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ONTOLOGY-BASED CORRELATION OF RESOURCE MANAGEMENT ACTIONS WITH WATER QUALITY DATA IN SOUTH-EAST QUEENSLAND

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This paper describes the ontology-based information management system "Health-e-Waterways" that has been developed to link over 500 management actions to the environmental monitoring data being acquired through the SEQ HWP's Ecosystem Health Monitoring Program. We describe the ontology that has been developed to link area-based Action Plans to specific regions, indicators and parameters. We also describe the Bing Maps/GoogleEarth interface that combines ontology-based querying with spatio-temporal querying to integrate the heterogeneous monitoring and management databases and visualize spatial and temporal trends in water quality. The ability to display Management Actions alongside related Ecosystem Health Indicators for a given catchment, enables policy makers to easily identify the impact of specific actions and investments and to adapt them accordingly. The ontology-based approach also enables the application of semantic and spatio-temporal inferencing to infer the flow-on effects of actions on sites that are downstream.

INTRODUCTION

This paper describes the latest developments associated with the Health-e-Waterways Project – a cross-disciplinary collaboration between information scientists and water resource managers and stakeholders that is developing the knowledge management infrastructure for adaptive whole-of-water-cycle management in South East Queensland. It begins by describing the challenges faced by South East Queensland Healthy Waterways Partnership (SEQ HWP) in managing the data associated with their Adaptive Management Strategy and Ecosystem Health Monitoring Program (EHMP). It goes on to describe the ontology-based knowledge management system developed by Health-e-Waterways to enable the integration and analysis of a wide range of data types. More specifically it describes the ontologies that have been developed, the system architecture and the query, reporting and visualization interfaces – that are enabling scientists and policy makers to identify trends in ecosystem health indicators both geographically and temporally and to understand the impact that water resource management actions are having on water quality.

BACKGROUND AND OBJECTIVES

South East Queensland Healthy Waterways Partnership (SEQ HWP) was established in 2002 by government, industry and community stakeholders working in close cooperation to develop a standardized approach to understanding and managing the region's waterways. The key elements of the SEQ HWP strategy include: the implementation of targeted management actions (ranging from upgrades of sewage treatment plants to rehabilitation of riparian vegetation); a multi-disciplinary science, research and monitoring program that underpins the management action program and monitors its effectiveness; and the Healthy Waterways promotional and educational program (Bunn *et al.* [1]). Figure 1 shows the "Adaptive Management" approach that underpins SEQ-HWP.

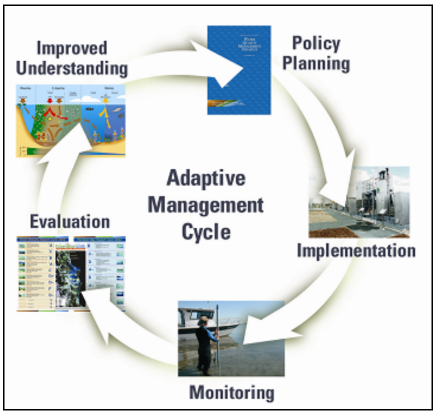

Figure1. The Adaptive Management Framework

Monitoring data is continually acquired through a comprehensive Ecosystem Health Monitoring Programme (EHMP) [2], analysed and assessed to monitor the effectiveness of management actions, that are then adapted as required. The EHMP comprises the Estuarine and Marine EHMP and the FreshWater EHMP. The Estuarine and Marine EHMP began in 2000 and includes monthly monitoring of water quality parameters at 260 sites in coastal waterways from Noosa to the New South Wales border.

The Freshwater EHMP commenced in 2002 and includes twice-yearly sampling at over 120 sites on all of the major streams in the region. The EHMP delivers an objective regional assessment of the ecosystem health for each of South East Queensland's 19 major catchments, 18 river estuaries, and Moreton Bay. One of the major outcomes from the Program is an Annual Report Card which aggregates measured values of water quality to provide a simple grade (A-F) for each of these waterways (EHMP [3]). The aim of the Health-e-Waterways project is to develop underlying data management, integration, reporting and visualization services to streamline the generation of the Annual Report Cards, enable more interactive online access to the data and associated analytical services and in the long term support the Adaptive Management approach, shown in Figure 1.

RELATED WORK

A number of previous projects and efforts have focused on the application of ontologies, artificial intelligence and machine learning to knowledge management and decision-support in the context of hydrological ecosystems. However the majority of these approaches have focused on computational modeling. For example, Chau [5] developed an ontology-based system for modeling water flow and quality. This system is based on numerical simulations (not near-real-time observational data) and uses inferencing to select the optimum model and parameters. Other related research efforts (Zhao *et al.* [6], Muttil and Chau [7], Lee *et al.* [8]) have focused on statistical and AI methods for identifying the ecologically significant variables associated with environmental models. For example, Lee *et al.* [8] applied neural networks to the modeling of coastal algal blooms using long-term water quality data. Although some water quality models have been developed for South East Queensland (Larsen [9]), there is insufficient long term data available at this stage for scientists and policy makers to be able to reliably depend on the accuracy of these predictive models. Our approach is to apply semantic web technologies to enable scientists to explore and better understand relationships between ecosystem health indicators and management actions in the past – in parallel with the development of more accurate, localized predictive models. A future objective will be to integrate these two approaches.

THE MANAGEMENT ACTION ONTOLOGY

The South East Queensland Healthy Waterways Strategy for 2007 ~ 2012 comprises a set of twelve Action Plans, including four area-based Action Plans for: Moreton Bay; Northern Catchments; Bremer Catchments; and Logan Albert Catchments.Each Action Plan comprises a number of high level Management Outcomes and sets of Actions that are linked via Management Action Targets. Table 1 provides an example of an Action Plan (using fictional data).

Table 1. Example of a Healthy Waterways Management Action Plan

Class	**Instance**
ActionPlan	Bremer River Catchment Action Plan
Goal	Management of Wastewater Treatment Plants
Action	Upgrade of Rosewood Wastewater Treatment Plant
Target	Total N of 5mg/L and total P of 2mg/L in effluent
Responsible Organization	Ipswich City Council
Involved Partners	Bremer Catchment Association
Catchment	Bremer
TimeFrame	2011
Investment	$2million
Status	Underway
PercentComplete	50
LastUpdate	20/09/2009

Over 500 such management actions have been stored in an Access database managed by SEQ HWP. Our objective is to integrate the Management Actions Database (MAD) with the environmental monitoring data (described in the EHMP ontology) in order to identify whether the actions and associated investments are having any impact on the quality of the water – and whether the strategy needs to be adapted or not. At this stage, only the Actions associated with area-based Action Plans are linked to specific regions and indicators. Based on an analysis of this data, we developed the Management Action Database (MAD) ontology (Figure 2).

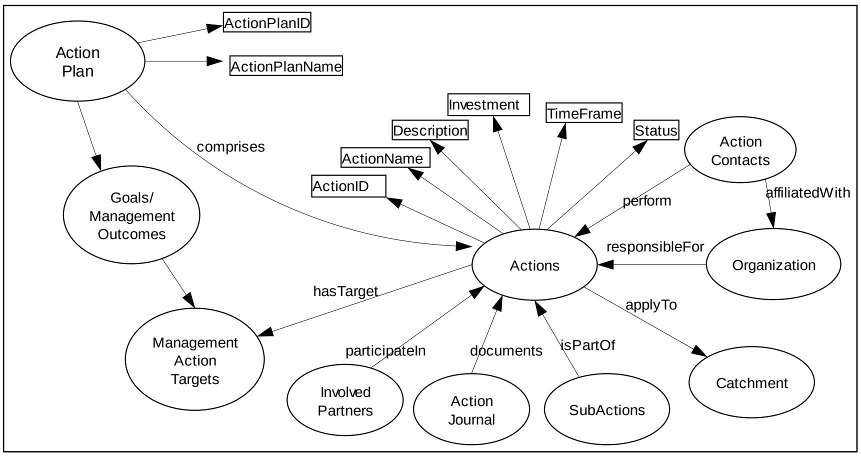

Figure 2. Graphical Representation of the MAD Ontology

SYSTEM IMPLEMENTATION

XSLT scripts were developed to automate the mapping of the legacy databases (Oracle and Access) to the common model/ontologies and the mapped data was loaded into a common (PostgreSQL + PostGIS) data store. Figure 3 below illustrates the ICT components of the system architecture.

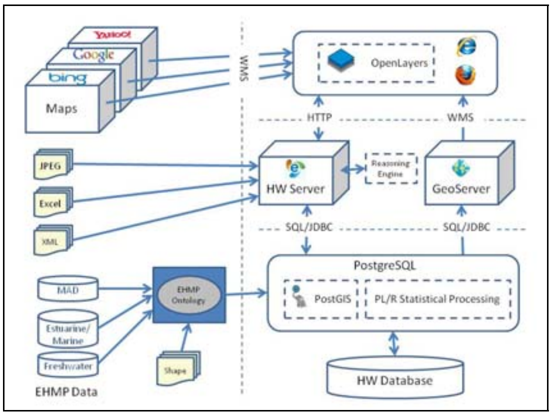

Figure 3. Architectural Components of the Health-e-Waterways System

VISUALIZING THE IMPACT OF MANAGEMENT ACTIONS

Over the past 18 months we have enabled the Report Card grades to be generated dynamically via R statistical processing tools and a Web-based mapping interface (overlaid on the integrated datasets). Figure 4 illustrates the interactive map interface that enables users to interactively generate report cards for specified regions, time periods and parameters.

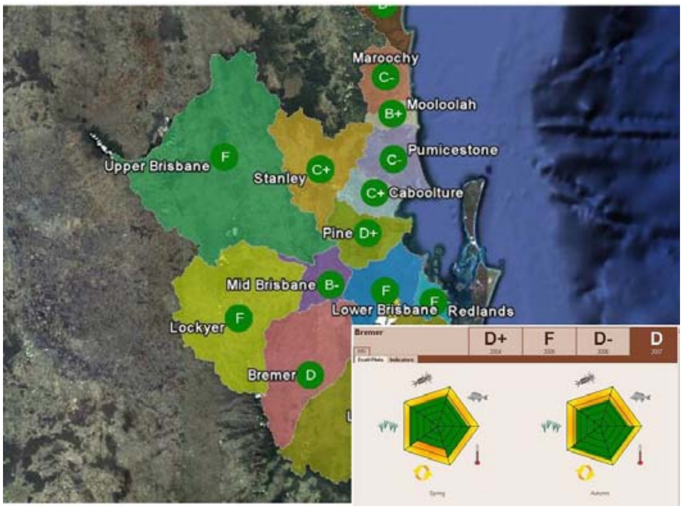

Figure 4. EcoH Plots and Report Card Grades for the Bremer catchment

These online report cards are extremely useful for communicating the health of waterways, however, in the long term, scientists, resource managers and policy makers want to be able to pose predictive queries such as: “If $10million is invested in landscape restoration works in the Bremer catchment today, what will be the ecosystem health outcomes in 2020?” Such predictive queries require the linking of complex models across the length of the waterway (from the upper catchment to middle and lower catchment, the estuary, coast and bay), so users can understand and simulate how changes propagate through the water flow cycle. Although such models are currently under development for SEQ, they are not yet at a stage where they can accurately predict the impact of management actions on ecosystem indicators. More comprehensive and longer-term monitoring data is required for calibration and validation of the models.

In the meantime however, we are able to quickly and easily display management actions associated with a particular region, alongside the corresponding ecosystem health trends for that region. Figure 5 illustrates such a visualization for the Bremer catchment. The management actions are displayed above box plots showing trends for the five freshwater ecosystem health indicators (*physical/chemical*, *nutrients*, *ecosystem processes*, *aquatic macroinvertebrates* and *fish*) over the period from 2004~2007. This display provides sufficient information to answer queries such as “Is the riparian revegetation in the Upper Bremer having any impact on water quality in the Bremer?" Figure 5 shows that in the past 3 years, the grade has improved from F to D due to improvements in the *physical/chemical*, *nutrient cycling* and *fish* indicators - presumably as a result of the riparian revegetation.

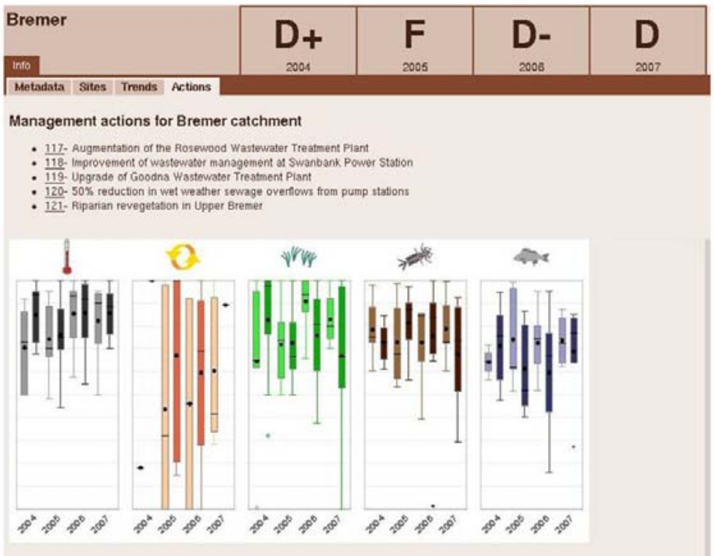

Figure 5. Juxtaposition of Relevant Management Actions Against Monitoring Data

DISCUSSION OF RESULTS TO DATE

The Health-e-Waterways project is still at a relatively early stage (we are currently only 18 months into a 3 year project), however the outcomes to date include the following:

- A set of OWL ontologies that represent ecosystem health monitoring data and management actions as common data models that are machine-processable and facilitate data integration and reasoning;
- A set of services that automatically map legacy datasets to the OWL data models and store/publish them in the PostGreSQL database;
- A set of optimized reporting services that dynamically generate a range of graphical plots showing trends in ecosystem health indicators over time and regions (sites, catchments, estuaries and bay zones) at different levels of granularity and resolution;
- Flexible Web Map-based user interfaces (using GoogleEarth, Microsoft Bing Maps or Yahoo Maps) that enable water resource managers to interactively visualize and assess the impact of specific management actions on water quality indicators.

Evaluation trials to date indicate that the technologies and services we have adopted and developed are delivering significant economic, scientific and environmental benefits. Feedback from our scientific collaborators within the Department of Environment and Resource Management (DERM) has been extremely positive. EcoH plots and graphical reports that previously took weeks to generate manually, can now be generated dynamically via the Web interface. Users can immediately access and compare ecosystem health and water quality data over time and across catchments. They can drill down into report card grades to quickly and easily identify which particular parameters are performing badly and the possible causes of poor ecosystem health.

The ability to display Management Actions alongside related Ecosystem Health Indicators for a given catchment, enables policy makers to easily identify the impact of specific actions and investments, and to adapt them accordingly. This capability is critical to support the "Adaptive Management" philosophy that underpins the SEQ HWP approach. However further input from the scientific experts panel is required in order to relate specific management actions and sub-actions to particular water quality parameters at specific sites. The current system does not yet take advantage of the inferencing capabilities available through technologies such as SWRL. Semantic and spatial inferencing could be usefully applied to automatically infer the anticipated impact of those actions on sites that are downstream e.g., sites that are downstream from a recently upgraded sewage treatment plant should show reductions in $\delta^{15}N$. Ideally the system would intelligently analyse the monitoring data and highlight those management actions that are not having any perceived impact.

FUTURE WORK AND CONCLUSIONS

Significant further work and usability studies are required in order to rigorously evaluate the Health-e-Waterways system and refine and enhance its capabilities. In particular, over the next 12 months we are planning to focus on the following activities:

- Add ontology-based conceptual querying (using the SPARQL query language) to the GoogleEarth interface to enable more interactive and intuitive querying "Which management actions are not meeting their targets in Cabbage Tree Estuary?";
- Add inferencing rules and geo-spatial reasoning (using SWRL) to the system to support richer querying "Which monitoring sites downstream of Rosewood WasteWater Treatment Plant have shown improved nutrient cycling in the past year";
- Establish a model registry that enables users to upload and share models as web services, link them using scientific workflows and execute them over grid computing infrastructure.

Numerous states, national and international agencies are advocating the need for standardized frameworks and procedures for environmental accounting. The Health-e-Waterways system provides an ideal model for delivering a standardized approach to the aggregation of ecosystem health monitoring data and the generation of dynamic, interactive reports (that incorporate links back to the raw data sets). The recently developed "Management Action" ontology, now enables users to link management actions to monitoring data, to identify which actions and investments are having the most impact. The *health-e-waterways* system will not only save agencies significant time and money in producing environmental accounts, but it can be used to guide and adapt local, state and national environmental policies and water resource management decisions.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Bunn S., Abal E., Greenfield P., Tarte D., "Making the connection between healthy waterways and healthy catchments: South east Queensland, Australia", *Water Science and Technology: Water Supply*, Vol. 7, No, 2, (2007), pp 93-100.

[2] Ecosystem Health Monitoring Program (EHMP) (2010) http://www.ehmp.org/.

[3] Ecosystem Health Monitoring Program (EHMP) Annual Report Cards (2009) http://www.healthywaterways.org/EcosystemHealthMonitoringProgram/ProductsandPublications/AnnualReportCards.aspx

[4] Alabri A., Hunter J., Van Ingen C and Abal E., "The Health-e-Waterways project", *8th HIC Conference*, Chile, (2009).

[5] Chau, K.W., "An ontology-based knowledge management system for flow and water quality modeling", *Advances in Engineering Software*, Vol. 38, No. 3, (2007), pp 172-181.

[6] Zhao, M.Y., Cheng, C.T., Chau, K.W., Li, G., "Multiple criteria data envelopment analysis for full ranking units associated to environment impact assessment", *International Journal of Environment and Pollution*, Vol. 28, No. 3-4, (2006), pp 448-464.

[7] Muttil, N. and Chau, K.W., "Machine learning paradigms for selecting ecologically significant input variables", *Engineering Applications of Artificial Intelligence*, Vol. 20, No. 6, (2007), pp 735-744.

[8] Lee J.H.W., Huang, Y., Dickman M., Jayawardena A.W., "Neural Network modelling of coastal algal blooms", *Ecological Modelling*, Vol. 159, Issue 2-3, (2003).

[9] Larsen, G., "*Modelling hydrodynamic processes within Pumicestone Passage, Northern Moreton Bay, Queensland*", PhD Thesis, QUT, 2007.

[10] Hunter J. and Mauger, B. "Health-e-Waterways Database Survey Report", May, (2008), http://www.health-e-waterways.org/reports.php.

[11] CUAHSI, "Hydrological Information System (HIS)", (2009), http://his.cuahsi.org/

[12] Horsburgh, J. S., D. G. Tarboton, D. R. Maidment and I. Zaslavsky, "A Relational Model for Environmental and Water Resources Data," *Water Resour. Res*, Vol. 44, (2008), W05406, doi:10.1029/2007WR006392.

[13] Open Geospatial Consortium (OGC), "Observations and Measurements" http://www.opengeospatial.org/standards/om, (2009).

[14] O'Hagan, R., Atkinson, R., Cox, S., Fitch, P., Lemon, D., Walker, G., "A Reference Model for a Water Resources Observation Network", *MODSIM07*, New Zealand, (2007).