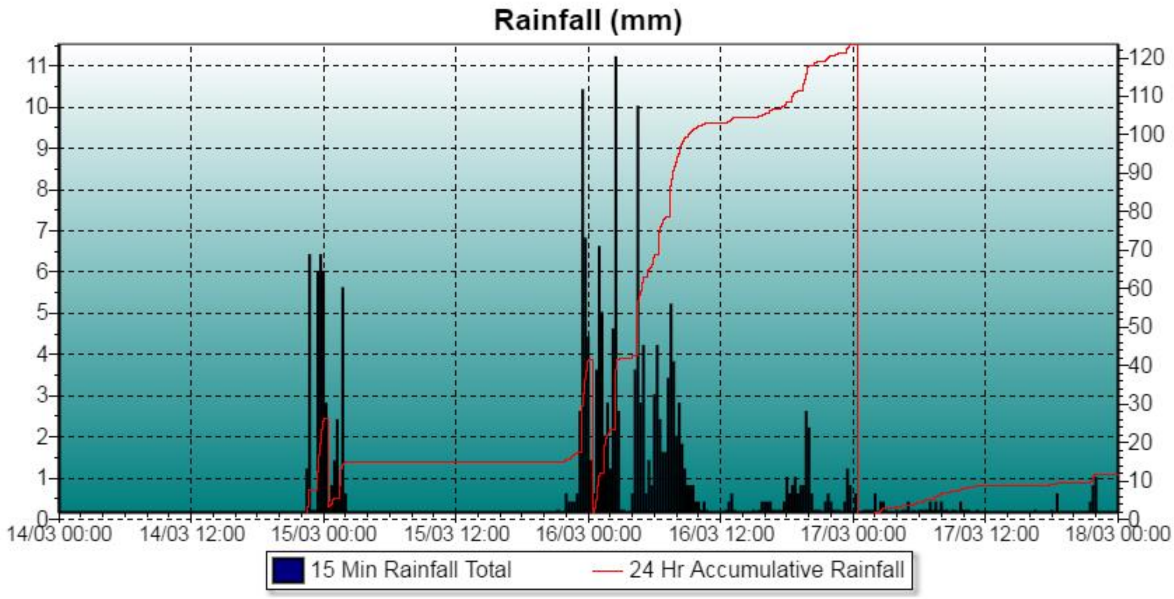

Figure 9: Rainfall data (14/03/16 00:00 to 18/03/16 00:00) from a weather station located 5.6 km North West of the Glendale Drive Roadway Flood Monitoring System. Right axis indicates 24 Hour Accumulative Rainfall totals. (Campbell Scientific Australia, 2016).

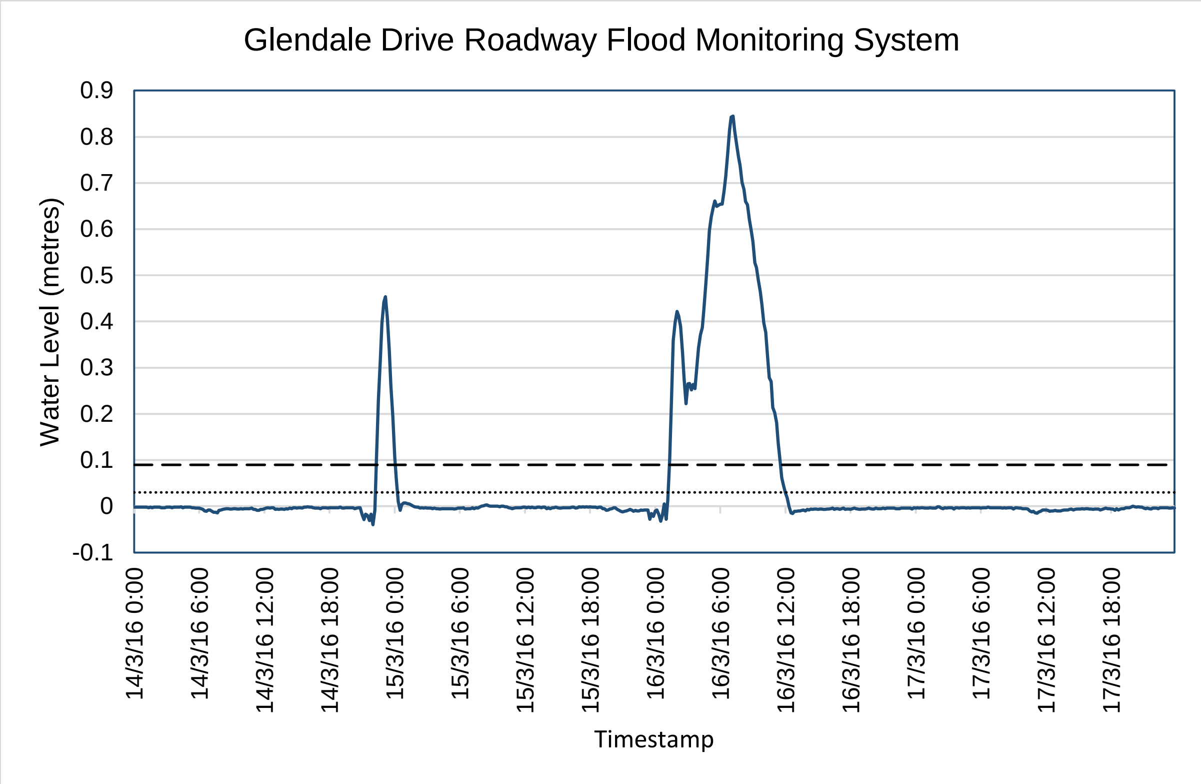

Figure 10: Radar water level data (14/03/16 00:00 to 18/03/16 00:00) measured by the Glendale Drive Roadway Flood Monitoring System.

Figure 9 shows rainfall data from a Campbell Scientific MET200 weather station located 5.6 km North West of the Glendale Drive floodway, and Figure 10 displays water level data recorded at the floodway during the 16th March flood event. The dotted line on Figure 9 indicates the 0.03 m threshold at which the Glendale Drive RCIS automatically displays “Caution”, and the dashed line indicates the 0.09 m “Closed” threshold. The rapid rise in water level just after midnight on 16th March illustrates the dangerous nature of flash flooding at these floodways, with the road condition during this flood event rapidly changing from a road “Open” state to a road “Closed” state within just 20 minutes. Within one hour the water level during this flood event increased from 0 to 0.4 m, with a maximum level of 0.85 m recorded at 07:10am. Figure 11 displays the floodway conditions at approximately 11.00am on 16th March when the water level at the floodway was receding but still in a road “Closed” state.

Figure 11: Glendale Drive floodway on 16th March 2016 under road closed conditions.

Benefits of an ITS Integrated Road Flood Monitoring System

The Glendale Drive Roadway Flood Monitoring System is the first in Queensland to be integrated into the State-wide STREAMS ITS software platform using a non-proprietary open communications protocol instead of a vendor specific implementation. The system has set a precedent upon which other 'hotspot' floodway locations around the state are now being reviewed. For the first time, TMCs have the systems available to provide full visibility of roadway flood conditions which can be automatically responded to through their ITS Traffic Management software.

Real-time delivery of water level data from roadway flooding hotspots into an ITS Traffic Management System ensures the timely distribution of road condition information to commuters as recommended by the Queensland Floods Commission of Inquiry. Indeed, the quick distribution of flood information is critical in deterring commuters from making the wrong decisions when confronted with a flooded roadway and driving through potentially hazardous flood waters.

Road authorities now have the systems and technology available within a common ITS platform to confidently move towards a policy of automated road closures during flood events without the delays and costly overheads associated with manual site inspections. In locations where road authorities continue to conduct manual on-site visual inspections prior to any road closure, the timeliness of these road closures can now be optimised since the STREAMS ITS platform is monitored 24-hours by the Department of Transport and Mains Roads TMCs. In these instances, RCIS can be automatically activated through STREAMS (based on water level data) to provide a "Caution" warning to commuters prior to any manual road "Closed" state being activated by a TMC operator. Likewise, once flood waters have receded STREAMS now has the real-time water level information available to notify engineers in a timely manner of when to perform structural inspections of roadways and bridges prior to their reopening (Department of Transport and Main Roads, 2016b). Without this information, structural inspection teams are often on standby for many hours, undertaking multiple visits to site until flood waters have receded to a level which enables full inspection of critical structures such as the road surface and bridge abutments. These improvements in operational efficiency can now allow roads and bridges affected by flooding to be reopened to traffic in a timely manner to minimise inconvenience to commuters, without compromising safety standards.

Summary

The integration of roadway flood information into an active ITS Traffic Management System (STREAMS) using an industry standard communications protocol provides significant operational benefits to road authorities. Local councils and the Department of Transport and Main Roads are no longer locked to specific hardware vendors when sourcing road weather monitoring systems, and the ability to integrate road condition information into a single, modular and scalable ITS platform used by TMCs enables optimised road network performance and future costs savings through reduced training and resourcing costs and efficient data management. The Glendale Drive floodway in Townsville, North Queensland, has provided a case study of a Roadway Flood Monitoring System with a non-proprietary communications interface into the STREAMS ITS Traffic Management System. This system has set a precedent upon which other roadway flood locations around the State of Queensland are now be reviewed, and a larger scale role out of such systems is anticipated over the coming months and years.

Whilst this paper has focused on Roadway Flood Monitoring Systems, the same core hardware and network infrastructure can be (and is being) used to integrate more “traditional” road weather data into STREAMS. A recently installed Campbell Scientific environmental monitoring system in Cardwell, North Queensland, provides visibility, rainfall and wind speed and direction data directly into STREAMS to assist in warning commuters of hazardous driving conditions over the Cardwell mountain range via VMS. In more southerly States with colder winter climates, road weather information such as snow and ice detection and surface friction data can be integrated into STREAMS using the same core hardware and system architecture described in this paper to allow TMCs to monitor and control winter road maintenance with their other ITS assets as a fully coordinated traffic management response.

Whilst the operational benefits of traditional Road Weather Information Systems in many Northern Hemisphere countries are well documented, the benefits from integrating road weather information into State-wide ITS Traffic Management Systems in Australia are only just starting to be fully realised. It is hoped that further collaboration between the Department of Transport and Main Roads, Transmax Pty Ltd (as the developer of STREAMS) hardware vendors and the Australian Bureau of Meteorology (BoM) will result in the addition of data from thousands of existing ALERT river gauging stations around Australia into the STREAMS ITS Traffic Management System. The integration of rainfall and water level data from these ALERT stations into STREAMS could be of great benefit to TMCs, providing additional data from upstream locations to enable the forecasting of road floodway closures and the subsequent re-routing of traffic prior to a flood event occurring. This type of “meteorologically optimised” road network performance, once realised, could further help in preventing a repeat of the tragic roadway flood events experienced in 2010/2011 in Queensland.

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